Effect of artificial community water fluoridation on dental health

An evidence review

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Acknowledgements

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Abbreviations

Abbreviation	Explanation
ANCOVA	analysis of covariance
ANOVA	analysis of variance
CADTH	Canadian Agency for Drugs and Technologies in Health
CENTRAL	Cochrane Central Register of Controlled Trials
CHMS	Canadian Health Measures Survey
CI	confidence interval
CINAHL	Cumulative Index to Nursing and Allied Health Literature
CWF	community water fluoridation
dm(e)ft	decayed, missing, or extracted, or filled primary teeth
dmfs-ss	decayed, missing, or filled primary surfaces – smooth surfaces
dmfs	decayed, missing, or filled primary surfaces
DMFS	decayed, missing, or filled permanent surfaces
DMFS-SS	decayed, missing, or filled permanent surfaces – smooth surfaces
dmft	decayed, missing, or filled primary teeth
DMFT	decayed, missing, or filled permanent teeth
D_1	non-cavitated caries in permanent teeth
D_2	cavitated caries with enamel involvement in permanent teeth
D_3	cavitated caries with enamel and dentine involvement in permanent teeth
d_1	non-cavitated caries in primary teeth
d_2	cavitated caries with enamel involvement in primary teeth
d_3	cavitated caries with enamel and dentine involvement in primary teeth
$d_{1–3}$mft/$D_{1–3}$MFT	decayed, missing, or filled primary or permanent teeth including level of cavitation to enamel and dentine
$D_{1–2}$MFS	decayed, missing, or filled permanent teeth surfaces including level of cavitation to enamel
$d_{1–3}$mfs/$D_{1–3}$MFS	decayed, missing, or filled primary or permanent teeth surfaces including level of cavitation to enamel and dentine
$D_{1–6}$MFT	Any decayed, missing, or filled permanent teeth
D_3MFT	decayed (with visible non-cavitated dentinal caries), missing, or filled permanent teeth
d3vcmft(cde)	decayed (with visible non-cavitated dentinal caries), missing, or filled primary canines (c) or first or second primary molars (d and e)
FACCT	he Fluoride and Caring for Children's Teeth project
g	Hedges' g
GRADE	Grading of Recommen$_d$ations, Assessment, Development and Evaluations
HRB	Health Research Board
I^2	*I* squared
ICC	intraclass correlation coefficient
ICDAS	International Caries Detection and Assessment System
ICD-9	International Classification of Diseases, Ninth Revision
IV	intervention
LILACS	Latin American and Caribbean Health Sciences Literature
MANCOVA	multivariate analysis of covariance
MANOVA	multivariate analysis of variance
MD	mean difference
MH	Mantel-Haenszel
MeSH	Medical Subject Headings
mg/L	milligrams per litre
N/A	not applicable
NHLBI	National Heart, Lung, and Blood Institute
no F	fluoride deficient
NR	not reported
OR	odds ratio
% with CDC	percentage of participants with cavitated dental caries
% without CDC	percentage of participants without cavitated dental caries
PICO	population, intervention, comparator, and outcome
ppm	parts per million
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
p-value	probability value
RoB 2	version 2 of the Cochrane risk-of-bias tool for randomised trials
SE	standard error [of mean]
SD	standard deviation

Abbreviation	Explanation
τ^2	Tau squared
TSIF	Tooth Surface Index of Fluorosis
UK	United Kingdom
USA	United States of America
WHO	World Health Organization

Glossary of terms

<table>
<tr><th>Term</th><th>Explanation</th></tr>
<tr><td>Al-Alousi et al. [1] criteria for mottling (fluorosis)</td><td>The Al-Alousi et al. criteria for mottling or fluorosis are based on the clinical appearance of fluorosis defects on teeth as described below:
Type A: white areas <2 millimetres (mm)
Type B: white areas ≥2 mm
Type C: coloured areas <2 mm
Type D: coloured areas ≥2 mm
Type E: horizontal white lines</td></tr>
<tr><td>American Dental Association (ADA) Caries Classification System (CCS) [2]</td><td>The ADA CCS is a dental caries index based on a 4-point… scale (sound, initial, moderate, or advanced):
Sound: The surface is sound, and there is no clinically detectable lesion.
Initial: Caries are limited to the enamel or cementum or the very outermost layer of dentine on the root surface and, in the mildest forms, are detectable only after drying (non-cavitated).
Moderate: Deeper demineralisation with some possibility of enamel surface micro-cavitation, early shallow cavitation, and/or dentine shadowing are visible through the enamel, which indicates the likelihood of dentine involvement; these lesions display visible signs of enamel/cementum or dentine loss or shadowing or translucency.
Advanced: There is full cavitation through the enamel, and the dentine is clinically exposed (decayed).</td></tr>
<tr><td>Australian Institute of Health and Welfare 2004–06 National Survey of Adult Oral Health[3]</td><td>The Australian Institute of Health and Welfare's National Survey of Adult Oral Health 2004–06 describes a dental caries index described as a 7-point scale, but reported as a 4-point (decayed, missing, or filled permanent teeth (DMFT)/, missing, or filled permanent surfaces (DMFS)):
Decay: cavitation of enamel, or dentinal involvement, or both are present
Recurrent caries: visible caries that are contiguous with a restoration
Filled unsatisfactorily: a filling placed for any reason in a surface that requires replacement but that has none of the above conditions
Filling to treat decay: a filling placed to treat decay in a surface that had none of the above conditions
Filling placed for reasons other than decay: a filling in a surface that has none of the above conditions (incisors and canines only)
Fissure sealant: a sealant in place where none of the above conditions was found, and
Sound: when none of the above conditions was found.</td></tr>
<tr><td>Backer-Dirks et al., 1961 [4]</td><td>Backer-Dirks et al. describe a dental caries index based on a clinical 4-point scale (CI–CIV) and a radiographic 5-point scale (CI–CV):
Clinical assessment: pit-and-fissure/smooth surfaces only on molars and premolars:
CI: black line
CII: black line and a white zone
CIII: small break in enamel
CIV: large cavity >3 mm wide, and
No clinical assessment of approximal surfaces.
Radiographic assessment of approximal surfaces (blind evaluation):
Caries I limited to enamel
Caries stages II, III, and IV indicate a lesion penetrating the dentine, a lesion halfway to the pulp, or a lesion that has reached the pulp, respectively, and
Category V filling (including crowns, etc.) or requiring filling; lower anterior teeth are excluded.</td></tr>
<tr><td>Baseline or design-related heterogeneity [5]</td><td>Arises when the population or research design of studies differs across studies. It can be reduced a priori by setting up a suitable PICO that determines which types of populations and designs are eligible for meta-analysis.</td></tr>
<tr><td>bias</td><td>Bias is a systematic overestimation or underestimation of an association in research. There are many types of bias, such as selection, recall, observer, and interviewer bias. Bias is minimised through good study design and implementation.</td></tr>
<tr><td>blinding</td><td>Blinding is a method used in research to ensure that the people involved in a research study – participants, clinicians, and researchers – do not know which participants are assigned to each study group, or which participants experienced the exposure or outcome of interest. Blinding is used in order to ensure that knowledge of the type of exposure, treatment, or diagnosis does not affect a participant's response to the treatment, a healthcare provider's behaviour, or an interviewer's approach to data collection.</td></tr>
</table>

Term	Explanation
British Association for the Study of Community Dentistry (BASCD) [6]	The BASCD uses a dental caries index based on a 3- point scale (D_3MFT): 1. D_3: decay into dentine 2. M: missing tooth due to decay, and 3. F: filled tooth.
Canadian Dental Association (CDA) [7]	The CDA uses a dental caries index based on a 4-point scale (D_1, D_2, M, F) by tooth surfaces: 1. D_1: an incipient lesion comprising: (i) incipient decay on a pit-and-fissure surface (white chalky enamel or softness), or (ii) a chalky white spot on a smooth surface that did not appear glossy after drying 2. D_2: a cavitated lesion on either pit-and-fissure or smooth surfaces 3. M: missing tooth, and 4. F: filled tooth.
case-control study	A case-control study is an analytic observational epidemiological study which examines volunteer participants (cases) with an outcome (disease) back to exposure (cause) and compares their exposures with self-selected controls that do not have the disease (but are otherwise similar) in order to determine the odds that the exposure may have caused the disease. The odds ratio is the measure of choice in a case-control study. This type of study can be used to identify exposures that cause rare diseases. They contribute low-quality evidence to causality or disease aetiology. The main drawbacks in case-control studies are their potential for recall bias and their inability to calculate incidence.
causality	Causality is the relation of cause and effect. The Bradford Hill criteria for causality are: strength of association or effect size; consistency of findings across studies (known as reproducibility); biological credibility (plausibility); specificity (other explanations); a temporal relationship (exposure occurred before the outcome) and biological gradient known as a dose–response relationship; coherence (consistent with other lines of evidence); and analogy (similar agents act similarly).
chance	Chance is sampling variability which can give rise to a particular result. It is the 'luck of the draw'. It is an unsystematic over- or underestimation of the cause-and-effect relationship. The probability value (*p*-value) measures the probability or likelihood that an observed result occurred by chance alone.
cohort study	A cohort study is a form of longitudinal (analytic observational) epidemiological study in which a group of participants, called a cohort, is followed over a period of time, and data relating to predetermined exposures and outcomes are collected on two or more occasions over this period. The incidence (new cases) of the outcome(s) of interest is calculated in the exposed people and compared with the incidence in the non-exposed people. This comparison of incidence is known as relative risk. The data for the cohort can be collected either by following the participants into the future (prospective study) or by asking them about their past (retrospective study). However, retrospective cohort studies are limited by recall bias. One of the indicators of a high-quality cohort study is a loss to follow-up rate of less than 20%. Cohort studies contribute to causality or disease aetiology and provide, at best, moderate-quality evidence.
community water fluoridation	The practice of artificially fluoridating water with a precise low dose of fluoride as a public health prevention measure to protect teeth from developing caries or cavities. In Ireland, statutory regulations for fluoridation of water supplies stipulate that fluoride may be added to public water supplies, typically in the form of hydrofluorosilicic acid. In 2000, the Forum on Fluoridation recommended that the fluoride level in drinking water should be within the range of 0.6–0.8 parts per million (ppm), with a target of 0.7 ppm.
confidence interval	A confidence interval is the range of values (for example, proportions) in which the true value is likely to be found with a degree of certainty (by convention, a 95% degree); that is, the range of values will include the true value 95% of the time.
confounding	Confounding is when a factor has an association with the exposure and can independently cause the outcome or disease. It can over- or underestimate an effect of interest or association. A confounding variable (also called a confounding factor or confounder) is a variable that has a relationship with both the exposure and the outcome variable. Confounding is controlled for by restricting the study population, matching the study population (for age, sex, geography, and/or socioeconomic factors), randomly selecting the study population, undertaking a stratification in the analysis (for example, by age, sex, geography, and/or socioeconomic factors), and performing regression analysis.
cross-sectional survey	A cross-sectional survey or prevalence survey is a descriptive epidemiological study in which the presence or absence of both the exposure and outcome is assessed at the same point in time. This study type is vulnerable to the problem of which came first: the exposure or the outcome (likened to 'the chicken or the egg'), as both exposure and outcome are collected at the same point in time. These types of studies are often used to assess the prevalence of acute or chronic

Term	Explanation
	conditions; to inform health planning and evaluation; or to formulate a theory. It can be difficult to control for factors that may be related to the exposure and outcome in cross-sectional surveys, so they cannot be used to determine causality. They are sometimes included in the hierarchy of evidence and are considered to provide very low-quality evidence.
developmental defects of enamel	Developmental defects of enamel are an alteration in the quality and quantity of enamel, caused by disruption and/or damage to the enamel organ during amelogenesis (i.e. the production of enamel). There are three classifications of disruption: demarcated opacities, diffuse opacities, and hypoplasia (or developmental enamel defect).
Developmental Defects of Enamel (DDE) index [8]	The DDE index allows for the measurement of demarcated opacities, diffuse opacities, and hypoplasia defects and their severity. There appear to be nine scores on the index: 0. Normal 1. Demarcated opacities 2. Diffuse opacities 3. Hypoplasia (or developmental enamel defect) 4. Other defects 5. Demarcated and diffuse opacities 6. Demarcated opacities and hypoplasia 7. Diffuse opacities and hypoplasia, and 8. All three: demarcated opacities, diffuse opacities, and hypoplasia.
Dean's Index of Fluorosis [9]	Dental fluorosis can be measured using the six categories of Dean's Index of Fluorosis as described in the World Health Organization (WHO) publication, *Oral Health Surveys, 5th Edition*. The categories are: Normal: The enamel surface is smooth, glossy, and usually a pale, creamy-white colour. Questionable: The enamel shows slight aberrations from the translucency of normal enamel, which may range from a few white flecks to occasional spots. Very mild: There are small opaque, paper-white areas scattered irregularly over the tooth but involving less than 25% of the labial tooth surface. Mild: The white opacity of the enamel of the teeth is more extensive than for category 3 but covers less than 50% of the tooth surface. Moderate: The enamel surfaces of the teeth show marked wear, and brown stain is frequently a disfiguring feature. Severe: The enamel surfaces are severely affected, and hypoplasia (or developmental enamel defect) is so marked that the general form of the tooth may be affected. There are pitted or worn areas, and brown stains are widespread; the teeth often have a corroded appearance. Dean's Index of Fluorosis has shortcomings, principally that it cannot measure fluorosis in different tooth surfaces. As it has been traditionally used, it also does not permit specifying the cosmetic importance of the most severe fluorosis detected in dentition.
dental caries [10,11]	A summary of existing literature reports that tooth mineral is lost and gained in a continuous process of demineralisation and remineralisation. Dental caries (dental decay) is a disease of the hard tissues of the teeth caused by an imbalance in this process over time, where there is net demineralisation of tooth structure by organic acids formed from the interactions between bacteria causing tooth decay in dental plaque and fermentable carbohydrates (sugars). The dental caries formation process is influenced by the susceptibility of the tooth surface, the bacterial profile, the quantity of saliva, and the presence of fluoride, which promotes remineralisation and inhibits demineralisation of the tooth structure.
dental fluorosis [12,13]	Dental fluorosis is a tooth enamel defect, which in a mild form is typically observed as mild white lines or opaque white spots on the enamel. Moderate and severe forms of dental fluorosis, which are far less common, cause more extensive enamel changes. More severe forms of dental fluorosis can cause discoloured, pitted, or weakened teeth. As tooth development occurs in the first 8 years of life, children are susceptible to fluorosis up to this age. The severe form hardly ever occurs in communities where the level of fluoride in water is less than 2 milligrams per litre, or 2 ppm. Dental fluorosis is caused by children taking in too much fluoride over a long period when the teeth are forming under the gums. Increases in the occurrence of mostly mild dental fluorosis were recognised as more sources of fluoride became available to prevent tooth decay. These sources include drinking water with fluoride, fluoride toothpaste (especially if swallowed by young children), and dietary prescription supplements in the form of tablets or drops (particularly if prescribed to children already drinking fluoridated water).
DMFT and dmft	DMFT is the sum of the number of decayed, missing (due to caries), or filled permanent teeth. The mean number of DMFT is the sum of individual DMFT values divided by the sum of the population. The acronym 'dmft' is the sum of the number of decayed, missing (due to caries), or

Term	Explanation
	filled primary teeth. Some countries use the acronym 'deft' (decayed, extracted/missing, or filled primary teeth) to assess primary teeth.
DMFS and dmfs	DMFS is the sum of the number of decayed, missing (due to dental caries), or filled teeth surfaces in permanent teeth. The mean number of DMFS is the sum of individual DMFS values divided by the sum of the population. The acronym 'dmfs' is the sum of the number of decayed, missing (due to dental caries), or filled teeth surfaces in primary teeth.
Downer *et al.*, 1979 [14]	Downer et al. describe a dental caries index based on a 3-point scale (D_3MFT): 1. D_3: decay into dentine 2. M: missing tooth due to decay, and 3. F: filled tooth.
ecological or correlational study	An ecological study is a descriptive epidemiological study carried out using aggregated population-based data to describe a disease (outcome) in relation to a factor of interest (exposure) and is used to formulate a theory, not to prove causality. Both the outcome and exposure are correlated to determine their linear association, which is expressed as a proportion of exposure and outcome that correlate with each other. This study type is vulnerable to ecological fallacy, as it is not known whether the individuals who were exposed were the same individuals who experienced the outcome (or disease). These types of studies are not usually included in the hierarchy of evidence and so would only provide very low-quality evidence.
Fédération Dentaire Internationale (FDI) Caries Matrix; Special Commission on Oral and Dental Statistics 2012 [15]	The FDI Caries Matrix is a dental caries matrix with three levels, with scales ranging from 0–3 to 0–6 for dental caries: 1. Level 1: WHO index 2. Level 2: D_1MFT threshold, ADA index, and 3. Level 3: International Caries Detection and Assessment System (ICDAS) index.
fluorine	Fluorine is a chemical element with the symbol F and atomic number 9. It is a member of the halogen family. Fluoride is the negative ion of the element fluorine.
Fluorosis Risk Index [16]	The Fluorosis Risk Index, developed by D.G. Pendrys, for use in analytical epidemiologic studies, is designed to permit a more accurate identification of associations between age-specific exposures to fluoride sources and the development of enamel fluorosis. The Index divides the enamel surfaces of the permanent dentition into two developmentally related groups of surface zones, designated either as having begun formation during the first year of life (classification I) or during the third through sixth years of life (classification II). The Fluorosis Risk Index assesses four zones of the buccal/facial surfaces (incisal edge/occlusal table, occlusal third, middle third, and cervical third) of the teeth. Zones are categorised as no fluorosis (Score=0), questionable fluorosis if 50% of the zone has white striations (Score=2), or severe fluorosis if a zone displays pitting or staining (Score=3).
g [17]	Small sample bias-corrected standardized mean difference
hierarchy of evidence	The hierarchy of evidence for primary epidemiological studies is, from highest to lowest quality: randomised controlled trials, non-randomised trials, longitudinal cohort studies, case-control studies, and cross-sectional surveys. Ecological or correlational studies are not usually on the hierarchy of evidence, as their role is to suggest rather than prove causal relationships.
I^2 [18]	The approximate proportion of total variability in point estimates that can be attributed to heterogeneity. Its value depends on the precision of included studies as well as their sample sizes such that as studies increase in sample size, I^2 tends toward 100% (refs). It is commonly classified as: I^2 = 25%: low heterogeneity I^2 = 50%: moderate heterogeneity I^2 = 75%: substantial heterogeneity
incidence	Incidence is a term used to describe the number of new cases of disease or events that develop among a population during a specified time interval.
†Intra	An abbreviation used in tables to indicate the level of agreement between different examiners
†Inter	An abbreviation used in tables to indicate the level of agreement of one examiners' repeated measurements
International Caries Detection and Assessment System (ICDAS II) [19,20]	ICDAS II is a dental caries index that uses a 7-point scale (0–6): 0. Sound; no caries change after air drying (5 seconds), or non-carious change such as stain, hypoplasia, wear, erosion, and other non-caries phenomena 1. First visual change in enamel, seen after air drying, or coloured change limited to the confines of the pit-and-fissure area 2. Distinct visual change in enamel seen when wet: white or coloured, and wider than the fissure/fossa 3. Localised enamel breakdown, with no visible dentine and widening of fissure

Term	Explanation
	4. Underlying dark shadow from dentine with or without localised enamel breakdown 5. Distinct cavity with dentine exposed at the base of the cavity, and 6. Extensive cavity with dentine visible at base and walls of the cavity (or half of the surface).
Ismail *et al.*, 1992 [21]	Ismail et al. describe a dental caries index that uses a 10-point scale (00–09): 00. The tooth is sound (sticking of the explorer by itself is not considered indicative of caries). 01. Non-cavitated carious lesion (pits and fissures): After drying and cleaning the tooth, the examiner visually checks whether the tooth surface is cavitated (loss of enamel) or not. If not, and if the pits or fissures are coloured light or dark brown at the base and/or a white change (demineralisation) on the sides of the pits or fissures is detected, then the area is diagnosed as carious. The lesion should have a leathery or tacky feeling upon gentle exploration (scratching with the explorer). Stained pits and fissures (black stained pits and fissures) should not be coded into this category. 02. Active incipient caries: This lesion has the following characteristics: i. The lesion is not well demarcated as in hypoplastic lesions. The white or brown lesion should also be differentiated from enamel fluorosis. ii. The lesion is usually covered by plaque. iii. The lesion is chalky white or light brown in colour and matted (non-glossy) after drying. iv. The lesion is located in a caries-susceptible area (usually in contact with gingival margin or within 1 mm of the gingival margin). 03. Cavitated carious lesion: This lesion has the following characteristics: i. The base or sides of the cavity contain demineralised dentine (usually light brown in colour) and have a soft texture. There is softness at the base or in the enamel adjacent to the area. Only gentle pressure should be used to check the softness of the area. ii. The lesion is usually located in a caries-susceptible area. iii. There is a frank cavity. Also included in this category is loss of the normal translucency of the enamel (opacity as evidence of undermining or demineralisation) adjacent to a pit or fissure, in contrast to the surrounding tooth structure. This condition is considered to be reliable evidence of undermining. The explorer may not catch or penetrate the pit. a. The tooth is indicated for extraction. b. The tooth was extracted for reasons other than dental caries. c. The tooth is excluded. d. The tooth is unerupted. e. The tooth surface is indicated for a restoration because of reasons other than caries. f. The tooth was extracted because of dental caries.
Jackson *et al.*, 1973 [22]	Jackson *et al.* describe a dental caries index that uses a 3- and 4-point scale (DMF/dmf and DMFC/dmfc) on both primary and permanent teeth: 1. D/d –decayed teeth 2. M/m – missing teeth, and 3. F/f – filled teeth. In 1973, the authors added a fourth point: 4. C/c – crowned teeth.
Jarman Score [23]	The Jarman Score is a census-based composite measure designed to identify underprivileged areas for purposes of health care resource allocation. The variables in the Australian version of the index are: percentage of the population aged over 60 years and living alone (6.62); percentage of the population under 5 years old (4.62); percentage of the population living in single parent families (3.01); percentage of the population employed as labourers and related workers (3.01); percentage of the economically active population unemployed (3.74); percentage of the population living in overcrowded conditions (2.88); percentage of the population that changed address in the previous year (2.68); and percentage of the population born overseas from non-English speaking countries (2.50). It rates areas from most advantages to least advantages.
logistic regression	Logistic regression is a statistical technique used in research designs that require the analysis of the relationship of an outcome or dependent variable to one or more predictors or independent variables when the dependent variable is either: (a) dichotomous, having only two categories (for example, whether one uses illicit drugs (no or yes)); (b) unordered polytomous, which is a nominal-scale variable with three or more categories (for example, eye colour (blue, brown, grey,

Term	Explanation
	or green)); or (c) ordered polytomous, which is an ordinal-scale variable with three or more categories (for example, the highest level of education completed (none or primary school incomplete, primary school, secondary school, third-level diploma, third-level primary degree, third-level master's degree, or third-level doctorate)).
Mantel-Haenszel odds ratio	The Mantel-Haenszel formula allows calculation of an overall, unconfounded (adjusted) effect estimate of a given exposure for a specific outcome by combining (pooling) stratum-specific odds ratios (OR) or relative risks (RR).
mean difference	The mean difference or difference in means is a standard statistic that measures the absolute difference between the mean value in two groups in an epidemiological study. It estimates the amount by which the exposure or intervention changes the outcome on average compared with the control.
Moller and Poulsen, 1973 [24]	Moller and Poulsen describe a dental caries index that uses a 10-point scale (0–9): 0. Sound tooth 1. Type 1 dental caries: white lesion in enamel 2. Type 2 dental caries: discontinuity of enamel, no dentine involvement 3. Type 3 dental caries: involvement of dentine (no more than 50%) 4. Type 4 dental caries: involvement of dentine (more than 50%) 5. Filled tooth 6. Missing tooth due to caries 7. Tooth not erupted 8. Tooth missing for reason other than caries, and 9. Congenitally missing tooth.
National Institute of Dental Research (now known as National Institute of Dental and Craniofacial Research) [25]	The National Institute of Dental Research uses a dental caries index comprising a 3-point scale: ft – filled teeth dt –decayed teeth, and dft –decayed and filled teeth (summed).
odds ratio	An odds ratio is a statistic that quantifies the strength of the association between two events, A and B. The odds ratio is defined as the ratio of the odds of A in the presence of B and the odds of A in the absence of B, or equivalently (due to symmetry), the ratio of the odds of B in the presence of A and the odds of B in the absence of A.
oral-health-related quality of life [26]	Oral-health-related quality of life is a multidimensional construct that includes a subjective evaluation of the individual's oral health, functional well-being, emotional well-being, expectations of and satisfaction with care, and sense of self. It has wide-reaching applications in survey and clinical research. It is recognised that oral diseases can have varying impacts on people and their well-being and quality of life. Dental diseases cause pain and discomfort; affect proper physical functions like chewing, talking, and smiling; and can influence an individual's social roles
outlier [27]	There are several ways to define the effect of a study as "outlying". In this review, outlier studies were classified as those wherein the confidence interval does not overlap with the confidence interval of the pooled effect. The idea behind this method is that: (1) studies with a high sampling error are expected to deviate substantially from the pooled effect. However, because the confidence interval of such studies will also be large, this increases the likelihood that the confidence intervals will overlap with the one of the pooled effect. (2) if a study has a low standard error and still (unexpectedly) deviates substantially from the pooled effect, there is a good chance that the confidence intervals will not overlap, and that the study is classified as an outlier.
Palmer *et al.*, 1984 [28]	Palmer, Anderson, and Downer describe a dental caries index that uses an 8-point scale: 1. Decayed 2. Missing 3. Filled 4. Filled and decayed 5. Unerupted 6. Orthodontic 7. Traumatised, and 8. Sound surface.
parts per million	The unit of measurement for fluoride in water is parts per million (ppm) or milligrams per litre (mg/L). The units are interchangeable: 1 ppm equals 1 mg/L.

<table>
<tr><th>Term</th><th>Explanation</th></tr>
<tr><td>prevalence</td><td>Prevalence is a term used to describe the proportion of people in a population who have a disease or condition at a specific point in time or during a specific period.</td></tr>
<tr><td>PUFA/pufa index [29]</td><td>An index to assess the clinical consequences of untreated carious lesions:
P/p: Pulpal involvement is recorded when the opening of the pulp chamber is visible or when the coronal tooth structures have been destroyed by the carious process and only roots or root fragments are left. No probing is performed to diagnose pulpal involvement.
U/u: Ulceration due to trauma from sharp pieces of tooth is recorded when sharp edges of a dislocated tooth with pulpal involvement or root fragments have caused traumatic ulceration of the surrounding soft tissues (e.g. tongue or buccal mucosa).
F/f: Fistula is scored when a pus-releasing sinus tract related to a tooth with pulpal involvement is present.
A/a: Abscess is scored when a pus-containing swelling related to a tooth with pulpal involvement is present.</td></tr>
<tr><td>relative risk or risk ratio</td><td>The relative risk or risk ratio is the ratio of the probability of an outcome in an exposed (or intervention) group relative to the probability of the outcome in an unexposed (or control) group, and it compares the incidence of the outcome in the exposed group with the incidence of the outcome in the unexposed group.</td></tr>
<tr><td>Russell's criteria [30]</td><td>Criteria to distinguish dental enamel effects from fluorosis.
Differential diagnosis: milder forms of fluorosis (questionable, very mild, and mild) and non-fluoride enamel opacities
<table>
<tr><th>Characteristic</th><th>Milder forms of fluorosis</th><th>Non-fluoride enamel opacities</th></tr>
<tr><td>Area affected</td><td>Usually seen on or near tips of cusps or incisal edges of teeth</td><td>Usually centred in smooth surface; may affect entire crown</td></tr>
<tr><td>Shape of lesion</td><td>Resembles line shading in pencil sketch; lines follow incremental lines in enamel; form irregular caps on cusps</td><td>Often round or oval</td></tr>
<tr><td>Demarcation</td><td>Shades of imperceptibility into surrounding normal enamel</td><td>Clearly differentiated from adjacent normal enamel</td></tr>
<tr><td>Colour</td><td>Slightly more opaque than normal enamel; paper white incisal edges; tips of cusps may have frosted appearance; does not show stain at time of eruption</td><td>Usually pigmented at time of eruption; often creamy yellow to dark reddish orange</td></tr>
<tr><td>Teeth affected</td><td>Most frequently on teeth which calcify slowly; usually in 6–8 homologous teeth; extremely rare in lower incisors or primary teeth</td><td>Any tooth may be affected; frequently occurs on labial surfaces of lower incisors; may occur singly, usually 1–3 teeth affected; common in primary teeth</td></tr>
<tr><td>Gross hypoplasia</td><td>None; pitting of enamel does not occur in the milder forms; enamel surface has glazed appearance and is smooth to point of explorer</td><td>Absent to severe; enamel surface may seem etched and rough to point of explorer</td></tr>
<tr><td>Detection</td><td>Often invisible under strong light; most easily detected by line of sight tangential to tooth crown</td><td>Seen most easily under strong light; most easily detected by line of sight perpendicular to tooth surface</td></tr>
</table></td></tr>
<tr><td>Slack et al., 1958 [31]</td><td>Slack et al. describe a dental caries index that uses a 3-point scale (dmft; primary teeth only):
d –decayed (no description of criteria for diagnosis of decay)
m – missing, and
f – filled.</td></tr>
<tr><td>social gradient effect</td><td>The social gradient in health is a term used to describe the phenomenon whereby people who are less advantaged in terms of socioeconomic position have worse health (and shorter lives) than those who are more advantaged.</td></tr>
<tr><td>standard deviation</td><td>The standard deviation is a summary measure of the differences of each observation from the mean within a normal distribution. It measures the amount of variation or dispersion within a set of normally distributed values. A low standard deviation indicates that the values tend to be close</td></tr>
</table>

Term	Explanation
	to the mean of the set of values, while a high standard deviation indicates that the values are spread out over a wider range. For a normal distribution, around 68.0% of scores are within 1 standard deviation of the mean; around 95.0% of scores are within 2 standard deviations of the mean; and around 99.7% of scores are within 3 standard deviations of the mean.
standard error	Standard error is a measure of the statistical accuracy of an estimate, equal to the standard deviation, of the theoretical distribution of a large population of such estimates.
statistical heterogeneity [32]	A quantifiable property, influenced by the spread and precision of the effect size estimates included in a meta-analysis. Baseline heterogeneity can lead to statistical heterogeneity (for example if effects differ between included populations) but does not have to. It is possible for a meta-analysis to display high statistical heterogeneity, even if the included studies themselves are virtually identical.
Stephen *et al.*, 1988 [33]	Stephen et al. describe a dental caries index that uses a 3-point scale, similar to the BASCD scale, at tooth surface level (D_3MFS): D_3 – decay into dentine M – missing tooth due to decay, and F – filled tooth.
student's two-tailed unpaired *t*-test	An unpaired *t*-test (also known as an independent *t*-test) is a statistical procedure that compares the means of two independent or unrelated groups in order to determine whether there is a significant difference between the means of the two groups.
τ^2 [32]	A point estimate of the among-study variance of true effects. It quantifies the variance of the true effect sizes underlying the data. Its value is insensitive to the number of studies and their precision.
Thylstrup and Fejerskov Index (TFI) [34]	Dental fluorosis can be measured using the Thylstrup and Fejerskov Index (TFI) which, in 1978, extended the fluorosis index score criteria: 0. Normal translucency of enamel remains after prolonged air drying. 1. Narrow white lines corresponding to the perikymata (growth lines). 2. Smooth surfaces: More pronounced lines of opacity that follow the perikymata. Occasional confluence of adjacent lines. Occlusal surfaces: Scattered areas of opacity. 3. Smooth surfaces: Merging and irregular cloudy areas of opacity. Accentuated drawing of perikymata often visible between opacities. Occlusal surfaces: Confluent areas of marked opacity. Worn areas appear almost normal but usually circumscribed by a rim of opaque enamel. 4. Smooth surfaces: The entire surface exhibits marked opacity or appears chalky white. Parts of surface exposed to attrition appear less affected. Occlusal surfaces: Entire surface exhibits marked opacity. Attrition is often pronounced shortly after eruption. 5. Smooth surfaces and occlusal surfaces: Entire surface displays marked opacity with focal loss of outermost enamel (pits) <2 mm in diameter. 6. Smooth surfaces: Pits are regularly arranged in horizontal bands involving one-half of the entire surface. Occlusal surfaces: Confluent areas <3 mm in diameter exhibit loss of enamel. Marked attrition. 7. Smooth surfaces: Loss of outermost enamel in irregular areas involving less than one-half of the entire surface. Occlusal surfaces: Changes in the morphology caused by merging pits and marked attrition. 8. Smooth and occlusal surfaces: Loss of outermost enamel involving more than one-half of the entire surface. 9. Smooth and occlusal surfaces: Loss of main part of enamel with change in anatomic appearance of surface. Cervical rim of almost unaffected enamel is often noted.
Tooth Surface Index of Fluorosis (TSIF) [35]	An index for measuring the prevalence of dental fluorosis, the Tooth Surface Index of Fluorosis (TSIF) eliminates or reduces some of the shortcomings of Dean's Index of Fluorosis, as it requires examination of all teeth and their surfaces. Use of the TSIF in a survey in Illinois was able to discriminate between the prevalence and severity of fluorosis in four groups of communities with different concentrations of fluoride in their drinking water. The TSIF criteria are: Score=0: Enamel shows no evidence of fluorosis. Score=1: Enamel shows definite evidence of fluorosis, namely areas with parchment-white colour that total less than one-third of the visible enamel surface. This category includes fluorosis confined only to incisal edges of anterior teeth and cusp tips of posterior teeth ('snow capping'). Score=2: Parchment-white fluorosis totals at least one-third of the visible surface, but less than two-thirds. Score=3: Parchment-white fluorosis totals at least two-thirds of the visible surface. Score=4: Enamel shows staining in conjunction with any of the preceding levels of fluorosis. Staining is defined as an area of definite discoloration that may range from light to very dark brown.

<table>
<tr><th>Term</th><th>Explanation</th></tr>
<tr><td></td><td>Score=5: Discrete pitting of the enamel exists, unaccompanied by evidence of staining of intact enamel. A pit is defined as a definite physical defect in the enamel surface with a rough floor that is surrounded by a wall of intact enamel. The pitted area is usually stained or differs in colour from the surrounding enamel.
Score=6: Both discrete pitting and staining of the intact enamel exist.
Score=7: Confluent pitting of the enamel surface exists. Large areas of enamel may be missing, and the anatomy of the tooth may be altered. Dark brown stain is usually present.</td></tr>
<tr><td>World Health Organization (WHO) [36]</td><td>The WHO uses a dental caries index that comprises an 11-point scale for permanent teeth (0–9 and T) and an 8-point scale for primary teeth (A–G and T) (in the 1987 version, dental caries were only recorded if cavitation had occurred (cavitated caries with enamel and dentine involvement in permanent teeth (D_3), D_3MFT, or D_3MFS)):
Coding the dentition status – primary and permanent teeth
Code
<table>
<tr><th>Primary teeth</th><th>Permanent teeth</th><th></th><th></th></tr>
<tr><th>Crown</th><th>Crown</th><th>Root</th><th>Condition/status</th></tr>
<tr><td>A</td><td>0</td><td>0</td><td>Sound</td></tr>
<tr><td>B</td><td>1</td><td>1</td><td>Caries</td></tr>
<tr><td>C</td><td>2</td><td>2</td><td>Filled, with caries</td></tr>
<tr><td>D</td><td>3</td><td>3</td><td>Filled, no caries</td></tr>
<tr><td>E</td><td>4</td><td>–</td><td>Missing due to caries</td></tr>
<tr><td>–</td><td>5</td><td>–</td><td>Missing for any other reason</td></tr>
<tr><td>F</td><td>6</td><td>–</td><td>Fissure sealant</td></tr>
<tr><td>G</td><td>7</td><td>7</td><td>Fixed dental prosthesis abutment, special crown or veneer/implant</td></tr>
<tr><td>–</td><td>8</td><td>8</td><td>Unerupted tooth (crown)/unexposed root</td></tr>
<tr><td>–</td><td>9</td><td>9</td><td>Not recorded</td></tr>
</table>
In the short version of the index, one-half of the mouth, the upper quadrant, and the contralateral lower quadrant are assessed and the result doubled.</td></tr>
<tr><td>Z-test</td><td>A Z-test is a statistical test used to determine whether two population means are different when the variances are known, and the sample size is large.</td></tr>
</table>

Executive summary

Background

Research indicates that artificial community water fluoridation (CWF) reduces the incidence of dental caries but increases the prevalence of very mild and mild dental fluorosis. Artificial CWF is usually accomplished by adding sodium fluoride (NaF), fluorosilicic acid (H_2SiF_6), or sodium fluorosilicate ($Na_2[SiF_6]$) to drinking water in which the naturally occurring fluoride concentration is sub-optimal. CWF was introduced in Ireland in 1964 following the Health (Fluoridation of Water Supplies) Act, 1960; fluoride was added at a level of 1 part per million (ppm). In 2000, water fluoridation policy in Ireland was the subject of a major review by the Forum on Fluoridation, which was established by the then Minister for Health and Children. Considering both international and Irish research reporting an increasing occurrence of dental fluorosis, the Forum on Fluoridation recommended that the fluoride level in drinking water be lowered from a target of 1.0 ppm to a range of 0.6–0.8 ppm, with a target of 0.7 ppm. This policy was implemented in 2007. Recent evidence suggests that lowering the fluoride concentration in drinking water to 0.7 ppm may have reduced the beneficial effect of CWF for the prevention of dental caries but has not decreased the prevalence of mild dental fluorosis. Fluoride can be ingested from swallowing toothpaste and other fluoride-based topical agents (mouth rinses, gels, foams, and varnishes) when used by young children, as their swallowing reflex has not yet fully developed. Topical fluoride therapies are therapies applied to the surfaces of teeth. The consumption of systemic fluoride supplement tablets or drops in combination with CWF can also contribute to dental fluorosis.

Purpose

The evidence for the potential effects of artificial CWF (at 0.5–1.2 ppm) on dental health is the primary focus of this systematic review. In addition, the use of other sources of topical fluoride in combination with CWF by children aged under 6 years is investigated. This systematic review collates the evidence on the positive and negative effects of artificial CWF on dental caries and fluorosis between 1948 and 2023, and it includes both before and after studies (prospective cohort and repeated cross-sectional surveys) and single point in time studies (cross-sectional surveys in CWF areas compared with fluoride deficient areas). It also attempts to establish if there are dose response relationships between CWF level (from 0.5ppm to 1.2ppm) and dental caries, and between CWF levels and dental fluorosis.

Research questions

The following questions are answered in this systematic evidence review:

1. What is the positive and negative effect* of artificial CWF (intervention or exposure) on dental health of the general population and does the effect on dental health vary with the level of fluoride in artificially fluoridated water?

2A. What is the effect of fluoride toothpaste in areas with CWF on dental health in children who are aged under 6 years when they receive the intervention?

2B. What is the additive effect of topical fluoride therapies† in areas with CWF (and with widespread use of fluoride toothpaste) on dental health in children who are aged under 6 years when they receive the intervention?

3. What are the recommendations in other countries currently implementing CWF for the use of topical fluorides in children aged under 6 years?

*For Question 1, impact implies a reduction in the incidence of dental caries resulting in damaged or missing teeth (positive outcome), a decrease in the proportion of cavitated caries per head of population, and an increase in the prevalence of dental fluorosis (negative outcome)

Methods

Following the recommended approach for systematic reviews, a structured database search was developed. The search concepts were based on 'artificially fluoridated water', 'oral health', and 'primary quantitative studies' for Question 1.

A separate systematic search strategy was created for Questions 2A and 2B, with the results differentiated during the screening process. For Questions 2A and 2B, as well as the concepts of 'artificially fluoridated water', 'oral health', and 'primary quantitative studies', two additional concepts – 'topical fluorides' and 'children' – were introduced. The 'topical fluorides' search language included language on toothpaste in order to answer Question 2A.

In February 2022, we searched four bibliographic databases (MEDLINE, Embase, Cochrane Library and LILACS) and a range of grey literature resources using structured searches in order to locate primary quantitative evidence published between 1946 and 2021 for Questions 1, 2A, and 2B. Only English-language evidence was considered at the full text stage, as it was not possible to have material professionally translated given the time frame for this evidence review. Supplemental searches of systematic reviews, as well as reference and forward citation chasing of included papers, were also performed. An updated database search was run in March 2023, and the results went through the same process of deduplication and screening as the original database search. All search results were imported into EndNote reference management software for deduplication. Records were then transferred to the EPPI-Reviewer 4 review management software, and further deduplication took place. Screening was done in duplicate at the title and abstract level, and subsequently on eligible full-text papers.

In order to answer Question 1, data were extracted into a bespoke Microsoft Excel extraction sheet (one sheet for each question) by one researcher, and the extracted data were independently verified by a second reviewer.

The quality of all papers included in response to Questions 1 was appraised using a tool appropriate to the epidemiological study design used in each paper under review. Questions 1, included studies employing different designs, including prospective cohort studies, and cross-sectional surveys. The appropriate National Heart, Lung, and Blood Institute (NHLBI) tool was employed in order to assess the quality of included prospective cohort studies and cross-sectional surveys. All studies were included regardless of quality. Feasibility assessments were completed for each dental caries and fluorosis outcome in order to determine if any form of meta-analysis was appropriate. Pairwise meta-analyses, sensitivity analyses for outliers, and subgroup analyses (i.e. CWF level, age and quality) were completed where appropriate and possible. Heterogeneity and its causes were also assessed where feasible. The certainty of evidence for the main outcomes was evaluated using GRADE (Grading of Recommendations, Assessment, Development and Evaluations).

At extraction, we focused on the four most relevant, commonly reported, and comparable dental caries outcomes: decayed, missing, or filled permanent teeth (DMFT)/decayed, missing, or filled primary teeth (dmft); decayed, missing, or filled permanent (tooth) surfaces (DMFS)/decayed, missing, or filled primary surfaces (dmfs); the percentage of participants without cavitated dental caries (% without CDC) in the primary or permanent dentition; and the percentage of participants with cavitated dental caries (% with CDC) in the primary or permanent dentition. We have made this distinction regarding the percentage of participants with or without dental caries because we are reporting dental caries at cavitation level only, as per the World Health Organization (WHO) and International Caries Detection and Assessment System (ICDAS) definitions.

In order to improve the comparability of the dental caries outcomes, we decided, at the extraction stage, on preferred ages for inclusion and to restrict the studies to those with life time exposure to artificial CWF compared with fluoride-free or fluoride-deficient water. In relation to the primary dentition, where possible, data were extracted for children aged 5–6 years, as this is the age at which the WHO recommends the assessment of dental caries in the primary dentition. If data for this age group were not reported, the population that was closest in age to 5–6 years was to be used. In relation to the permanent dentition, where possible, data were extracted for participants aged 12 years in order to capture the fullest dentition with minimum impact from confounders. If data for this age group were not reported, the population that was closest in age to 12 years was to be used. In this analysis, we included all studies, regardless of quality, for narrative synthesis and meta-analysis of dental caries outcomes.

CWF level was grouped as <0.6ppm, 0.6–0.8ppm, 0.80–1.0ppm for meta-analyses of dental caries outcomes.

We extracted the prevalence of dental fluorosis in CWF and fluoride deficient areas, and its means of measurement. We also extracted age at examination and study country.

For Questions 2A and 2B, we used all measurements of cavitated dental caries and dental fluorosis.

The Department of Health specified seven countries of interest for Question 3. Question 3 was best answered using national-level policy and clinical guideline documents. In order to answer Question 3, a separate search was carried out for the seven countries on government and public body websites by an information specialist in February 2022, and was updated in February 2023. A comprehensive search of seven countries' national public dental programmes and government health websites was conducted to obtain current policies and guidelines in February 2022 and updated in February 2023. The seven countries specified by the Department of Health were Australia, Brazil, Canada, Israel, New Zealand, the UK and the USA

Findings

Table 1 presents summary findings with GRADE recommendation by question and these findings are presented in more detail here.

Dental caries in a CWF area compared with a fluoride-deficient area or baseline

We included 55 studies (reported in 87 papers) estimating the four dental caries outcomes in primary and permanent teeth in an area with CWF compared with a fluoride-deficient area or compared with baseline. For the purposes of the dental caries analysis by the four dental caries outcomes in primary and permanent teeth, we have presented the findings by individual paper rather than by study, as some of the papers within a study series had different characteristics, for example different age profiles or different exposure times to CWF.

Four studies (reported in 5 papers) were based on a prospective cohort study design, while 51 studies (reported in 82 papers) were based on a cross-sectional survey design. The papers were published between 1950 and 2022 and covered 17 countries: Australia, Brazil, Canada, Chile, Cuba, England, Finland, Germany, Ireland, Malaysia, the Netherlands, New Zealand, Scotland, Singapore, Taiwan, the USA, and Wales. The lowest concentration of fluoride in the fluoridated water supply for the CWF areas in the included studies was 0.5 ppm, and the highest was 1.2 ppm. The concentration of fluoride in the comparator water was described by primary study authors as 'never fluoridated', 'no fluoride', 'negligible fluoride' or 'fluoridation ended', or 'lower than 0.4 ppm'; we refer to these as fluoride deficient areas.

Mean decayed, missing, or filled primary teeth (dmft)

Twenty one papers published between 1975 and 2022, compared the effect of CWF in the intervention areas with the control (or fluoride-deficient) areas using the outcome of mean dmft and were judged suitable for pairwise random effects meta-analysis. The study populations were aged 5–8 years. Four single-time point/cross-sectional papers reported a lowest CWF level of 0.6–0.8 ppm, 17 single-time point/cross-sectional papers reported a CWF level of 0.8–1.0 ppm and the single two-time point/longitudinal paper reported a CWF level of 0.8–1.0 ppm at baseline and 0.6–0.8 ppm at the final time point.

The most reliable single-time-point pairwise random effects meta-analysis is a sensitivity analysis of 18 papers, with 3 outlier papers removed because their findings were not compatible other included papers, i.e. results greater than four standard deviations from the standardised MD. The results of this meta-analysis indicate a statistically significant effect of CWF on dmft, providing very low certainty evidence that exposure to artificially fluoridated water reduced dental caries in the primary dentition (standardised mean difference; SMD -0.65, 95% CI: -0.87 to - 0.44; 18 papers). The very high level of heterogeneity on the model (I^2 = 97.1%) is partly due to study quality and level of fluoride in the CWF group. In subgroup analyses, there was no difference in effectiveness by CWF level, and the high and moderate quality papers had results closer to the line indicating no difference in effectiveness when compared with low quality papers. The results imply there is very low certainty evidence that the mean difference for dmft equates to just over one-half additional healthy tooth per child aged 5–8 years in the CWF area compared with similar children in the fluoride-deficient area at a single time point.

Five of the 21 papers published between 1981 and 2021, comparing the effect of CWF in the intervention areas with the control (or fluoride-deficient) areas using the outcome mean dmft reported data for two time points. Meta-analysis was not possible for these papers as the follow-up periods were different in each study, ranging from 7–15 years. The mean difference for dmft over time in the areas with CWF was -0.1 higher to 2.49 lower (a lowering of dmft over time is a better result). The mean difference for dmft over time in the fluoride deficient areas was -2.2 higher to 1.0 lower. The follow-up periods ranged from 9 to 15 years, the children were aged between 5 and 8 years. The results imply that there is very low certainty evidence of mixed findings for dmft in children between 5 and 8 years over two time points with three papers reporting a reduction in mean dmft in the CWF area compared with the fluoride deficient area, and two papers reporting no significant difference in mean dmft.

Mean decayed, missing, or filled primary surfaces (dmfs)

Seven papers of low or moderate quality, published between 1977 and 2000, compared the effect of CWF in the intervention areas with the control (or fluoride-deficient) areas using the outcome of mean dmfs and were judged suitable for pairwise random effect meta-analysis. The children included in these papers were aged between 5 and 6 years. The CWF level in all papers was 1.0 ppm so subgroup analysis was not feasible. All the papers were based on single-time-point studies. The most reliable single-time-point pairwise random effects meta-analysis is a sensitivity analysis of 6 papers, with 1 outlier study removed because its finding was not compatible with other included papers. The results of this single-time-point pairwise random effects meta-analysis indicate a standardised MD of −0.62 (95% CI: −1.2 to −0.04; I^2: 92.6%; 6 papers) in favour of CWF for dmfs, and this difference is statistically significant. The I^2 value (92.6%) was high indicating substantial statistical heterogeneity. The very high level of heterogeneity on the model is partly due to study quality. The subgroup analysis examining low and moderate quality indicate that the subgroup with low quality papers had wider confidence intervals and these cross the line from effectiveness to no effectiveness in reducing dmfs, while the moderate quality papers indicate that CWF is effective. The results imply that there is very low certainty evidence that the mean difference for dmfs equates to just over one-half additional healthy tooth surface per child aged 5–6 years in the CWF area compared with similar children in the fluoride-deficient areas at a single time point.

Percentage of participants without cavitated dental caries in the primary dentition

Four papers of low or moderate quality, published between 1953 and 2001, compared the effect of CWF in the intervention and control (or fluoride-deficient) areas using the outcome of percentage of participants without cavitated dental caries in the primary dentition. The four papers were judged suitable for single-time-point meta-analysis. The children in these papers were aged 5–11 years. The CWF level was between 1.0 and 1.2 ppm in the four papers, so subgroup analysis was not feasible. The results of the single-time-point pairwise random effects meta-analysis indicate an odds ratio of 1.75 (95% CI: 0.87–3.51; I^2: 84.0%; 4 papers) in favour of CWF, the results are not statistically significant and have considerable heterogeneity. The subgroup analysis examining low and moderate quality indicate that the subgroup with low quality papers had wider confidence intervals but similar results when compared with moderate quality papers. The results imply there is very low certainty evidence that children aged 5–11 years have 1.75 higher odds of having cavity free primary teeth in the CWF area compared with the fluoride-deficient area at a single time point.

One paper of moderate quality, published in 1960, compared the effect of CWF in the intervention (1.0–1.2 ppm) and control (or fluoride-deficient) areas using the outcome of percentage of participants without cavitated dental caries in the primary dentition and reported data for two time points. There is very low certainty evidence that the overall percentage point difference after 11 years equates to an average of 6 additional children in every 100 children aged 9–11 years having no cavitated dental caries in their primary teeth in the CWF area compared with the fluoride-deficient area.

Percentage of participants with cavitated dental caries in the primary dentition

Four papers of moderate or high quality, published between 1984 and 2021, compared the effect of CWF in the intervention and control (or fluoride-deficient) areas using the outcome of percentage of participants with cavitated dental caries in the primary dentition. The four papers were judged suitable for single-time-point meta-analysis. The children in these papers were aged 5–7 years. The CWF level was circa 0.6 ppm in one paper, 0.6 ppm–0.8 ppm in two papers and 1.0 ppm in the remaining paper, so subgroup analysis was not recommended. The results of the single-time-point pairwise random effects meta-analysis indicate an odds ratio of 0.50 (95% CI: 0.40–0.63; I^2: 0%; 4 papers) in favour of CWF, the results are statistically significant and had very low heterogeneity between studies. The results imply there is low certainty evidence that children aged 5–7 years have 50% lower odds of having cavitated dental caries in one or more teeth in the primary dentition in the CWF area compared with the fluoride-deficient area at a single time point.

Two of the included papers in a census study series reported data for 5-year-olds at two time points (baseline and 9 or 12 years later); the CWF level in both papers was 0.6–0.8 ppm, a meta-analysis could not be undertaken to examine the difference over time due to an inadequate number of papers and different follow-up periods. The papers reported that the percentage of 5 year old participants with cavitated dental caries in the primary dentition was lower in the CWF groups after 9 or 12 years of CWF compared with the respective fluoride-deficient area, although the absolute rates from the two papers were very different at 8.70 (95% CI: 8.84–8.56) and 0.1 (95% CI: 0.24–0.04) percentage points difference at the final timepoint). Ther results imply there is very low certainty evidence that the percentage of 5-year-olds with cavitated dental caries in the primary dentition was much lower in the first study and marginally lower in the second in the CWF area compared with the fluoride-deficient area after 9 or 12 years, respectively.

Mean decayed, missing, or filled permanent teeth (DMFT)

Twenty five included papers of low, moderate or high quality, published between 1960 and 2021, compared the effect of CWF in the intervention and control (or fluoride-deficient) areas using the outcome of mean DMFT and were judged suitable for meta-analysis. The participants were aged 6–32 years. The CWF level reported was circa 0.6 ppm in two papers, 0.6–0.8 ppm in seven papers, and higher than 0.8 ppm in six papers. The most reliable single-time-point pairwise random effects meta-analysis is a sensitivity analysis of 21 papers, with 4 outlier papers removed because their findings were not compatible with the other included 21 papers. The results of this single-time-point meta-analysis indicate a standardised mean difference of −0.83 (95% CI: −1.27 to -0.38; I^2: 98.4%; 21 papers) in favour of CWF, the result is statistically significantly different. There is very high statistical heterogeneity in the model partly due to the wide age span , higher ppm, and study quality. In subgroup analyses, there was no difference in mean DMFT by CWF level, and the results of high-quality papers crossed the line indicating no significant difference in effectiveness on DMFT while the overall results of moderate quality papers indicated higher effectiveness. The results imply there is very low certainty evidence that the mean difference for DMFT equates to an average gain of almost one additional healthy tooth per person aged 6–32 years in the CWF areas compared with the fluoride-deficient areas at a single time point.

Five of the 21 papers of, published between 1960 and 1986, comparing the effect of CWF in the intervention areas with the control (or fluoride-deficient) areas using the outcome of mean DMFT reported data for two time points, meta-analysis was not possible as the follow-up period was different in each of the papers, ranging from 6–12 years. The participants were aged 6–15 years. The CWF level was 0.6 ppm in three papers, and 0.8 ppm or higher in the remaining two papers. The mean difference over time for DMFT in the areas with CWF was 2.55 (0.12 SD) higher to -0.8 (3.06 SD) lower, (lower mean difference equates with better outcome). The mean difference over time for DMFT in the fluoride deficient areas was 3.75 (0.73 SD) higher to -3.5 (4.42 SD) lower. Therefore, there is very low certainty evidence of mixed findings for DMFT in persons aged 6–15 years over two time points with four papers reporting a greater reduction in mean DMFT in the CWF area compared with the fluoride deficient area, and one paper reporting a greater reduction in the fluoride deficient area compared with the CWF area.

Mean decayed, missing, or filled permanent surfaces (DMFS)

Six papers of low or moderate quality, published between 1991 and 2001, compared the effect of CWF in the intervention and control (or fluoride-deficient) areas using the outcome of mean DMFS and were judged suitable for meta-analysis. The participants were 5–16-year-old children and all papers were single-time-point studies. Two papers reported a level of 0.6–0.8 ppm and four papers reported a CWF level of 0.8–1.0 ppm. The most reliable single-time-point pairwise random effects meta-analysis is a sensitivity analysis of 5 papers, with 1 outlier study removed because its finding was not compatible with other included papers. The results of this single-time-point meta-analysis indicate a standardised mean difference of −0.72 (95% CI: −1.46 to 0.3; I^2: 98.5%; 5 papers) in favour of CWF, the result is not statistically significantly different. There is very high statistical heterogeneity in the model partly due to the wide age span. In subgroup analyses, there was no difference by CWF level or study quality. The results imply there is very low certainty evidence that the mean difference for DMFS equates to an average gain of almost one additional healthy tooth surface per person aged 5–16 years in the CWF areas compared with the fluoride-deficient areas at a single time point.

Percentage of participants without cavitated dental caries in the permanent dentition

Three papers of low or moderate quality, published between 1960 and 2001, compared the effect of CWF in the intervention and control (or fluoride-deficient) areas using the outcome of percentage of participants without cavitated dental caries in the permanent dentition. The three papers were judged suitable for single-time-point meta-analysis. The participants in these papers were aged 5–17 years. The CWF level was between 1.0 and 1.2 ppm in the three papers. The results of the single-time-point pairwise random effects meta-analysis indicate an odds ratio of 6.67 (95% CI: 0.11–393.50; I^2: 96.6%; 3 papers) in favour of CWF, the results are not statistically significant and have very high heterogeneity partly due to age span and study year; two of the three papers were completed before widespread availability of fluoride toothpaste. The results imply there is very low certainty evidence that children aged 5–17 years have 6.67 higher odds of having cavity free primary teeth in the CWF area compared with the fluoride-deficient area at a single time point.

One paper of moderate quality, published in 1960, compared the effect of CWF in the intervention (1.0–1.2 ppm) and control (or fluoride-deficient) areas using the outcome of percentage of participants without cavitated dental caries in the permanent dentition and reported data for two time points. The study found that the percentage of 12–14-year-old children without cavitated dental caries in the permanent dentition after 11 years was greater in the CWF group than in the fluoride-deficient group; the proportion of participants without cavitated dental caries in the CWF group had increased by 17.51 percentage points compared with the fluoride-deficient group, which had experienced an increase of only 1.65 percentage points over the 11-year study period. The percentage point difference at the end of the study was 16.42 (95% CI: 12.77–20.07) percentage points higher in favour of CWF. The result was reported by the authors to be statistically significant. The results imply there is very low certainty evidence that the overall percentage point difference after 11 years equates to an average of 16 additional children in every 100 children aged 12–14 years having no cavitated dental caries in the CWF area compared with the fluoride-deficient area.

Percentage of participants with cavitated dental caries in the permanent dentition

Three included papers of moderate or high quality, published between 1984 and 2021, compared the effect of CWF in the intervention and control (or fluoride-deficient) areas using the outcome of percentage of participants with cavitated dental caries in the permanent dentition.

The three papers were judged suitable for single-time-point meta-analysis. The participants were aged 7–12 years. The CWF level was 0.5–0.7 ppm in one paper, and 0.6 ppm in two papers. The results of the single-time-point pairwise random effects meta-analysis indicate an odds ratio of 0.37 (95% CI: 0.07 to 1.90; I^2: 95%; 3 papers) in favour of CWF. However, the confidence intervals are very wide, and the results are not statistically significant. Study heterogeneity is very high but there were too few papers to identify factors that contributed to heterogeneity in the meta-analysis. Heterogeneity may be due to study location (1 study was located in Canada and 2 were in Taiwan). The results imply there is very low certainty evidence that children aged 7–12 years have 63% lower odds of having cavitated dental caries in one or more teeth in the permanent dentition in the CWF area compared with the fluoride-deficient area at a single time point.

A meta-analysis could not be undertaken for two time points due to an inadequate number of papers and the different follow-up periods. The participants were aged 10–12 years and the CWF level in the two papers was 0.6 ppm. Both papers found that the percentage of participants with cavitated dental caries in the permanent dentition was lower in the CWF group at both time points: the percentage of 10- and 12-year-olds with cavitated dental caries in the CWF group had increased by 10.2 and 11.2 percentage points, respectively, compared with the comparator group, for which these percentages had increased by 42.3 and 39.7 percentage points, respectively, over the course of 9 or 12 years. Statistical significance testing was not reported. The results imply there is low certainty evidence that the overall percentage point difference, after 9 or 12 years, equates to children aged 10- and 12-years having less cavitated dental caries in one or more teeth in the permanent dentition in the CWF area compared with the fluoride-deficient area.

Narrative synthesis of CWF as an independent determinant of cavitated dental caries

We examined the papers on dental caries in order to determine if we could complete a meta-analysis to identify the independent influence of CWF on the dental caries outcomes of interest for the primary dentition (dmft, dmfs, percentage without cavitated dental caries, and percentage with cavitated dental caries) and the permanent dentition (DMFT, DMFS, percentage without cavitated dental caries, and percentage with cavitated dental caries). We identified all papers that completed regression analysis to control for the influence of confounding and examined the respective authors' regression analysis models in order to determine if they identified the odds (with 95% CIs) that CWF was associated with dental caries after controlling for at least one of five groups of confounders (i.e. demographic factors, socioeconomic factors, nutritional factors, other sources of dental fluoride, and access to and affordability of dental services). None of the four outcomes in primary and permanent dentition has three or more papers with a regression analysis model to determine the odds (with 95% CIs) that CWF was associated with dental caries after controlling for at least one of the five groups of confounders so we could not complete a meta-analysis.

Dental fluorosis in a CWF area compared with a fluoride-deficient area or baseline

We included 26 studies, reported in 33 papers, estimating the prevalence of dental fluorosis in a CWF area compared with a fluoride-deficient area or baseline (prior to the introduction of CWF) in 13 countries, specifically: Australia, Brazil, Canada, Chile, Cuba, Ireland, Malaysia, New Zealand, Singapore, Taiwan, the United Kingdom (UK) (England and Wales), and the United States of America (USA). All 26 studies (reported in 33 papers) were cross-sectional in nature, and 15 of the 26 studies (18 of the 33 papers) were low quality with regard to conduct and design. Only one of the 33 papers controlled for all five groups of confounding variables (demographic, socioeconomic, nutrition, other sources of dental fluoride, and access to and affordability of dental services), and the pattern of dental fluorosis prevalence estimates by fluoride concentration in the drinking water did not demonstrate a clear pattern across countries. However, a pattern of dental fluorosis could be observed within some countries, specifically England (with similar levels at 54% in the two included studies), Ireland (with increasing levels over time, for example, the levels were 1.1% in 1992, 12% in 2002 and 18% in 2017 among 8 year olds), and the USA (with increasing levels over time, for example, 7.8% in 1989 and 19.6% in 1998 and 2000). Only four studies provided population prevalence estimates for dental fluorosis, and another four studies provided sample estimates with 95% CIs. Of note, one of the sample estimates did not state whether the authors took account of the cluster sampling design effect when calculating the 95% CIs. Taking all the factors mentioned in this summary into account, we felt that it would be unwise to present an overall global estimate of dental fluorosis as a result of CWF, and the certainty of evidence for the prevalence of fluorosis across countries with CWF is very low.

For analysis by the index of dental fluorosis employed by the primary study authors, we excluded four studies (reported in six papers) that did not use or identify the index employed. This analysis is based on 22 studies reported in 27 papers. The prevalence of dental fluorosis increased over time in Brazil, Ireland, and the USA, and this increase was observed both in areas with and without CWF. We used three indices in this review in order to measure the prevalence of dental fluorosis, specifically Dean's Index of Fluorosis, the Tooth Surface Index of Fluorosis, and the Thylstrup and Fejerskov Index. The prevalence of dental fluorosis by index was lower using Dean's Index of Fluorosis. For example, the synthesised evidence in this review found that:

- The prevalence of dental fluorosis in permanent teeth of 10–15-year-old children living in CWF areas, using Dean's Index of Fluorosis, ranged from 1.3% to 47.7%.
- The prevalence of dental fluorosis in permanent teeth of schoolchildren and young people living in CWF areas, using the Tooth Surface Index of Fluorosis, ranged from 18.3% to 69.2%.
- The prevalence of dental fluorosis in permanent teeth of among 6–14-year-old children living in CWF areas, using the Thylstrup and Fejerskov Index, ranged from 13.3% to 69.6%.

The lower dental fluorosis prevalence using the Dean's index of fluorosis is likely explained by the exclusion of questionable dental fluorosis cases when using this index to measure prevalence.

The synthesised evidence in this review indicated that the prevalence of both moderate and severe dental fluorosis ranged from 0.0% to 18.0%, while the reported prevalence of severe dental fluorosis was almost 0.0%. The evidence synthesised in this systematic review found few cases of severe dental fluorosis in areas with CWF. Moderate and severe dental fluorosis are the classifications of dental fluorosis that cause concern among dentists, parents, and children. Moderate dental fluorosis is associated with aesthetic concerns among affected children and their parents and may require topical treatment, while severe dental fluorosis requires restorative interventions by dentists in order to address the damage.

The between-country difference in the prevalence of both moderate and severe dental fluorosis was most apparent when using the Thylstrup and Fejerskov Index. For example, in Brazil, the prevalence of both moderate and severe dental fluorosis in children living in CWF areas was 18.0% (no severe cases), compared with 9% in Canada, 3% in England, and 1% in Ireland (no severe cases) using Dean's index of fluorosis. The prevalence of both moderate and severe dental fluorosis was higher in CWF areas compared with fluoride-deficient areas in in Brazil, Canada and England. The difference in the prevalence of moderate and severe dental fluorosis combined among children living in CWF and fluoride-deficient areas was 14.7 percentage points in Brazil, 9.0 percentage points in Canada, and 2.5 percentage points in England.

We completed a pairwise meta-analysis using the results of three moderate-quality cross-sectional surveys in order to determine the standardised odds of having dental fluorosis when exposed to CWF. This pairwise meta-analysis indicated that children living in CWF areas had three times higher adjusted odds of dental fluorosis than children living in fluoride-deficient areas (adjusted odds ratio (AOR): 3.66; 95% CI: 1.92–6.98; I^2: 0%). None of the studies included in the meta-analysis controlled for all five groups of confounding variables. The vast majority of cases had very mild or mild fluorosis. There is very low certainty of evidence that the adjusted odds of dental fluorosis are three times higher in children living in CWF areas than those in fluoride deficient areas.

What is the effect of fluoride toothpaste in areas with CWF on dental health in children who are aged under 6 years when they receive the intervention?

The HRB identified 19 papers (18 studies), published between 1988 and 2021, which examined the effects of non-prescribed fluoride toothpaste on permanent and/or primary teeth in children who used fluoride toothpaste when they were aged under 6 years and lived in communities with CWF. The study designs were 16 cross-sectional surveys and two case-control studies. The study countries were Australia, Brazil, Canada, England, Ireland, Malaysia, and the USA. Eleven studies reported data on dental caries and 17 studies reported on dental fluorosis.

Dental caries studies narrative synthesis

Eleven studies reported data on dental caries, CWF, and fluoride toothpaste based on oral hygiene practices, particularly during the first 6 years of life. Although data were collected, the relationship between fluoride toothpaste use and dental caries was not reported for five studies. Five of the remaining six studies examined the relationship between dental caries and CWF together with fluoride toothpaste use, and one of these studies reported that using fluoride toothpaste before the age of 24 months was associated with reduced prevalence of dental caries in Dublin, an area with CWF at a concentration of 0.6–0.8 ppm. In addition, this same study reported that toothbrushing (with fluoride toothpaste) once per day or less (compared with twice per day or more) was associated with an increased prevalence of dental caries. Another of the five studies reported that 5-year-old children who had brushed their teeth on their own since eruption were marginally more likely to have dental caries in their primary teeth than 5-year-old children whose parents brushed their teeth for them. The remaining three studies found no relationship between the use of fluoride toothpaste alongside CWF and dental caries among children in the first 6 years of life. The 11th study examined the added effect of CWF (at a concentration of 0.6–0.8 ppm) in an area where there was universal use of fluoride toothpaste and reported a beneficial effect for the addition of CWF alongside fluoride toothpaste use on dental caries prevalence and severity. For example, children who were living in fluoride-deficient areas had increased odds (odds ratio (OR): 2.01; 95% CI: 1.35–2.99) of having tooth decay. In addition, the mean DMFT (± standard deviation (SD)) was significantly higher in children from areas that did not have fluoridated water (3.83 (±3.28)) compared with those from areas with CWF (2.48 (±2.71)). None of the studies calculated the exact additive effect of fluoride toothpaste use during the first 6 years of life in addition to CWF on dental caries.

The results of five studies indicate there is very low certainty of evidence of mixed findings for the relationship between using fluoride toothpaste in a CWF area during the first 6 years of life and dental caries, with two studies reporting a protective effect and three studies reporting no relationship.

Dental fluorosis studies narrative synthesis

The additive effect that using fluoride toothpaste in CWF areas during the first 6 years of life has on dental fluorosis was not studied in any of the papers identified; however, factors associated with dental fluorosis were studied. Seventeen studies measured dental fluorosis in the context of CWF (at concentrations of 0.5–1.2 ppm) and the use of fluoride toothpaste during the first 6 years of life using observational studies (cross-sectional surveys or case-control studies). The prevalence of mild to severe dental fluorosis in permanent teeth in areas with CWF varied across the 17 studies, ranging from 11.5% to 80.9%. Twelve studies reported a lower prevalence of dental fluorosis in fluoride-deficient or fluoride-free areas, ranging from 3% to 55%. One study reported no cases of dental fluorosis in primary teeth among its 5-year-old participants.

Eight studies reported an association between fluoride toothpaste use and oral hygiene practices during the first 6 years of life and any dental fluorosis in erupted permanent teeth. Specifically, one study reported a statistically significant positive interaction between the use of fluoride toothpaste, the amount of toothpaste used, and toothbrushing frequency, and an increased likelihood of a diagnosis of dental fluorosis in permanent teeth. Another study reported a significant interaction between the amount of toothpaste used, toothpaste ingestion, and use of an adult-sized toothbrush and an increased likelihood of diagnosis with dental fluorosis. Five of the eight studies supported aspects of these findings; for example, early toothbrushing and higher toothbrushing frequency were also positively associated with a diagnosis of dental fluorosis. One study reported that the use of fluoride toothpaste intended for adults (by young children) was positively associated with a diagnosis of dental fluorosis, and two other studies reported that licking, eating, and/or swallowing toothpaste during the first 6 years of life was associated with a diagnosis of dental fluorosis. One study reported a protective effect of oral hygiene education on increasing the correct use of fluoride toothpaste and reducing the likelihood of a diagnosis of dental fluorosis in young children. On the other hand, four studies found no association between the use of fluoride toothpaste during the first 6 years of life (including toothbrushing frequency and toothpaste ingestion) and a diagnosis of dental fluorosis. However, three of these four studies did not report standardised numeric data, preventing the opportunity to complete a meta-analysis.

Eight studies in CWF areas identified a relationship between oral hygiene practices related to the use or misuse of fluoride toothpaste commenced during the first 6 years of life and dental fluorosis, indicating very low certainty evidence that there may be a relationship between exposure to fluoride toothpaste and how it is used, and the outcome of dental fluorosis in permanent teeth.

What is the additive effect of topical fluoride therapies in areas with CWF (and with widespread use of fluoride toothpaste) on dental health in children who are aged under 6 years when they receive the intervention?

The HRB identified seven studies, published between 1988 and 2021, which examined the effects of topical fluoride on permanent and/or primary teeth in children when they were aged under 6 years and lived in communities with CWF. The study designs comprised four cross-sectional surveys, one longitudinal prospective cohort study with a 3-year follow-up, and two randomised controlled trials. The study countries were Australia, Canada, Hong Kong, and the USA. Five studies reported data on dental caries and four studies reported on dental fluorosis.

Dental caries studies narrative synthesis

Five studies reported on children who were aged under 6 years when they commenced the use of topical fluoride. Three of these studies examined the influence of mouth rinses on dental caries, and two studies examined the influence of fluoride varnish on dental caries.

Three studies reported data on children who were aged under 6 years when they commenced using mouth rinses. One study reported no significant association between topical fluoride therapies (including mouth rinses, but the other therapies were not further described) and the prevalence of dental caries. Another study reported that the use of topical fluoride mouth rinses since tooth eruption by children living in CWF areas had no effect on dental caries prevention, while the third study measured the use of fluoride mouth rinses in CWF areas, but not their effect on dental caries prevention.

Two randomised controlled trials, based on very low-certainty evidence, reported mixed findings on fluoride varnish use on primary dentition. One trial demonstrated that twice-annual applications of fluoride varnish did not have any additional dental caries prevention effect in the primary teeth of young children with a low risk of dental caries who were living in an area with CWF. The second trial reported that both fluoride varnish and glass ionomer sealants had the same positive effect on primary second molar teeth in children who had a moderate to high risk of dental caries and who lived in areas with CWF.

The findings of five studies indicate that it was difficult to calculate an exact additive effect on dental caries of fluoride-based topical therapies commenced when children living in areas with CWF were aged under 6 years. The certainty of evidence for no effect of topical fluoride therapies (including mouth rinses) during the first 6 years of life and the outcome of dental caries is very low. Apart from mouth rinses and fluoride varnish, other topical fluoride therapies were not explicitly studied.

Dental fluorosis studies narrative synthesis

The association between the use of fluoride mouth rinses together with CWF, when children were aged under 6 years, and dental fluorosis is mixed based on the four included studies and the evidence is very low certainty. Two studies reported no effect of fluoride mouth rinses used by children who were aged under 6 years on dental fluorosis prevalence, and a third study reported an increased prevalence of dental fluorosis. The fourth study did not test the effect of fluoride mouth rinses together with CWF on dental fluorosis. Other topical fluoride therapies were not studied.

Executive Summary Table

The overall summary findings with GRADE recommendation by Question 1, 2A and 2B are presented in Table 1.

Table 1 Summary findings with GRADE recommendation by question

Outcome	Number of papers included in final analysis	Summary finding using primary studies of moderate and high methodological quality
		Question 1: CWF and dental caries
		Primary dentition
dmft (single point in time comparison)	18	There is very low certainty evidence that the mean difference for dmft equates to just over one-half additional healthy tooth per child aged 5–8 years in the CWF area compared with similar children in the fluoride-deficient area at a single time point.
dmft (baseline and follow-up comparison)	5	There is very low certainty evidence of mixed findings for dmft in children between 5 and 8 years over two time points with three papers reporting a reduction in mean dmft in the CWF area compared with the fluoride deficient area, and two papers reporting no significant difference in mean dmft.
dmfs (single point in time comparison)	6	There is very low certainty evidence that the mean difference for dmfs equates to just over one-half additional healthy tooth surface per child aged 5–6 years in the CWF area compared with similar children in the fluoride-deficient areas at a single time point.
dmfs (baseline and follow-up comparison)	0	No findings due to lack of suitable studies
% without CDC in primary dentition (single point in time comparison)	3	There is very low certainty evidence that children aged 5–11 years have 1.75 higher odds of being cavity free in their primary teeth in the CWF area compared with the fluoride-deficient area at a single time point.
% without CDC in primary dentition (baseline and follow-up comparison)	1	There is very low certainty evidence that the overall percentage point difference after 11 years equates to an average of 6 additional children in every 100 children aged 9–11 years having no cavitated dental caries in their primary teeth in the CWF area compared with the fluoride-deficient area.
% with CDC in primary dentition	4	The results imply there is low certainty evidence that children aged 5–7 years have 50% lower odds of having cavitated dental caries in one or more teeth in the

Outcome	Number of papers included in final analysis	Summary finding using primary studies of moderate and high methodological quality
(single point in time comparison)		primary dentition in the CWF area compared with the fluoride-deficient area at a single time point.
% with CDC in primary dentition (baseline and follow-up comparison)	2	There is very low certainty evidence that the percentage of 5-year-olds with cavitated dental caries in the primary dentition was much lower in the first study and marginally lower in the second in the CWF area compared with the fluoride-deficient area after 9 or 12 years, respectively.
		Permanent dentition
DMFT (single point in time comparison)	21	There is very low certainty evidence that the mean difference for DMFT equates to an average gain of almost one additional healthy tooth per person aged 6–32 years in the CWF areas compared with the fluoride-deficient areas at a single time point.
DMFT (baseline and follow-up comparison)	5	There is very low certainty evidence of mixed findings for DMFT in persons aged 6–15 years over two time points with four papers reporting a greater reduction in mean DMFT in the CWF area compared with the fluoride deficient area, and one paper reporting a greater reduction in the fluoride deficient area compared with the CWF area.
DMFS (single point in time comparison)	5	There is very low certainty evidence that the mean difference for DMFS equates to an average gain of almost one additional healthy tooth surface per person aged 5–16 years in the CWF areas compared with the fluoride-deficient areas at a single time point.
DMFS (baseline and follow-up comparison)	0	No findings due to lack of suitable studies
% without CDC in permanent dentition (single point in time comparison)	3	The results imply there is very low certainty evidence that children aged 5–17 years have 6.67 higher odds of being cavity free in their permanent teeth in the CWF area compared with the fluoride-deficient area at a single time point.
% without CDC in permanent dentition (baseline and follow-up comparison)	1	There is very low certainty evidence that the overall percentage point difference after 11 years equates to an average of 16 additional children in every 100 children aged 12–14 years having no cavitated dental caries in the CWF area compared with the fluoride-deficient area.
% with CDC in permanent dentition (single point in time comparison)	3	There is very low certainty evidence that children aged 7–12 years have 63% lower odds of having cavitated dental caries in one or more teeth in the permanent dentition in the CWF area compared with the fluoride-deficient area at a single time point.
% with CDC in permanent dentition (baseline and follow-up comparison)	2	There is very low certainty evidence that the overall percentage point difference, after 9 or 12 years, equates to children aged 10- and 12-years having less cavitated dental caries in the permanent dentition in the CWF area compared with the fluoride-deficient area.
CWF as a determinant of dental caries	0	Inadequate data to determine an association

Outcome	Number of papers included in final analysis	Question 1: CWF and dental fluorosis Summary finding using primary studies of moderate and high methodological quality
Fluorosis prevalence by index	23	There is very low certainty evidence that the prevalence of dental fluorosis in permanent teeth of 10–15-year-old children living in CWF areas, using Dean's Index of Fluorosis, ranged from 1.3% to 47.7%. There is very low certainty evidence that the prevalence of dental fluorosis in permanent teeth of schoolchildren and young people living in CWF areas, using the Tooth Surface Index of Fluorosis, ranged from 18.3% to 69.2%. There is very low certainty evidence that the prevalence of dental fluorosis in permanent teeth of among 6–14-year-old children living in CWF areas, using the Thylstrup and Fejerskov Index, ranged from 13.3% to 69.6%. The vast majority of cases assessed using one of the three indexes had very mild or mild fluorosis.
Fluorosis by country	26	Due to data limitations, the HRB authors felt that it would be unwise to present an overall global estimate of dental fluorosis as a result of CWF. There is very low certainty evidence that the prevalence of dental fluorosis increased over time in Brazil, Ireland, and the USA, and this increase was observed both in areas with and without CWF. A pattern of dental fluorosis could be observed within some countries, specifically England (with similar levels at 54% in the two included studies), Ireland (with increasing levels over time, for example, the levels were 1.1% in 1992, 12% in 2002 and 18% in 2017 among 8 year olds), and the USA (with increasing levels over time, for example, 7.8% in 1989 and 19.6% in 1998 and 2000). In Brazil, the prevalence of both moderate and severe dental fluorosis in children living in CWF areas was 18.0% (no severe cases), compared with 9% in Canada, 3% in England, and 1% in Ireland (no severe cases); All based on very low certainty evidence.
CWF as a determinant of dental fluorosis	3	There is very low certainty of evidence that children living in CWF areas had three times higher adjusted odds of dental fluorosis than children living in fluoride-deficient areas (adjusted odds ratio (AOR): 3.66; 95% CI: 1.92–6.98; I^2: 0%). The vast majority of cases had very mild or mild fluorosis.
		Question 2A CWF plus toothpaste and dental caries and fluorosis
Dental caries	5	The results of five studies indicate there is very low certainty of evidence of mixed findings for the relationship between using fluoride toothpaste in a CWF area during the first 6 years of life and the outcome dental caries, with two studies reporting a protective effect and three studies reporting no relationship.
Dental fluorosis	8	Eight studies in CWF areas identified a relationship between oral hygiene practices related to the use or misuse of fluoride toothpaste commenced during the first 6 years of life and the outcome dental fluorosis, indicating very low certainty evidence that there may be a positive relationship between exposure to fluoride toothpaste and how it is used, and the outcome of dental fluorosis in permanent teeth.
		Question 2B: CWF plus topical fluoride and dental caries and fluorosis
Dental caries	5	Two randomised controlled trials, based on very low-certainty evidence, reported mixed findings on fluoride varnish use on primary dentition for children aged under 6 years living in areas with CWF.

Outcome	Number of papers included in final analysis	Question 1: CWF and dental fluorosis Summary finding using primary studies of moderate and high methodological quality
		The certainty of evidence for no effect of topical fluoride therapies (including mouth rinses) in areas with CWF during the first 6 years of life and the outcome of dental caries is very low. This finding is based on three studies.
Dental fluorosis	4	The association between the use of fluoride mouth rinses commenced when children were aged under 6 years and living in areas with CWF, and the outcome dental fluorosis is mixed based on the findings of four included studies and the evidence is very low certainty.

What are the recommendations in other countries currently implementing CWF for the use of topical fluorides in children aged under 6 years?

The Department of Health selected seven countries of interest to answer this question, as they have (or had) CWF programmes and existing clinical guidelines on the prevention of caries. The countries of interest were Australia, Brazil, Canada, Israel, New Zealand, the UK, and the USA.

Dietary fluoride supplements are not recommended for use by the population in Australia, Canada, or Israel, while the USA does not recommend fluoride supplements in areas with optimal water fluoridation.

The use of fluoride toothpaste by children with no dental caries risk is not recommended in Australia (until children are at least aged 18 months), Israel (until children are at least aged 24 months), or Canada (until children are at least aged 36 months). Brazil, England, New Zealand, Scotland, and the USA recommend the use of a smear of toothpaste containing 1000 ppm fluoride twice per day once the teeth erupt. In Australia, toothpaste with 500 ppm fluoride is recommended for use by children aged 18–59 or 71 months.

Brazil was the only country recommending the use of fluoride mouth rinses. Fluoride mouth rinses are recommended for high-risk children aged 3 years and over who live in fluoride-deficient areas.

The guidance on the use of fluoride varnish for children aged under 6 years is country specific. All countries examined (except Brazil) recommend fluoride varnish use.

The advice on fluoride gel is also country specific, with Australia not recommending it for children aged under 10 years and the USA permitting it for very young children with a high risk of dental caries.

Conclusion

This systematic review collates the evidence on the effects of artificial CWF on dental caries and fluorosis between 1948 and 2023 and includes mainly before and after studies (cohort or cross-sectional) and single point in time studies (cross-sectional). It also attempted to establish if there is a dose response ratio for CWF with dental caries and with dental fluorosis at different CWF levels between 0.5ppm and 1.2ppm. We did not find evidence of a dose response at different CWF levels between 0.5ppm and 1.2ppm and the outcomes dental caries and dental fluorosis.

The certainty of the evidence for all dental caries outcomes and the intervention CWF is low or very low. The majority of dental caries outcomes in primary dentition indicated a reduction in cavitated caries that favoured CWF areas over the fluoride deficient areas. The findings for one outcome (dmft at two time points) were mixed. The findings for permanent dentition outcomes indicated a reduction in cavitated caries for all except one outcome and the reduction favoured the CWF areas over the fluoride deficient areas. The findings for one outcome (DMFT at two time points) were mixed.

The certainty of evidence for the prevalence of fluorosis across countries with CWF is very low. The prevalence of dental fluorosis in permanent teeth of 10–15-year-old children living in CWF areas, using Dean's Index of Fluorosis, ranged from 1.3% to 47.7%. The prevalence of dental fluorosis in permanent teeth of schoolchildren and young people living in CWF areas, using the Tooth Surface Index of Fluorosis, ranged from 18.3% to 69.2%, and was similar among schoolchildren using the Thylstrup and Fejerskov Index (ranging from 13.3% to 69.6%). The vast majority of cases had very mild or mild dental fluorosis. The prevalence of dental fluorosis increased over time in Brazil, Ireland, and the USA, and this increase was observed both in areas with and without CWF. This meta-analysis indicated that children living in CWF areas had three times higher adjusted odds of dental fluorosis than children living in fluoride-deficient areas. In Brazil, the prevalence of both moderate and severe dental fluorosis in children living in CWF areas was 18.0% (no severe cases), compared with 9% in Canada, 3% in England, and 1% in Ireland (no severe cases). The prevalence of both moderate and severe dental fluorosis was higher in CWF areas compared with fluoride-deficient areas in the four countries.

The results of five studies indicate there is very low certainty of evidence of mixed findings for the relationship between using fluoride toothpaste in a CWF area during the first 6 years of life and dental caries, with two studies reporting a protective effect and three studies reporting no relationship. Eight studies in CWF areas identified a relationship between oral hygiene practices related to the use or misuse of fluoride toothpaste commenced during the first 6 years of life and dental fluorosis, indicating low certainty evidence that there may be a relationship between exposure to fluoride toothpaste and how it is used, and the outcome of dental fluorosis in permanent teeth.

Two randomised controlled trials, based on very low-certainty evidence, reported mixed findings on fluoride varnish use on primary dentition. The certainty of evidence for no effect of topical fluoride therapies (including mouth rinses) during the first 6 years of life and the outcome of dental caries is very low. The association between the use of fluoride mouth rinses together with CWF, when children living in areas with CWF were aged under 6 years, and dental fluorosis is mixed in the four included studies and the evidence is very low certainty.

Dietary fluoride supplements are not recommended for use by the population in Australia, Canada, or Israel, while the USA does not recommend fluoride supplements in areas with optimal water fluoridation. The use of fluoride toothpaste by children with no dental caries risk is not recommended in Australia until children are at least aged 18 months, in Israel until children are at least aged 24 months, or in Canada until children are at least aged 36 months. Brazil, England, New Zealand, Scotland, and the USA recommend the use of a smear of toothpaste containing 1000 ppm fluoride twice per day once the teeth erupt. In Australia, toothpaste with 500 ppm fluoride is recommended for use by children aged 18–59 months. Brazil was the only country recommending the use of fluoride mouth rinses, and it recommends fluoride mouth rinses for high-risk children aged 3 years and over who live in fluoride-deficient areas. The guidance on the use of fluoride varnish for children aged under 6 years is country specific. All countries examined (except Brazil) recommend fluoride varnish use. The advice on fluoride gel is also country specific, with Australia not recommending it for children aged under 10 years and the USA permitting it for very young children with a high risk of dental caries.

The evidence provided in this evidence review does not provide adequate evidence to discontinue CWF in Ireland. Overall, CWF has a positive effect on reducing caries in teeth and the prevalence of moderate and severe fluorosis is low. In 2017, the prevalence of moderate dental fluorosis was under 1%, and there were no cases of severe dental fluorosis in the studies of CWF area in Ireland.

1 Introduction

1.1 Background

1.1.1 Fluoride and dental health

In humans, fluoride primarily produces effects on skeletal tissues (i.e. bones and teeth). Exposure to fluoride at high concentrations increases the risk of dental fluorosis (pitting or mottling of tooth enamel) and skeletal fluorosis (deposits on bone with adverse changes in bone structure) [37]. The enamel of the teeth is mainly composed of hydroxide, calcium, and phosphate ions, a chemical construction called hydroxyapatite. Fluoride reacts strongly with these ions in developing teeth, resulting in teeth with enamel that is more resistant to the type of decay known as dental caries [38]. In this reaction, fluoride replaces hydroxide, transforming hydroxyapatite into fluorapatite. These fluorapatite crystals are symmetrical and stack better than the hydroxyapatite crystals. With topical exposure to fluoride through fluoridated water, toothpaste, mouthwash, and dental products such as gels and varnishes, fluoride is found throughout the mouth, including in saliva and plaque, and bound to the gums, tongue, and cheeks, as well as in the enamel. Fluoride-based preventive interventions introduce fluoride through direct contact with the exposed surface of the teeth, which increases resistance to decay from bacterial acid attack by inhibiting tooth demineralisation, promoting tooth remineralisation, and inhibiting the activity of bacteria in plaque [39]. The biggest effect of fluoride in reducing tooth decay comes from ongoing topical exposure, although benefits are maximised if there is also systemic exposure while the teeth are forming [38]. Prevention of caries is an important public health priority, as it is associated with a reduction in the numbers of hospital attendances for tooth extractions and anaesthesia, the cost of dental treatment for children, and tooth loss due to dental caries in adulthood [40].

Fluoridated drinking water has the advantage of making fluoride accessible to the entire population of an area, thereby reducing the need for individual compliance and conferring benefits on those who lack access to fluoridated products or treatments and/or to professional dental care [41,42]. Alternative publicly funded dental health schemes, such as the provision of topical fluoride varnishes through schools, tend to target only high-risk or young populations [40]. Community water fluoridation (CWF) also has particular benefits for reducing dental caries among children, with long-term benefits for dental health; pre-eruptive exposure (exposure before the teeth emerge) allows ingested fluoride to be incorporated into the enamel during tooth formation, which strengthens the teeth and makes them more resistant to decay [40]. Apart from water, other methods of delivering systemic fluoride include milk, salt, or supplements, but these are not of interest to the Department of Health in Ireland, as it has chosen to deliver systemic fluoride through CWF.

Some countries (such as Australia, Brazil, Canada, England, New Zealand, Singapore, and the United States of America (USA)) control fluoride levels in the public water supply by artificially supplementing or removing fluoride in order to reach an optimal level or range while keeping the fluoride concentration below the World Health Organization (WHO) guideline level of 1.5 parts per million (ppm), which was set in 1984 and which is regarded as the maximum allowable level. Recommended levels for artificially fluoridated water are usually between 0.5 and 1.0 ppm [37]. The amount of fluoride in drinking water considered to be optimal varies regionally; recommendations must take into account factors such as average daily water consumption (which may be higher in hotter climates) and the availability of fluoride from other sources, such as food, tea, and dental products [43]. Table 2 presents an overview of the effects of various concentrations of fluoridated water on skeletal tissues.

Table 2 Effects of various concentrations of fluoridated water on skeletal tissues

Fluoride levels in water	Effects on skeletal tissues
0.0–0.3 ppm	Unlikely to confer benefits to dental health; increased risk of caries [44,45]
0.5–1.0 ppm	Recommended level for artificially fluoridated water supplies (varies according to local environmental factors, including climate), providing protection against dental caries, tooth decay, and tooth loss for children and adults; increased risk of mild dental fluorosis [37]
≥1.5 ppm	Increased risk of moderate or severe dental fluorosis [37]
3.0–6.0 ppm	Increased risk of skeletal fluorosis [37]
>10.0 ppm	Increased risk of crippling skeletal fluorosis [37]

1.1.2 Community water fluoridation

Water fluoridation is usually accomplished by adding sodium fluoride (NaF), fluorosilicic acid (H_2SiF_6), or sodium fluorosilicate ($Na_2[SiF_6]$) to drinking water in which the naturally occurring fluoride concentration is sub-optimal. The practice began in 1945, when Grand Rapids, Michigan, USA became the first city in the world to artificially fluoridate its drinking water following the results of epidemiological studies that showed a link between increased levels of fluoride in drinking water and reduced prevalence and severity of tooth decay in local populations [46].

The estimated number of people with access to artificially fluoridated water worldwide as of November 2012 was 377,655,000 in 24 countries, including Argentina, Australia, Brazil, Brunei, Canada, Chile, Fiji, Guatemala, Guyana, Ireland, Israel (ceased in 2014), Libya, Malaysia, New Zealand, Panama, Papua New Guinea, Peru, Serbia, Singapore, South Korea, Spain, the United Kingdom (UK), the USA, and Vietnam. In 2012, these countries also had an estimated 17,910,000 people with access to naturally fluoridated water at or around the optimal level (i.e. 0.5–1.0 ppm), bringing the total number of people with access to optimally fluoridated water in those countries to 395,565,000 [47]. Hong Kong also fluoridates its water. Estimates of the proportion of populations in countries worldwide receiving government-regulated fluoridated water as of 2020 are shown in **Error! Reference source not found.** [48].

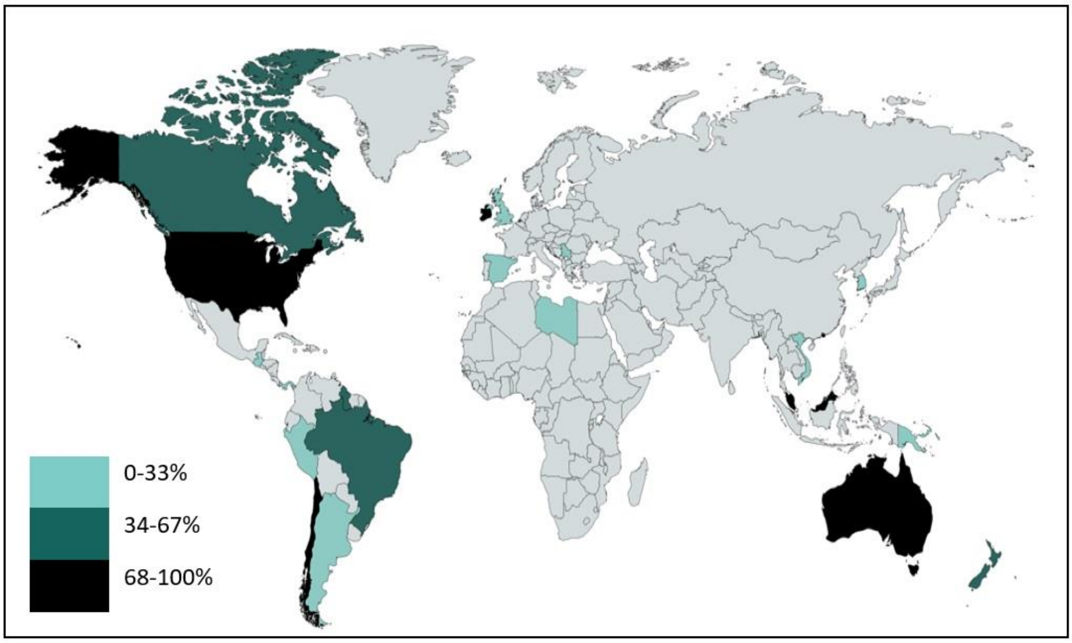


Figure 1 Proportion of the population receiving government-regulated fluoridated water

Source: Johnston and Strobel, 2020 [48]

1.1.3 Community water fluoridation in Ireland

CWF was introduced in Ireland in 1964 following the Health (Fluoridation of Water Supplies) Act, 1960 [49]; fluoride was added at a level of 1 ppm. In 2000, water fluoridation policy in Ireland was the subject of a major review by the Forum on Fluoridation, which was established by the then Minister for Health and Children. Considering both international and Irish research showing an increasing occurrence of dental fluorosis [50], the Forum on Fluoridation recommended that the fluoride level in drinking water be lowered from a target of 1.0 ppm to a range of 0.6–0.8 ppm, with a target of 0.7 ppm [51]. This policy was implemented in 2007 [51]. Recent evidence suggests that lowering the fluoride level to 0.7 ppm may have reduced the beneficial impact of CWF for the prevention of dental caries [52]. In addition, survey data on the prevalence of mild dental fluorosis do not suggest any decrease [52,53]. Therefore, it will also be important to investigate how changing levels of fluoride can impact on the prevalence of both dental caries and dental fluorosis.

The Fluoridation of Water Supplies Regulations 2007 [51] stipulate that fluoride may be added to public water supplies either in the form of hydrofluorosilicic acid or in such other form as may be approved by the Minister for Health and Children. It is further stipulated that the fluoride content of public water supplies to which fluoride has been added shall be determined daily at the water treatment plant. Water supplied by local government (which services all urban areas) is required to be fluoridated; however, private water supplies from wells or local community group water schemes are not required to be fluoridated [54]. In 2017, just over 71% of people living in Ireland had access to publicly provided CWF at an average annual cost to the Irish Government of €2.15 per capita of population receiving fluoridated water [55].

To date, the research on topical fluoride therapies is mainly conducted in fluoride-deficient communities where fluoride therapies are not being provided in the presence of both CWF and fluoride toothpaste use. The main concern with regard to the use of fluoride therapies is their use in children aged under 6 years whose permanent teeth are still developing. If excessive fluoride is ingested while the permanent teeth are still developing, dental fluorosis (i.e. white chalky patches on permanent teeth) can develop. Fluoride can be ingested by swallowing toothpaste or other topical agents (mouth rinses, gels, foams, and varnishes) when used by young children, as their swallowing reflex has not fully developed. The consumption of systemic fluoride supplement tablets or drops can also contribute to dental fluorosis.

1.1.4 Systematic review literature

There are two international systematic reviews covering water fluoridation [41,56] and][57]. In 2015, Iheozor-Ejiofor *et al* [41,56], the Cochrane Review authors, updated the dental health aspects of McDonagh *et al.*'s 2000 systematic review [57], by evaluating the effects of water fluoridation (artificial or natural) on the prevention of dental caries and on the prevalence of dental fluorosis [41]. The Cochrane review included studies that covered two time points only. This Health Research Board (HRB) review is updating Iheozor-Ejiofor *et al.*'s 2015 systematic review; Since the time of writing, the Cochrane review was updated to include 1 new study [58]. However, at the request of the Department of Health in Ireland, there are some differences in our systematic review design. We include studies with artificial CWF as their exposure/intervention and exclude all studies with natural fluoridation as their only intervention, as natural fluoridation is less well monitored and controlled. In addition, some natural water has fluoride levels that exceed safe fluoride levels. We also include single point in time studies as well as two time point studies. Finally, we include a number of studies conducted since 2014.

1.1.5 Policy considerations

Public health policies should be based on sound scientific evidence about risks and benefits, and on an economic evaluation of interventions to address a specific issue in a population. Decision-makers should also be cognisant of the impact of not employing a proven intervention.

CWF is a cost-efficient intervention that can reach large populations without necessitating the active participation of individuals, and it can deliver dental health benefits to a broad spectrum of people, reducing disparities in dental health [57,59]. In Ireland, despite current access to numerous fluoride sources and a reported increase in the prevalence of dental fluorosis, CWF remains a cost-effective public health intervention for Irish schoolchildren [55]. However, there is opposition to, and scepticism regarding, the practice of artificially fluoridating water supplies, both in Ireland and internationally.

Arguments against CWF include concerns about negative environmental impacts [60] and the ethics of the practice. While CWF is implemented with the goal of reducing inequalities in dental health by providing benefits to all, regardless of age, socioeconomic status, or access to dental care, the fact that it is a mass intervention removes individual choice and raises difficult questions about the right to refuse health interventions [46]. Disagreement about the quality of the evidence base regarding benefits and harms [46], and about the accuracy with which this evidence is represented on both sides of the debate [61], has sometimes created a tense discourse around CWF in the public sphere.

The evidence for the potential effects (impact and dose response) of artificial CWF (at concentrations of 0.5–1.2 ppm) on dental health is the primary focus of this systematic review and . We employ a systematic review approach to combine evidence from the many available primary research studies published between 1946 and 2023, to provide an overview of the effects of CWF on dental health (dental caries and fluorosis). The effects of the use of other sources of topical fluoride in combination with CWF by children aged under 6 years are also investigated. Systemic health outcomes relating to CWF are addressed in a related Health Research Board (HRB) publication [65]. This systematic review was completed at the request of the Department of Health in Ireland.

1.2 Research questions

The following questions are answered in this systematic evidence review:

4. What is the positive and negative effect* of artificial CWF (intervention or exposure) on dental health of the general population and does the effect on dental health vary with the level of fluoride in artificially fluoridated water?

2C. What is the effect of fluoride toothpaste in areas with CWF on dental health in children who are aged under 6 years when they receive the intervention?

2D. What is the additive effect of topical fluoride therapies† in areas with CWF (and with widespread use of fluoride toothpaste) on dental health in children who are aged under 6 years when they receive the intervention?

5. What are the recommendations in other countries currently implementing CWF for the use of topical fluorides in children aged under 6 years?

*For Question 1, effect implies a reduction in the incidence of dental caries resulting in damaged or missing teeth (positive outcome), a decrease in the proportion of cavitated caries per head of population, and an increase in the prevalence of dental fluorosis (negative outcome)

†Topical fluoride therapies are therapies applied to the surfaces of teeth, such as fluoride varnish.

2 Methods

2.1 Introduction

We conducted two separate, comprehensive searches of the published, peer-reviewed research on the effect of CWF, of varying levels of artificially fluoridated water, and of topical fluoride therapies on the dental health of the human population, and on the dental health of children aged under 6 years, in order to answer Questions 1, 2A, and 2B. In order to answer Question 3, we carried out a bespoke grey literature search on national recommendations for children aged under 6 years.

An information specialist (AF) and the team conducted the initial scoping searches in June and July 2021 in order to inform and shape the search strategy, using the MEDLINE and Embase (Ovid) databases, the systematic review database Epistemonikos, and the Cochrane Library (John Wiley & Sons), as well as the Google search engine. Separate searches were conducted for Question 1 and for Questions 2A and 2B, as Questions 2A and 2B have two added concepts of topical fluoride and an age limit, and these are described separately below. The searches were updated in February 2023.

2.2 Eligibility criteria

2.2.1 Question 1

The eligibility criteria for Question 1, in relation to dental health and CWF and the concentration of fluoride in drinking water, are described in

Table 3.

Table 3 Question 1 eligibility criteria

Criterion	Inclusion	Exclusion
Population	Human populations of any age	Animal studies
Intervention or exposure	Artificially fluoridated water (with a fluoride concentration of 0.4–1.5 ppm) or CWF At extraction stage, we added: Lifetime exposure to CWF	Endemic high-dose fluoride areas or areas with a drinking water supply at naturally occurring optimal fluoride concentrations. Mixed artificially fluoridated water and water with naturally occurring optimal fluoride levels where data cannot be separated.
Comparators	Different levels of fluoride, including: • Sub-optimal levels of natural fluoride in drinking water (usually 0.3 ppm or less) • Change over time in the levels of fluoridated water, and • Withdrawal of an artificially fluoridated water programme. At extraction stage, we added: Lifetime exposure to fluoride deficient water CWF	No comparator Fluoride dose not reported
Outcomes	Dental caries: (decayed, missing, or filled teeth or surfaces) Tooth loss (missing teeth) At the extraction stage, we decided to analyse only studies with the full dmft, dmfs, DMFT, DMFS, % with and without cavitated dental caries Dental fluorosis (severity and prevalence) Periodontal disease Oral-health-related quality of life	Other outcomes
Study design	Primary quantitative study designs: • Randomised controlled trials • Clinical trials • Retrospective/prospective cohort studies • Case-control studies • Cross-sectional surveys including census surveys, and • Ecological/correlation studies.	Case studies Opinion pieces Qualitative studies Standalone theses/dissertations (as not peer reviewed) Reviews Systematic reviews
Language	At the full text stage, we included English language studies only	Excluded all other languages
Study quality and completeness		We excluded studies with missing key data, including standard deviations, confidence intervals Lack of control for time Duplicate data across more than one paper At the synthesis stage we excluded low quality studies

2.2.2 Questions 2A and 2B

The eligibility criteria for Questions 2A and 2B on the effect of fluoride toothpaste and other topical fluoride interventions on dental health in children who are aged under 6 years when they receive the intervention are outlined in **Error! Not a valid bookmark self-reference.** Questions 2A and 2B required children under 6 years as this is the time when systemic fluoride is incorporated into the developing tooth structure and where there is the highest risk of fluorosis and most benefit for prevention of dental caries. The eligibility criteria for the two questions only differ regarding the exposure investigated. The criteria for Question 2A include studies investigating the intervention of fluoride toothpaste, whereas those for Question 2B include studies of other topical fluoride interventions, such as mouth rinses, varnishes, gels, foams, and slow-release fluoride devices. The protocol for Questions 2A and 2B was registered on the systematic review register PROSPERO [62].

2.2.3 Question 3

Table 5 presents the eligibility criteria for Question 3. For Question 3, no comparator was required. Guidelines which mention or are specifically about children aged under 6 years were eligible for inclusion. The guidelines should be published by government departments or professional organisations operating at national level from countries or areas with CWF. The search was limited to Australia, Brazil, Canada, Israel, New Zealand, the UK, and the USA as these were the countries specified by the Department of Health. The cut-off publication dates for guidelines were 2011–2023. Several countries have issued new guidance in the areas concerned, with some removing the recommendation for water to be artificially fluoridated (e.g. in the cities of Juneau and Fairbanks in Alaska in 2007 and 2011, respectively, and in Israel in 2014) [63]. A note could be made of guidelines published prior to 2011 if those guidelines were in current use. For inclusion, the guideline should mention or deal specifically with the application and use of dental fluoride products for dental caries prevention and management, such as mouth rinses, gels, foams, or varnishes.

Table 4 Questions 2A and 2B eligibility criteria

Criterion	Inclusion	Exclusion
Population	Children aged under 6 years at the time of exposure (outcomes can be collected at a later age)	Adults and children aged over 6 years at the time of exposure
Intervention or exposure	Question 2A: fluoride toothpaste Question 2B: topical fluoride interventions used in the prevention of dental caries (e.g. professionally applied topical fluorides such as mouth rinses, varnishes, gels, foams, and slow-release fluoride devices, and personal use of mouthwashes) IN areas with artificially fluoridated water (with a fluoride concentration of 0.4–1.5 ppm)	Fluoridated food products: salt and milk Endemic fluoride areas/naturally occurring fluoride areas Mixed artificially fluoridated and endemic fluoride areas where data cannot be separated
Comparators	Artificially fluoridated water only Non-fluoride topical therapies plus artificially fluoridated water only Fluoride topical therapies in areas with fluoride deficient water	Non-invasive and micro-invasive therapies prescribed to manage non-cavitated dental caries No comparator
Outcomes	Dental caries Dental fluorosis	Others
Study design	Primary quantitative study designs: • Randomised controlled trials • Clinical trials • Retrospective/prospective cohort studies • Case-control studies • Cross-sectional surveys, and • Ecological/correlation studies.	Case studies Opinion pieces Qualitative studies Standalone theses/dissertations (as not peer reviewed) Reviews Systematic reviews
Language	At the full text stage, we included English language studies only	Excluded all other languages

Table 5 Question 3 eligibility criteria

Criterion	Inclusion	Exclusion
Population	Children aged under 6 years	Adults, and children aged over 6 years at the time of intervention
Intervention or exposure	Fluoride toothpaste Topical fluoride interventions used in the prevention of dental caries (e.g. professionally applied topical fluorides such as gels, foams, varnishes, and slow-release fluoride devices, and personal use of mouth rinses) IN areas with artificially fluoridated water or areas which had recently changed from artificially fluoridated water	Non-fluoride interventions for dental caries prevention Non-invasive and micro-invasive therapies prescribed to manage non-cavitated dental caries
Outcomes	National recommendations (including from regulatory bodies and governments) for the use of topical fluorides in children aged under 6 years	Non-national recommendations
Study design	Published guidelines	Unpublished data
Date range	2011 to present	Pre-2011
Location	Department of Health specified: Australia, Brazil, Canada, Israel, New Zealand, the UK, and the USA	Other countries

2.3 Search concepts

2.3.1 Question 1

Following the scoping searches, the team developed search concepts for the following research question:

1 What is the positive and negative effect* of artificial CWF (intervention or exposure) on dental health of the general population and does the effect on dental health vary with the level of fluoride in artificially fluoridated water?

Three search concepts emerged that best captured the relevant research evidence for Question 1: artificially fluoridated water, the effect of artificially fluoridated water on dental health within the human population, and study design (primary quantitative study designs) (Figure 2).

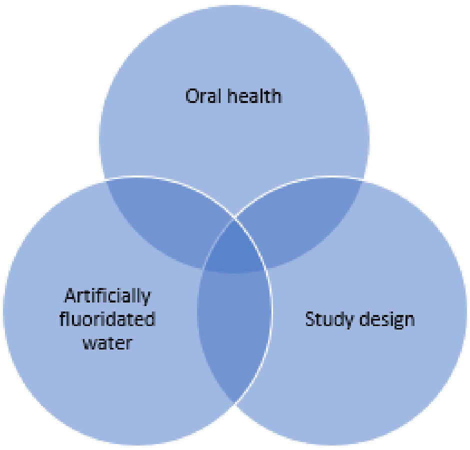


Figure 2 Question 1 search concepts

2.3.2 Questions 2A and 2B

Question 2 is a two-part question with one search strategy which covered three search concepts (

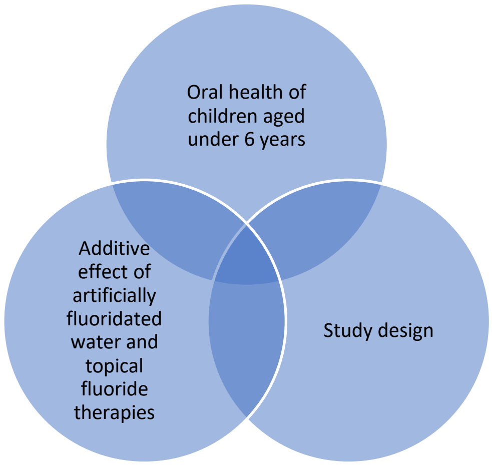


Figure 3): the additive effect of topical fluoride therapies and artificially fluoridated water; the effect on dental health within the population aged under 6 years; and study design (primary quantitative study designs). These search concepts answered the following research questions:

2A. What is the effect of fluoride toothpaste in areas with CWF on dental health in children who are aged under 6 years when they receive the intervention?

2B. What is the additive effect of topical fluoride therapies in areas with CWF (and with widespread use of fluoride toothpaste) on dental health in children who are aged under 6 years when they receive the intervention?

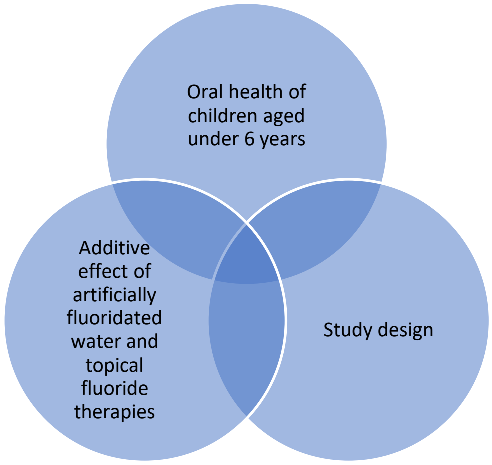


Figure 3 Questions 2A and 2B search concepts

2.3.3 Question 3

Question 3 asks: What are the recommendations in other countries currently implementing CWF for the use of topical fluorides in children aged under 6 years?

As this research question was best answered using national-level policy documents, a comprehensive search of relevant countries' national public dental programmes and government health websites was conducted in February 2022 and updated in February 2023. The following countries were selected by the Department of Health, as they have (or had) CWF programmes:

- Australia
- Brazil
- Canada
- Israel
- New Zealand
- The UK, and
- The USA.

2.4 Search strategy development for Questions 1, 2A, and 2B

2.4.1 Scoping

A scoping search was conducted in June 2021 in order to identify key publications and capture typical vocabulary on the subject area for these three questions. A search of relevant national and international bodies also helped in creating the protocol for the review questions and eliciting conceptual language for the searches. The scoping search helped build the language used for the systematic database searches.

2.4.2 Search terms and search strategy

Search strategies were developed by the information specialist (AF) with input from another information specialist (CL) who had experience in dental health research. The strategies were peer reviewed by the senior information specialist in the organisation (LF).

Search terms for Question 1 were based on the concepts of 'water fluoridation' and 'oral health'. Natural language terms, such as 'community water fluoridation', 'water supply', or 'drinking water', were used with Medical Subject Headings (MeSH) terms (e.g. 'fluorides' or 'fluorine'). Various MeSH and natural language terms around the concept of oral health were used, including technical language and language around quality of life that was gleaned from the literature.

For Questions 2A and 2B, one comprehensive search strategy was used and adapted across the selected databases and resources. The strategy included the concepts of topical fluorides, toothpastes, and children aged under 6 years, as well as the concepts of water fluoridation and dental health. This broad search captured as much relevant material to answer both questions as possible. The results were screened separately, using different screening criteria for each question.

The search strategies aimed to retrieve primary studies (see Appendix A of Section 6 for Question and Appendix A of Section 7 for Questions 2A and 2B).

2.4.3 Search resources

A range of academic databases, research repositories, and grey literature resources were chosen in order to gain the widest geographic and academic reach. The MEDLINE and Embase databases (both on the Ovid platform) were selected on that basis. The Latin American and Caribbean Health Sciences Literature (LILACS) repository was also selected in order to address any unintended bias towards European and North American research, as well as to reflect the availability of published evidence on fluoridated water in South America. The Cochrane Library (John Wiley & Sons) was also searched, as were Epistemonikos (a database of systematic reviews and primary research that sources material from 26 other databases) and PROSPERO (a registry of systematic reviews). The selection of databases was informed by the recommendations in Chapter 4 of the *Cochrane Handbook for Systematic Reviews of Interventions*:

> The Cochrane Central Register of Controlled Trials (CENTRAL) and MEDLINE, together with Embase (if access to Embase is available to the review team) should be searched for all Cochrane Reviews. Additionally, for all Cochrane Reviews, the Specialized Register of the relevant Cochrane Review Groups should be searched, either internally within the Review Group or via CENTRAL. [64] p67

The initial scoping search was carried out in MEDLINE and was then translated for searching in the Google search engine, the Cochrane Library and Epistemonikos databases, and grey literature resources.

2.4.3.1 Databases

The inception date is 1946 or the start date of the database. However, the searches were completed in three stages.

An initial systematic search was carried out in the MEDLINE and Embase databases (both on the Ovid platform) and the Epistemonikos database of systematic reviews on 13 July 2021. The Cochrane Library and LILACS databases, and the registers PROSPERO systematic review register and CENTRAL, were also searched for relevant material. The initial MEDLINE and Embase searches had a date range of 1990–2021.

In December 2021, on the advice of an external expert, the review team extended the date range of the review to include relevant historical material. An additional search was completed to cover a date range of 1946–1990 using the same search strategies for all the databases (see Appendix A of Section 6 for Question 1, and Appendix A of Section 7 for Questions 2A and 2B). The Embase database carries records from its inception in 1974. LILACS includes material going back to 1978. Epistemonikos commenced compiling records in 2009, and PROSPERO contains records dating back to 2011. Both MEDLINE and the Cochrane Library have materials dating from 1946 to 2023.

Updated searches of MEDLINE and Embase, using the same search strategies, were conducted on 24 February 2022 and on 28 March 2023 in order to capture recent evidence.

Summary tables of the comprehensive search results are available in Appendix A of Section 6 for Question 1, and in Appendix A of Section 7 for Questions 2A and 2B. A search of systematic review repositories (Epistemonikos, the Cochrane Library, and the PROSPERO register of systematic reviews) was completed for Questions 1, 2A, and 2B.

2.4.3.2 Supplementary searches

Supplemental searching was completed in order to broaden the capture of relevant data. The reference lists of systematic reviews (identified during scoping searches and the screening process) and the included full-text primary research papers were retrieved to identify additional primary studies.

2.4.3.3 Grey literature

For Questions 1, 2A, and 2B, comprehensive searches of the websites of relevant national and international organisations, registers, and professional bodies, as well as the Google.com search engine, were carried out using language developed during the scoping search. Where applicable, subject headings, website filters (e.g. 'publications'), and natural language terms were used based on the search concepts of 'oral health', 'topical fluoride', 'artificially fluoridated water', and 'children aged under 6 years'.

2.5 Search strategy for Question 3

We completed targeted searches of the websites of Government Departments, dental/health organisations, and regulatory bodies from seven countries which were known to use CWF. The countries included in the search were Australia, Brazil, Canada, Israel (ceased CWF in 2014), New Zealand, the UK (including all devolved countries), and the USA. The countries were selected by the Department of Health. Country-level information was searched, and the guidelines of individual states within the USA were not included, given that they would typically have to match national guidance.

The websites included in the search dealt with dental health or public health or were government-level websites that would likely include national guidance on fluoride use, dental caries prevention and management, or early years dental health. The websites of organisations that may use (but not author) relevant guidelines, and thus may publish details of them, were also searched. Details of these websites are listed by country in Appendix A of Section 9. Searches were carried out both directly (using the search function of the individual websites) and by using the Google site search command (for example, searching for 'site:www.ada.org fluoride' in Google in order to find results from the American Dental Association website). These searches were much less structured than would be possible with standard bibliographic databases, as the search function of these websites is not designed for complex searching.

The website searches were supplemented with database searches carried out in MEDLINE (Ebsco), the Virtual Health Library, the Bielefeld Academic Search Engine (BASE), Informit, Google.com, and Google Scholar. Some organisations (including dental organisations) publish their guidelines in academic journals, and it was expected that these could be captured using MEDLINE (Ebsco), which indexes a wide range of dental, medical, health policy, and other journal titles. This database includes more English-language material than material in other languages. The Virtual Health Library portal (https://bvsalud.org/en/) was searched, as it derives information from sources such as LILACS, the Brazilian Dentistry Bibliography (BBO), and the website of the Secretaria de Estado da Saúde, among many other sites. The Informit portal (https://search.informit.org/) contains data from eight databases, including research and other content relating to Australia, New Zealand, and Southeast Asia and the Pacific. BASE (https://www.base-search.net/) was included because it indexes international academic resources, including guidelines. In addition to using the Google.com search engine for website searches as described above, we used Google.com and Google Scholar for general searches for any relevant guidelines. These were unstructured searches, as these search engines do not allow for complex searches. The OpenGrey search resource was discontinued in 2020, but its archived contents are available and were searched. Search strategies and search terms for Question 3 are described in Appendix A of Section 9.

We examined the references/bibliographies of identified guidelines in order to identify any related guidelines mentioned, such as in the case of a superseding guideline referencing a previous guideline.

2.5.1 Search terms

Searches were based around the concepts of fluoride, dental caries, children, and guidelines. While the parameters of the question included children aged under 6 years, the search was not limited to this age group, as relevant guidelines may not have that exact age in their searchable fields. Any guidelines or policies relating to children were examined and included or excluded based on their content. While non-English guidelines were not required to be included under the terms of the question, it was of interest to know whether non-English guidelines existed for the included countries; therefore, we included non-English terminology in the search. Search terms used for the website searches are briefly outlined in Table 6.

Results from these searches were included where they matched the requirements of the Question 3 inclusion criteria. These searches were comprehensive but not exhaustive, and there may be guidance on topical fluoride use available outside of the websites we searched.

Table 6 Sample search terms used in website searches for Question 3

Topic	Sample search terms
Fluoride	Fluoride, fluorides, fluoridation, topical, toothpaste, dentifrice, sealant, varnish, rinse, gel, foam, Professionally Applied Topical Fluorides (PATFs), פלואוריד מקומי, משחת שיניי טיפו שיניים, flúor tópico
Guidelines	Guideline, guidelines, guidance, policy, policies, statement, white paper, diretriz, declaração de posição, orientação, guia, recomendações, guia odontopediatra, הַדְרָכָה , הַצהָרָה, מְדִינִיוּת, מַנחֶה קו
Age	child, children, infant, pediatric, paediatric, under 5, under 6, 5 years, 6 years, primary tooth/teeth, deciduous tooth/teeth, primary molar, ילדה , יֶלֶד , ילדים, Criança, pediátric*, infantile
Dental caries	Caries, anti-caries, oral health, dental health, dentition, בריאות דנטלית

2.6 Screening for Questions 1, 2A, and 2B

We used EPPI-Reviewer in order to manage the study screening process for Questions 1, 2A, and 2B[65]. The search results from both date ranges were imported into EndNote reference management software and deduplicated. Each title and abstract were screened against the eligibility criteria in

Table 3 and Table 4 by two independent reviewers. Four screeners, divided into two teams (SS and JL; TM and AF), were involved in the process of screening on title and abstract. Each pair of reviewers compared their included and excluded studies, and resolved any disagreements through discussion until consensus was reached. Any study without an abstract was sourced at this stage and a decision was made regarding whether to include or exclude it during full-text screening. Where duplicate items were identified, one record was marked as a duplicate in the EPPI-Reviewer database and was excluded. The study selection process for each question is presented in a complete Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) Checklist in Appendix B of Sections 6, 7, and 8, respectively.

Each full text article screened against the eligibility criteria in

Table 3 and Table 4 by two independent reviewers. Four screeners, divided into two teams (TM and OC; JL and SS), completed full-text review. The two reviewers compared their included and excluded studies, and resolved any disagreements through discussion until consensus was reached. At the full text stage, we included English language studies only Where duplicate items were identified, one record was marked as a duplicate in the EPPI-Reviewer database and was excluded. Reasons for exclusion were recorded for any excluded papers (see Appendix C of Sections 6, 7, and 8 for Questions 1, 2A, and 2B, respectively).

For follow-up searches, the search results went through the same process of deduplication in EndNote as that described above before being imported into EPPI-Reviewer for further deduplication and two-stage screening. The records were screened on title and abstract and then on full text by two reviewers (JL, AF) following the processes described in the two preceding paragraphs.

2.7 Extraction

One researcher extracted data into a bespoke Microsoft Excel extraction sheet, and a second reviewer independently verified the extracted data.

The following information was extracted for all studies and research documents for all questions:

- Study ID
- Author
- Publication year, and
- Study country.

2.7.1 Questions 1, 2A, and 2B

We extracted the following data points for studies identified as relevant for Questions 1, 2A, and 2B:

- Study method:
  - Study design
  - Study objective
  - Study time period
  - Eligibility criteria
  - Study population
  - Details of exposure, including dose
  - Exposure time period (At extraction stage, we added: Lifetime exposure to CWF to Question 1)
  - Details of comparator (At extraction stage, we added: Lifetime exposure to fluoride deficient water CWF to Question 1)
  - Percentage lost to follow-up
  - Method for handling missing data
  - Confounders
  - Method to control for confounding
  - Effect modifiers, and
  - Method to assess effect modification.
- Participant characteristics:
  - Number of participants enrolled
  - Age (mean and range)
  - Proportion of female participants, and
  - Number of participants in analysis.
- Outcomes:
  - Type of dentition
  - Outcome(s) measured: Dental caries, tooth loss, dental fluorosis, periodontal disease, and oral health-related quality of life.
  - Method(s) of measurement (At the extraction stage, we decided to analyse only studies with the full dmft, dmfs, DMFT, DMFS, % with and without cavitated dental caries, and dental fluorosis using one of three established indexes for Question 1)
  - Statistical method of analysis, and
  - Numeric results (e.g. mean change, mean difference (MD), proportion difference, and measure of uncertainty).

We checked journal websites of the included articles for supplementary data and errata. We completed verbatim extraction where feasible and took care when extracting numeric results. Where multiple time points, study populations by individual ages, measures, or analyses were presented, we extracted results that were compatible with each outcome domain in each study. We noted instances where information was missing, unclear, or conflicting, and took a conservative approach to the extraction and interpretation of conflicting information.

A second reviewer independently verified extracted data using a clean copy of the publication. All errors were amended. Further details of the extraction form are available in Appendix D of Sections 6, 7, and 8 for Questions 1, 2A, and 2B, respectively.

We attempted to record two decimal points for all numeric data extracted from the included primary study papers, but in some cases this was not possible, so we reported the data as reported by the primary study authors, i.e. zero, one, or two decimel points.

2.7.1.1 Dental caries: Question 1

For all dental caries studies included in response to Question 1, we extracted baseline data where available; where baseline data were not available, this was noted. For all studies, we extracted the comparator data which matched the exposure data.

At the extraction stage, we decided to include one age group from each primary study to represent dental caries in primary teeth and one age group to represent dental caries in permanent teeth. The age group we focused on for Question 1 in relation to dental caries in primary dentition was children aged 5–6 years, as this age group would have the greatest number of primary teeth prior to exfoliation. If data for this age group were not reported, the population that was closest in age to 5–6 years was extracted from the primary study. The age group we focused on for Question 1 in relation to dental caries in permanent dentition was those aged 12 years where possible, in order to capture the fullest permanent dentition. If data for this age group were not reported, the population that was closest in age to 12 years was extracted. We also decided to use data for the population with lifetime exposure to CWF for the dental caries studies that were included in Question 1.

We used the four most relevant, commonly reported, and comparable outcomes: decayed, missing, or filled permanent teeth (DMFT/dmft); decayed, missing, or filled permanent surfaces (DMFS/dmfs); the percentage of participants without cavitated dental caries (% without CDC) in the primary or permanent dentition; and the percentage of participants with cavitated dental caries (% with CDC) in the primary or permanent dentition. We used measures of dental caries at cavitation level only, without radiographs or adjusted data, and excluded other measures for dental caries. We did not use data relating to individual tooth surfaces, specific teeth, or index teeth (i.e. a shortened assessment of dental caries using six particular teeth: the upper right first molar, the upper right lateral incisor, the upper left first premolar, the lower left first molar, the lower left lateral incisor, and the lower right first premolar); data combining primary and permanent dentitions (mixed dentition); or data for naturally fluoridated populations.

It is not uncommon in older studies reporting on dental caries in primary teeth to report decayed or filled primary teeth (dft)/decayed or filled primary surfaces (dfs) only, as opposed to decayed, missing, or filled primary teeth (dmft)/decayed, missing, or filled primary surfaces (dmfs), as it was considered to be unclear if the teeth were missing due to extraction or exfoliation. The WHO suggests that this issue can be avoided by focusing on children aged 6 years, when exfoliation has not yet commenced, and states that if older age groups are being assessed, missing primary incisors should not be scored as missing because of the difficulty in differentiating between normally exfoliated primary incisors and those lost because of dental caries or trauma [36]. For this reason, we have excluded studies that did not report missing teeth as part of the dmft/dmfs indices. The justification for this decision can be clearly seen in one of the included studies in this review which reports both dmfs and dfs [66]. When the missing teeth are included in the analysis, the number of dmfs for children’s teeth was 2.52 and 5.49 for CWF and fluoride-deficient areas, respectively, but when missing teeth are not included, the dfs was considerably lower, at 1.59 and 3.41 for CWF and fluoride-deficient areas, respectively. Some studies use the term ‘extracted’ instead of ‘missing’ (decayed, extracted/missing, or filled primary teeth (deft)/decayed, extracted/missing, or filled primary surfaces (defs)) when reporting on the primary dentition; in this review, we assumed that the ‘e’ and ‘m’ were synonymous. This is not an issue for permanent teeth.

We used both the percentage of participants with or without dental caries because we are reporting dental caries at cavitation level only, as per the WHO definition, “caries is recorded as present when a lesion in a pit or fissure, or on a smooth tooth surface, has an unmistakable cavity, undermined enamel, or a detectably softened floor or wall” p.44 ((World Health Organization 2013), and the International Caries Detection and Assessment System (ICDAS) levels 4–6 definitions:

> Code 4 represents those lesions where there are underlying shadows indicating that the carious demineralization has progressed into dentin, the dentine is discolored, and the enamel surface is un-supported by the dentine (ICDAS code 4). If the cavitation exposes dentin, then the carious process has progressed into a stage referred to as ‘distinct cavitation’ (ICDAS code 5). A cavity that destroys at least one-half of a tooth surface is referred to as ‘extensive’ (ICDAS code 6). [19] p.172

Therefore, the analysis does not include participants with early dental carious lesions or caries at the enamel level only, as such participants could not be accurately described as either caries-free or with dental caries. In the study characteristics sections for each outcome, when papers have used the terms ‘caries-free’ or ‘with dental caries’ but recorded dental caries at cavitation level only, we have described these participants using the terms ‘without cavitated dental caries’ (% without CDC) or ‘with cavitated dental caries’ (% with CDC) as appropriate.

If linked or follow-up papers reporting on the same study presented the same data, the paper with the most extensive and/or detailed relevant data was used. Single-time-point studies were included. If data for the four outcome measures of interest could be calculated from the presented data, they were calculated and identified as such.

2.7.1.2 Dental fluorosis: Question 1

For all dental fluorosis studies included in response to Question 1, we extracted all data from the papers, but we used data that included individuals with lifetime exposure to CWF as the intervention group and no exposure to CWF for the comparator group.

2.7.1.3 Dental caries and dental fluorosis: Questions 2A and 2B,

The HRB identified and extracted data from included papers to answer Question 2A on the use of fluoride toothpaste by children when they were aged under 6 years and lived in communities with CWF and Question 2B on the use of other topical fluoride technologies by children when they were aged under 6 years and lived in communities with CWF. The data were extracted for the outcomes’ dental caries and dental fluorosis. As the number of studies was low for each outcome and the studies were different from one another, we retained all studies and reported all outcomes.

2.7.1.4 Confounders with regard to CWF and dental health outcomes for Question 1, 2A and 2B

During literature scoping and full text reading, we identified five groups of possible confounding variables that could be associated with the exposure (in this case, CWF) and could independently prevent or cause the outcome (in this case, dental caries or dental fluorosis):

1. Group 1: demographics (age, sex, lifetime CWF exposure or years of residence in a CWF area, ethnicity)
2. Group 2: socioeconomic status (socioeconomic group, level of education, type of employment)
3. Group 3: nutrition (breastfeeding versus artificial formula feeding, snacks, other food such as tea)
4. Group 4: other sources of fluoride (CWF, fluoride toothpaste and toothbrushing, fluoride mouthwashes, fluoride supplements, fluoride varnishes, fluoride sealants), and
5. Group 5: affordable and accessible dental services (public, comprehensive, and free for children, or paid for through dental care insurance).

We documented the confounders controlled for in each paper and used these data to answer the quality assessment question.

2.7.2 Question 3

We extracted the following data points for publications included in response to Question 3:

- Date of issue of recommendations, and
- Recommendations for the use of topical fluorides in children aged under 6 years (where no specific recommendation has been issued, this was also noted).

2.8 Quality assessment for Questions 1, 2A, and 2B and Question 3

All papers included in response to Questions 1, 2A, and 2B were assessed in order to determine the quality of their design and conduct. Randomised controlled trials were assessed by two independent reviewers using the Cochrane Risk of Bias 2 (RoB 2) tool [64]. Two independent reviewers assessed observational study designs (i.e. cross-sectional surveys, cohort studies, and case-control studies) for methodological quality using the appropriate National Heart, Lung, and Blood Institute's (NHLBI's) quality assessment tools [67]. We chose the NHLBI tools because one is designed to assess cohort and cross-sectional surveys and another is designed to assess case-control studies, and these study designs were the most frequently cited when we completed our scoping exercise for this systematic review. Any disagreements that arose between the reviewers were resolved through discussion.

The tools are presented in full in Appendix E of Sections 6, 7, and 8 for Questions 1, 2A, and 2B, respectively. For each paper, we calculated an overall quality rating using a bespoke system, based on essential criteria for high-quality longitudinal cohort studies, cross-sectional surveys, and case-control studies [68]. For longitudinal cohort studies and cross-sectional surveys, five items from the respective NHLBI's tool were selected and scored as outlined in Table 7, and for case-control studies five items were chosen from the specific case-control studies tool and scored as outlined in Table 8. The items chosen identified the aspects of studies that were most likely to introduce bias to the results through unrepresentative sampling (proxy for effect of assignment or exposure), sample size (proxy for ability to detect true differences in outcomes), loss to follow-up (proxy for missing outcome data and proxy for complete reporting of outcomes and experiences), and confounding (proxy for randomisation); The criteria were chosen to mimic risk of bias.

Table 7 Overall quality rating calculation for cross-sectional surveys and longitudinal cohort studies using specific NHLBI tool

Item	Scoring
3. Was the participation rate of eligible persons at least 50% and was an appropriate target population clearly defined per the research question and did the cases adequately represent the cases that arose in the target population?	Yes: 1.0 No: 0.0
4. Were all the subjects selected or recruited from the same or similar populations (including the same period) and were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?	Yes: 1.0 No: 0.0
5. Was a sample size calculation, power description, or variance and effect estimates provided and did the authors include a sample size justification?	Yes: 1.0 Partly: 0.5 No: 0.0 Not applicable (census data): 1.0
13. Was loss to follow-up after baseline 20% or less?	Yes: 1.0 No: 0.0
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	Extensive: 1.0 Partial: 0.5 Some: 0.0 None: 0.0

Note: Responses of 'Not reported', 'Cannot determine', and 'Not applicable' were scored 0.0 for each item except for item 5, where 'Not applicable' was scored 1.0, as it related to the study design. For item 14, key potential confounding variables were identified based on established risk factors for the condition under consideration (see Appendix E of Sections 6, 7, and 8 for Questions 1, 2A, and 2B, respectively); while some papers controlled for a large number of variables in their models, only these key confounding variables were considered for item 14. The scoring system for Item 14 was:

0 = No control for confounders

0 = Some: control for one or more confounders in one or two groups;

0.5 = Partial: control for one or more confounders in three or four groups;

1 = Extensive: must have controlled for 1 or more confounders in each of the five groups.

Table 8 Overall quality rating calculation for case-control studies using specific NHLBI tool

Item	Scoring
3. Was an appropriate target population clearly defined per the research question? Did the cases adequately represent the cases that arose in the target population?	Yes: 1.0 No: 0.0
4. Did the authors include a sample size justification?	Yes: 1.0 No: 0.0
6. Were the definitions, inclusion and exclusion criteria, algorithms or processes used to identify or select cases and controls valid, reliable, and implemented consistently across all study participants?	Yes: 1.0 No: 0.0
12. Were the assessors of exposure/risk blinded to the case or control status of participants?	Yes: 1.0 No: 0.0
13. Were key potential confounding variables measured and adjusted statistically in the analyses? If matching was used, did the investigators account for matching during study analysis?	Extensive: 1.0 Partial: 0.5 Some: 0.0 None: 0.0

Note: Responses of 'Not reported' and 'Not applicable' were scored 0.0 for each item. For item 13, key potential confounding variables were identified based on established risk factors for the condition under consideration (see Appendix E of Sections 6, 7, and 8 for Questions 1, 2A, and 2B, respectively); while some papers controlled for a large number of variables in their models, only these key confounding variables were considered for item 13. The scoring system for Item 13 was:

0 = No control for confounders

0 = Some: control for one or more confounders in one or two groups;

0.5 = Partial: control for one or more confounders in three or four groups;

1 = Extensive: must have controlled for 1 or more confounders in each of the five groups.

For each paper reporting on a longitudinal cohort study, cross-sectional survey, or case-control study, the scores were summed (for a total score ranging from 0.0 to 5.0). Papers scoring less than 3.0 were rated 'low quality', papers scoring 3.0 were rated 'moderate quality', and papers scoring 3.5 or more were rated ‘high quality’. As many studies were cross-sectional in nature (point-in-time surveys) and scored 0.0 on item 13 (loss to follow-up not applicable), the maximum possible score for papers reporting on these types of studies was effectively capped at 4.0; for this reason, the threshold for ‘high quality’ was set at 3.5, rather than 4.0, in order to allow more effective differentiation of papers at the upper end of the range of scores. We also report the quality deficiencies by low-, moderate- and high-quality papers.

For Question 2B, we also included two randomised controlled trials. We used the RoB2 tool in order to assess the risk of bias of the two included randomised controlled trials. The domains included in the RoB2 tool cover all five types of bias that are currently understood to affect the results of randomised controlled trials [64]. These are:

1. Bias arising from the randomisation process
2. Bias due to deviations from intended interventions
3. Bias due to missing outcome data
4. Bias in measurement of the outcome, and
5. Bias in selection of the reported result.

The judgement for each type of bias can be ’that there is a ‘low’ or ’‘high’ risk of bias, or can express ‘some concerns’ [64].

The overall risk of bias is taken as the least favourable assessment result across the five domains of bias.

The response to Question 3 is based on reports of clinical recommendations rather than primary research studies, and so quality assessment was not required.

2.9 Synthesis: Questions 1, 2A, and 2B

2.9.1 Narrative synthesis

Narrative synthesis employs a textual approach to providing an analysis of the relationships within and between studies and an overall assessment of the robustness of the evidence [69]. Narrative synthesis of the included papers was undertaken where the results of the meta-analytic feasibility assessment indicated that papers were too diverse (either clinically or methodologically) to combine in a meta-analysis. Where meta-analysis was possible, aspects of narrative synthesis were required in order to fully interpret the collected evidence.

For the dental caries aspect of Question 1, we analyse the data by permanent and primary dentition, and within each dentition type we analyse the data by four outcomes: DMFT/dmft, DMFS/dmfs, the percentage of participants without cavitated dental caries, and the percentage of participants with cavitated dental caries. We used the data reported by the authors, where specific measures were required, we hand calculated these using appropriate formulas, e.g. for the final differences between groups and for GRADE.

At the analysis stage, we did not calculate a global prevalence of dental fluorosis in Question 1, as when viewing the data on CWF between 0.5 and 1.2 ppm, the prevalence of dental fluorosis appears to vary with context (including geology, diet, environment), and the possible misuse of fluoride toothpaste. Instead, we undertook structured reporting of prevalence by country, index measure, and diagnosis severity, but we could not calculate a standardised effect measure for dental fluorosis prevalence by individual paper for the included studies because most papers did not report 95% confidence intervals (CIs) or measures of variance around their prevalence estimates.

For both dental caries and dental fluorosis, we have taken account of the effect of the concentration of fluoride in fluoridated water supplies, lifetime exposure to CWF, cluster sampling, and rater agreement on the diagnosis of dental caries or dental fluorosis in our narrative synthesis. In addition, we estimated, where feasible, the independent contribution of CWF – after controlling for other determinants – on diagnosis with dental caries, and separately on diagnosis with dental fluorosis.

For Questions 2A and 2B, we narratively analyse and present the papers reporting on dental caries and on dental fluorosis separately, and in chronological order by year of publication. These papers were quite diverse in design, means of measurement, and outcome measured so we completed a narrative text-based thematic-like analysis.

2.9.2 Feasibility assessment

A feasibility assessment is a stepwise framework that ensures that the underlying assumptions in extracted data are systematically explored and that the risks (and benefits) of pooling and comparing intervention effects are identified. For each outcome of interest, we completed an assessment of the feasibility of meta-analysis following published guidance [70]. Papers were first grouped by outcome and then by dentition type for the dental caries and dental fluorosis outcomes, then by outcome measures, and, where necessary, by the measure employed in order to assess the outcome. Where necessary and feasible, we converted SEs to SDs using the appropriate formula. Following this, for each group of papers, comparability on the following variables was assessed in this order:

1. Study design and accounting for cluster sampling effect (required)
2. Population (based on participant age and dentition type) (dentition type and age stated in study)
3. Intervention (based on concentration of 0.5 to 1.2 ppm fluoride in fluoridated water supplies and lifetime exposure to CWF)
4. Outcome measures (methods of measurement one of dental caries outcomes using one or more of our indexes for Question 1, level of agreement between measurers, measurement of statistical variance required)
5. Extent of control for confounding (statement required)
6. Regression analysis to adjust for confounding (statement required), and
7. Study quality to determine bias in analysis allowance made for sample size and control for confounding but not for sample selection and outcome measurement.

In addition, where data were available for two time points, we also considered the similarity of the duration of follow-up.

2.9.3 Meta-analysis

Pairwise meta-analyses, sensitivity analyses, and subgroup analyses (i.e. CWF level, age and quality) were completed where appropriate. The approach to pairwise meta-analysis for each individual study outcome was guided by the *Cochrane Handbook for Systematic Reviews of Interventions* [64]. Analyses were performed in R version 4.2.3, named "Shortstop Beagle" using the meta, metafor and tidyverse R packages [71–74]. In order to prepare the data for analyses, CWF ppm measures reported for individual studies were categorised as follows:

1 = <0.6 ppm

2 = 0.6–0.8 ppm

3 = >0.8 ppm

Population-level census surveys do not require standard deviations or confidence intervals around the parameters of interest, as these included the complete population of interest (rather than a probability sample of the population) and therefore results are the actual experience of the population of interest rather than estimates. In order to facilitate computerised statistical analysis we provided a notional measure of 0.1 for SDs for population-level census surveys.

A series of single time point meta-analysis models were run in order to pool the:

- Difference in the average dmft between CWF and low/no fluoridated areas for both primary and permanent dentitions (smd)
- Difference in the average dmfs between CWF and low/no fluoridated areas for both primary and permanent dentitions (smd)
- Difference in the number of cavitated dental caries events measured using dmft between CWF and low/no fluoridated areas for both primary and permanent dentitions (OR)
- Precalculated adjusted odds of dental fluorosis when exposed to CWF compared with fluoride-free or fluoride-deficient water (OR)

Based on the results of the feasibility assessment for meta-analysis, we anticipated considerable between-study heterogeneity for all feasible meta-analysis models and therefore used a random-effects model to pool effect sizes for each model [64]. The random-effects model meta-analyses take into account both study sample size and the estimate of between-study variation (i.e. study heterogeneity) when weighting study effects [64]. The random effects model was estimated using the restricted maximum likelihood estimator for differences in the average dmft and dmfs given its robust performance in continuous outcome data [75]. The random effects model was estimated using the Paule-Mandel estimator [76] for differences in the number of cavitated dental caries events measured using dmft between CWF and low/no fluoridated areas for both primary and permanent dentitions and for precalculated adjusted odds of dental fluorosis when exposed to CWF compared with fluoride-free or fluoride-deficient water given that it has been recommended for pooling binary outcomes [77], including where the number of studies is small [78] and their sample sizes do not vary drastically [79]. Meta-analytic ORs and SMDs are expressed with 95% CIs. ORs were calculated for categorical outcomes, and SMDs were calculated for continuous outcomes. Heterogeneity between studies was assessed by the I^2 statistic and τ^2. Higgins and Thompson's I^2 statistic is defined as the percentage of variability in the effect sizes that is not caused by sampling error [64] and τ^2 quantifies the variance of the true effect sizes underlying the data [32]. The results from the meta-analysis were presented in a forest plot. Outlier studies, defined as those wherein the confidence interval does not overlap with the confidence interval of the pooled effect of the meta-analysis [27], were identified using the 'find.outliers' function in R [27] and were removed. Specific subgroup analyses were planned *a priori* in order to test specific hypotheses, describing why some type of study produces lower or higher effects than another. Subgroups of interest were study quality, study CWF ppm category, and participant age. Sensitivity analyses were also planned in order to assess the effect of the widespread use of fluoride toothpaste on the results of studies using a study publication year cut off of 1975 onwards as a proxy indicating general availability of fluoride toothpaste. The decision on the general availability of fluoride toothpaste is in line with other similar systematic review studies undertaken on this topic [41].

Trends in outcomes over time could not be pooled due to the lack of comparable data for similar follow-up periods. We therefore followed the approach adopted by Iheozor-Ejiofor *et al.* to analyse these data [41]. Specifically, for the analyses of mean changes over time in dmft for primary and permanent dentitions for CWF compared with fluoride deficient groups, we calculated mean change score for water fluoridation and control group separately, and the summary effect estimates for the age group of interest. The resulting estimates for the CWF and control groups for each study were then used to calculate the mean difference in change scores for the review. We displayed this data using the average of the analytic samples for the before and after data for each study to give an indication of the power of the studies. Owing to differences in the follow-up periods of studies reported, the raw data and summary statistics were not reported in forest plots but were tabulated instead.

2.10 Application of GRADE

We employed the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) system [80] in order to grade the quality of evidence and strength of the recommendations for each primary outcome of interest. While the quality assessment process described in Section **Error! Reference source not found.** rates the methodological quality of individual papers, the GRADE approach is used to rate the quality of evidence for eligible primary outcomes across all included papers. In line with best practice, we only apply GRADE assessments to primary review outcomes [80].

Under the GRADE system, the initial certainty of the evidence is determined based on study design, with well-designed randomised controlled trials providing a high degree of certainty and well-designed observational studies providing a moderate or low degree of certainty depending on the study design (longitudinal cohort study, case-control study, or cross-sectional survey). The level of certainty is then adjusted upwards or downwards based on several factors. Ultimately, a body of evidence related to an outcome receives one of four grades (high, moderate, low, or very low), reflecting the level of certainty we may have that the true effect is similar to, or substantially different from, the estimate of the effect.

Following the GRADE approach, we downgraded the quality of the evidence considering five criteria (risk of bias or study quality, inconsistency, indirectness, imprecision, and publication bias), and for outcomes where all five criteria were met, we upgraded the quality of the evidence based on three criteria (large consistent effect, the presence of a dose–response gradient, and confounders reducing the effect size). For all GRADE domains, JL carried out the initial assessment and CW validated the initial assessments. The reviewers agreed on the final decisions for each risk of bias and each GRADE domain through a consensus process.

Each paper starts at 10 points and can lose 0, 1, or 2 points for each of the five downgrading criteria. However, if all five criteria are met, it can gain an additional 1 or 2 points for a large consistent effect, and 1 point for the presence of a dose–response gradient and/or confounders reducing the effect size. The five reasons for downgrading are:

1. Risk of bias, which takes account of study design considering the hierarchy of evidence and the methodological quality of the study
2. Inconsistency, which considers both clinical and statistical heterogeneity that cannot be controlled for in the analysis
3. Indirectness, which considers the comparator intervention and whether it is the current gold standard or is being used as a proxy, and which also considers the population, intervention, and outcome
4. Imprecision, which takes account of the size of the variance and the optimal effect size and is closely related to sample size and the number of events of interest, and
5. Publication bias, which is a systematic underestimation or overestimation of the underlying beneficial or harmful effect of an intervention due to the selective publication of papers (risk of publication bias was evaluated indirectly in this review, since funnel plots are not recommended for meta-analysis containing a small number of papers/studies [81]) We used our search strategy to minimise publication bias.

The decision to upgrade should only rarely be made if no serious limitations are present in any of these areas, and the decision should only be made after full consideration and in the context of reasons to downgrade. The three reasons for upgrading are:

1. Large or very large estimates of the magnitude of an intervention or exposure effect
2. The presence of a dose–response gradient, which may increase certainty in the findings of observational studies, and
3. Where all plausible residual confounding factors from observational studies may be working to increase or decrease the demonstrated effect if no effect was observed.

2.11 Summarisation of data for Question 3

We extracted, tabulated, and summarised the recommendations for the use of topical and systemic fluorides for children aged under 6 years in other countries that are currently or were recently implementing CWF.

3 Findings

3.1 Question 1: What is the positive and negative effect* of artificial CWF (intervention or exposure) on dental health of the general population and does the effect on dental health vary with the level of fluoride in artificially fluoridated water?

3.1.1 Search and screening results

The database search retrieved 4,853 records, which we exported to EndNote. There were 1,412 duplicate records removed in EndNote, leaving 3,441 records. These 3,441 records were imported into EPPI-Reviewer for dual screening on title and abstract by one of two sets of two reviewers (JL and SS; OC and AF), and 2,874 were excluded, leaving 567 records. All 567 papers were sought for full-text screening and 559 were retrieved. The 559 retrieved papers were screened on full text, resulting in the inclusion of 73 full-text papers. Supplemental searching and reference and citation chasing identified 3,614 additional records; of these, 426 were duplicates and were removed, leaving 3,188 records. These 3,188 records were screened on title and abstract and 2,985 were excluded, leaving 203 records, one of which could not be obtained. The remaining 202 full-text papers were retrieved and screened, of which 177 were excluded and 25 were included. In total, 98 papers were included in response to Question 1.

See Appendix F of Section 6 for the PRISMA flow diagram for Question 1.

We extracted data for five outcomes dental caries, tooth loss, dental fluorosis, periodontal disease, and oral health-related quality of life. In this review, we present the findings on dental caries (including tooth loss), and dental fluorosis in the findings chapter of the document. We did not identify any study that examined oral health-related quality of life in areas with CWF. We present the results for periodontal health in Appendix G of Section 6 as they are few and do not appear to be related to CWF.

We identified 98 papers that measured the effects of CWF on dental caries and/or dental fluorosis compared with fluoride-free or fluoride-deficient water. There was initial uncertainty regarding one of the reported studies [58], but on contacting the lead author via email, it was established that "the average for the non-fluoridated areas was usually less than 0.02 [ppm] for areas which received community water fluoridation" [82]. Twenty-two of the included papers covered both dental caries and dental fluorosis [52,53,83–102], 65 papers covered dental caries only [4,58,66,103–164], and 11 papers covered dental fluorosis only [165–175]. We further describe the study characteristics of papers covering dental caries and dental fluorosis in Sections 3.1.2 and 3.1.5, respectively. In addition, we present the findings for Question 1 in two sections: the first on dental caries (3.1.4) and the second on dental fluorosis (3.1.7).

We identified only seven papers (6 studies) published between 1972 and 1996 that examined periodontal disease [113] [124] [144] [145] [146] [147] [153]. These most recent of these papers were published more than 28 years ago and some of the papers were published before the widespread use of fluoride toothpaste. We present a narrative summary of these papers in Appendix G of Section 6. We did not identify any study that examined oral health-related quality of life in areas with CWF.

3.1.2 Study characteristics: dental caries

A total of 87 papers (55 studies) reported outcomes relating to dental caries (Table 9); 40 papers reported on 40 unique studies [52,53,58,86,87,89,90,93,95–101,108–114,118,119,122,123,127,128,135–137,139–141,149,155,156,162–164], and the remaining 47 papers reported outcomes for 15 studies [4,66,83–85,88,91,92,94,102–107,115–117,120,121,124–126,129–134,138,142–148,150–154,157–161]. Two of these studies [105,147] had five follow-up papers; one study [153] had four follow-up papers; two studies [4,124] had three follow-up papers; two studies [102,133] had two follow-up papers; and eight studies [103,115,130,138,143,144,157,159] had one follow-up paper (See Table 9). In Table 9 authors of linked papers are presented in bold for the earliest paper and in italics for subsequent papers. Authors of unique papers are presented in normal font.

Some of the methodological characteristics of the linked studies were reported in one paper and not in another, so the quality assessment scores in some papers reporting on the same study differ from each other. Some other characteristics, such as the mean age, percentage of female participants, or index used, were also reported in one linked paper and not in another so the total number of studies will exceed 55 when reporting these characteristics.

The papers were published between 1950 and 2022 and covered 17 countries: Australia (3 papers on 3 studies) [95,111,164], Brazil (4 papers on 3 studies) [87,98,157,158], Canada (11 papers on 8 studies) [83,85,86,89,90,94,102,112,113,138,163], Chile (1 paper on 1 study) [100], Cuba (2 papers on 2 studies) [93,135], England, UK (18 papers on 12 studies) [58,66,88,108–110,115–117,119,122,127,128,139,141,146–148], Finland (9 papers on 4 studies) [123,137,144,145,150–154], Germany (4 papers on 2 studies) [132–134,162], Ireland (6 papers on 5 studies) [52,53,136,140,142,143], Malaysia (1 paper on 1 study) [97], the Netherlands (4 papers on 1 study) [4,120,131,161], New Zealand (4 papers on 3 studies) [96,114,159,160], Scotland, UK (1 paper on 1 study) [155], Singapore (1 paper on 1 study) [101], Taiwan (4 papers on 1 study) [121,124–126], the USA (10 papers on 4 studies) [84,91,91,92,99,103–106,118], and Wales, UK (4 papers on 3 studies) [129,130,149,156].

Four studies (reported in 5 papers) were based on a prospective cohort study design [58,120,122,123,163], while 51 studies (reported in 82 papers) were based on a cross-sectional survey design [4,52,53,66,83–119,121,124–162,164].

The study populations were adults or children in the community (36 papers on 24 studies) [4,58,66,93,96,98,99,108,110,111,114,116,120,121,123–127,129–131,133,140,141,148–156,159,161], schoolchildren or children in kindergarten (48 papers on 30 studies) [52,53,83–92,94,95,97,100–107,109,112,113,115,117,118,122,128,132,134–139,142–147,160,162–164], and children in daycare (2 papers on 1 study) [157,158]; 1 paper/study [119] did not describe its population. The mean age of participants, or the specific age of participants, was reported in 50 papers (35 studies) [52,53,58,66,88,94,95,97,98,100,108–111,113–116,118,122,127–131,136–154,157,159–161,163,164], where the ages ranged from 3 to 32 years. Thirty-four papers (20 studies) reported participants by age groups only; the ages ranged from 18 months to 75 years and over [4,33,83–87,89,91–93,96,99,101–107,112,120,121,123–126,132–135,156,158,162]. Three papers (three studies) [90,117,119] did not report the age of participants.

Two papers (two studies) did not report the number of participants [133,138], while the remaining studies varied in size: the smallest study [120] had 196 participants and the largest had 286,176 participants [132]. The proportion of female participants was not reported in 55 papers (38 studies) [66,83–86,88–91,93–95,101–110,112,114,115,119,120,122,123,127–135,137–139,141,142,148–155,157,158,161,162]. In one paper the focus was on pregnant mothers, so all participants were female [156]. In the remaining 31 papers (21 studies), the proportion of female participants varied from 42% to 61% across the papers as well as between the intervention and comparator groups within the same paper [4,52,53,82,87,92,96–100,111,113,116–118,121,124–126,136,140,143–147,159,160,163,164].

The lowest concentration of fluoride in the fluoridated water supply for the intervention group in the included studies was 0.5 ppm, and the highest was 1.3 ppm. In some studies, the concentration of fluoride in the fluoridated water supply differed or fluctuated at different time points during the study: 69

papers (42 studies) reported the lowest intervention concentration of fluoride as somewhere between 0.8 and 1.3 ppm [4,52,53,58,66,83–86,90–92,96,99,100,102–114,116–120,122,123,127–137,139,141–156,159–164], and 15 papers (10 studies) reported the lowest intervention concentration of fluoride as somewhere between 0.6 and 0.75 ppm [87–89,93,95,101,115,121,124–126,138,140,157,158]. Three papers (three studies) reported a lowest intervention concentration of fluoride of 0.50–0.59 ppm [94,97,98]. Three papers (two studies) had relevant comparator groups with fluoride concentrations between 0.30 and 0.35 ppm [94,108,138], and two papers (one study) [157,158] had a comparator fluoride concentration described as 'lower than 4.0 ppm'. One paper/study [140] did not give an exact concentration of fluoride in the fluoridated water supply but estimated the level based on percentage lifetime exposure to water fluoridation, a method used by Slade *et al.* (1995) [176], which calculates lifetime exposure using the history of residency since birth. Five papers reporting on four studies undertaken in Ireland were known to have a concentration of fluoride in the fluoridated water supply of <0.30 ppm in fluoride-deficient areas [52,53,136,142,143], and seven other papers (four studies) described the fluoride levels broadly as 'never fluoridated', 'no fluoride', 'negligible fluoride', or 'fluoridation ended' [83,85,86,102,105,159,160]. All the remaining comparator groups reported a concentration of fluoride in the fluoridated water supply of <0.3 ppm.

Sixteen different indices, or modified or updated versions of them, were used to measure dental caries in the 87 included papers (55 studies). These indices are:

1. American Dental Association (ADA) Caries Classification System (CCS) [2]
2. Australian Institute of Health and Welfare's 2004–06 National Survey of Adult Oral Health (ANS) [3]
3. Backer-Dirks *et al.*, 1961 [4]
4. British Association for the Study of Community Dentistry (BASCD) [6]
5. Canadian Dental Association (CDA) [7]
6. Downer *et al.*, 1979 [14]
7. Fédération Dentaire Internationale (FDI) Caries Matrix; Special Commission on Oral and Dental Statistics [15]
8. ICDAS [19]
9. Ismail *et al.*, 1992 [21]
10. Jackson *et al.*, 1973 [22]
11. Moller and Poulsen, 1973 [24]
12. National Institute of Dental Research (NIDR) [25]
13. Palmer *et al.*, 1984 [28]
14. Slack *et al.*, 1958 [31]
15. Stephen *et al.*, 1988 [33], and
16. –The WHO's *Oral Health Surveys: Basic Methods, 5th Edition*, 2013 [36]

The most used index was the WHO index (16 studies reported in 24 papers) [52,53,91,93,94,100,101,113,114,121,124–126,132,135,138,142–145,157,158,162,164]; 5 studies (6 papers) used the Palmer *et al.*, 1984 index [110,141,149,156,159,160]; 4 studies (8 papers) used the Backer-Dirks *et al.*, 1961 index [4,117,120,131,146–148,161]; 4 studies (5 papers) used the BASCD index [58,66,116,119,140]; 3 studies (5 papers) used the Jackson *et al.*, 1973 index [108,127–130]; 3 studies (3 papers) used the NIDR index [89,92,99]; 3 studies (3 papers) used the Downer *et al.*, 1979 index [122,136,139]; 2 studies (2 papers) used the CDA index [112,163]; 1 study (2 papers) used the Stephen *et al.*, 1988 index [88,115]; and 1 study (5 papers) used the Moller and Poulsen, 1973 index [150–154]. The ANS index [96], ICDAS [97], FDI index [95], Ismail *et al.*, 1992 index [90], and Slack *et al.*, 1958 index [109] were each used by one study/paper. Two studies (3 papers) [118,157,158] used the ADA CCS index, one of which (reported in 2 papers) also used the WHO index [157,158]. Ten studies (17 papers) did not name the index used [83–87,98,102–107,111,123,133,134,137], all of which used DMFT/dmft to measure dental caries; and 4 studies (6 papers) provided a definition of what 'decayed', 'missing', and 'filled' represented [83,85,87,102,134,137].

In relation to inter- and/or intra-examiner reliability, 24 papers (21 studies) reported a Kappa score ranging from 0.72 to 1.0 [52,58,87,89,90,92,94,98–100,112,115,131,132,136,137,140,149–152,161,163,164], and 6 other papers (5 studies) reported an equivalent rating – intraclass correlation coefficient (ICC) or percentage agreement – ranging from 0.78 to >0.95 ICC or –88.9–97.6% agreement [96,122,142,143,155,162]. Seventeen papers (15 studies) reported that calibration was assessed but did not report the levels [4,53,66,88,97,103,114,117,119,124,130,138,139,141,146,153,156]. Two papers (2 studies) acknowledged that they did not measure examiner reliability [118,147], and the remaining 38 papers (13 studies) did not report on this element.

Seven papers (five studies) reported undertaking cluster sampling adjustments [89,91,92,94,96,98,138]; only two papers (two studies) reported the design effect, which ranged from 1.7 to 2.4 [96,98]. In six other papers (five studies), cluster sampling adjustments were implied [53,118,143,149,159,160]. In 15 papers (9 studies), adjustments were not required, as they were census surveys [86,90,104,105,107,121,124–126,128,132,134,154,155,163]. The remaining 59 papers (36 studies) did not report on cluster sampling adjustments.

As mentioned in Section 2.7.1.1, we have focused on the four most relevant, commonly reported, and comparable outcomes: DMFT/dmft; DMFS/dmfs; the percentage of participants without cavitated dental caries (% without CDC) in the primary or permanent dentition; and the percentage of participants with cavitated dental caries (% with CDC) in the primary or permanent dentition.

Table 9 Summary of study characteristics for studies examining CWF and dental caries

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Australia	Medcalf [95]	1975	Cross-sectional survey	Schoolchildren (aged 6–8 years) both pre- and 6 years post-CWF in the Goldfields region. None of the 1973 group had lifetime exposure to CWF.	During the first 3 years of CWF, the fluoride level was 0.7 ppm during the summer months (October to March) and 0.9 ppm during the winter months (April to September). This seasonal variation was discontinued from 1 October 1971 in favour of a constant level of 0.9 ppm.	0.7–0.9	Pre-CWF in the Goldfields region (0.1–0.2 ppm of fluoride)	DMFT	Pre-CWF: 362 Post-CWF: 601	7.9 years	Not reported
Australia	Carr [111]	1976	Cross-sectional survey	Children aged 5–12 years who had lived in Canberra since CWF commenced compared with another study conducted prior to CWF.	Canberra: From September 1964 to April 1970, the mean concentration of fluoride was 0.87 ppm. From April 1970, the amount of fluoride was increased slightly to 0.95 ppm.	0.87–0.95	Pre-CWF study in 1966, when Canberra's water supply contained <0.1 ppm fluoride.	DMFT, deft	Not reported	Exposure: 8.6 years Comparator: 9.0 years	1964: 49% 1974: 48%
Australia	Riordan [164]	1991	Cross-sectional survey	Schoolchildren born in 1978 with 4–12 years of CWF exposure, living in fluoridated Perth or fluoride-deficient Bunbury region. Schools to which Dental Therapy Centres are attached were selected.	Fluoridated Perth (0.8 ppm in 1968)	0.8	Fluoride-deficient Bunbury region (<0.2 ppm)	DMFT (0.84)	Total: 592 Exposure: 339 Comparator: 253	Mean age: 11 years, 7 months (SD: 2.7 months)	Perth: 48% Bunbury: 47%
Brazil	Cortes *et al.* [87]	1996	Cross-sectional survey	Schoolchildren aged 6–12 years from three economically deprived groups who were lifetime residents of their respective areas and who used local drinking water sources.	Vitória, Espírito Santo (artificially fluoridated since 1982, at 0.7 ppm)	0.7	Maceió, Alagoas (<0.1 ppm of natural fluoride)	DMFT, dmft (0.95)	361	Mean age not reported/age range: 6–12 years	53%

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Brazil	**Tiano *et al.*** [157]	**2009a**	Cross-sectional survey	Children aged 36 months and under in public daycare centres of two municipalities located in the southeastern region of Brazil.	Gabriel Monteiro, São Paulo (2005 level: 0.60–0.75 ppm)	0.60–0.75	Clementina (0.40 ppm) and Gabriel Monteiro, São Paulo (year not reported; 0.60–0.75 ppm)	dmft, dmfs (cavitated caries with enamel and dentine involvement in primary teeth (d_3) only)	68	Mean age not reported/age range: 6–35 months	Not reported
Brazil	*Tiano et al.* [158]	*2009b*	Cross-sectional survey	Children aged 36 months and under in public daycare centres of two municipalities located in the southeastern region of Brazil.	Gabriel Monteiro, São Paulo (2005 level: 0.60–0.75 ppm)	0.60–0.75	Clementina (0.40 ppm) and Gabriel Monteiro, São Paulo (year not reported; 0.60–0.75 ppm)	dmft, dmfs	68	Exposure age range: 8–36 months (23.63 ± 9.28) Comparator age range: 8–36 months (23.70 ± 8.30)	Not reported
Brazil	Silva *et al.* [98]	2021	Cross-sectional survey	Children aged 5 years (in daycare) and 12 years (in school).	Lifelong exposure to CWF via the piped water of Teresina, Piauí	0.5–0.6	Areas of Teresina, Piauí not connected to piped water supply (<0.05 ppm)	DMFT, D/M/F, dmft, d/m/f, % without CDC (0.92)	Total: 692 (5-year-olds: 330; 12-year-olds: 362)	Mean age not reported; children were aged 5 years and 12 years	Exposure: 5-year-olds: 48.4%; 12-year-olds: 48.9% Comparator: 5-year-olds: 44.4%; 12-year-olds: 55.4%
Canada	**Brown** [102]	**1951**	Cross-sectional survey	Schoolchildren aged at least 6 years but not more than 14 years, not absent from the city concerned for holidays or other reasons for more than 6 weeks at any one time.	Brantford, Ontario commenced CWF in June 1945 (1.0–1.2 ppm)–	1.0–1.2	Sarnia, Ontario (fluorine-free); Stratford, Ontario (1.3 ppm of fluorine from a natural source)	DMFT, % without CDC	Exposure: 1948: 1,807; 1951: 1,742 Comparator Sarnia: 1948: 1,726; 1951: 1,816; Stratford: 1948: 1,308	Mean age not reported/age range: 6–14 years	Not reported

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Canada	*Brown et al.* [83]	*1960*	Cross-sectional survey	''9–11-year-olds and 12–14-year-olds with 'continuous' residence in their respective cities, defined as including absences (since birth) of 6 weeks or less. Residence eligibility is determined from information supplied by the parents. All schools of each city were canvassed.	Brantford, Ontario commenced CWF in 1945 (1.0–1.2 ppm)–	1.0–1.2	Sarnia, Ontario (fluorine-free, negligible amount of fluoride) and Stratford, Ontario (1.3 ppm of fluorine from a natural source)	DMFT, % without CDC in primary and permanent teeth	1948: 3,048; 1959: 3,018	Mean age not reported/age range: 9–14 years	Not reported
Canada	Connor [86]	1963	Cross-sectional survey (census)	Schoolchildren aged 6–8 years, 9–11 years, and 12–14 years, who were continuous residents in each area.	Brandon, Manitoba: CWF commenced in March 1955 at 1.0 ppm	1.0	Fluoride deficient (survey in 1955 reported no baseline concentration, but reported that water was fluoride-free	DMFT	Exposure: 1960: 1,236; 1962: 1,212 Comparator: 1955: 994	Mean age not reported/age range: 6–14 years	Not reported
Canada	*Brown and Poplove* [85]	*1965*	Cross-sectional survey	All schoolchildren aged 16–17 years continuously resident in each city.	Brantford, Ontario commenced CWF in June 1945 (1.0–1.2 ppm)	1.0–1.2	Sarnia, Ontario (fluorine-free, negligible amount of fluoride) and Stratford, Ontario (1.3 ppm of fluorine from a natural source)	DMFT, % without CDC, tooth mortality rate, narrative report on dental fluorosis	Total: 1,065 Exposure: 356 Comparator: Sarnia: 482; Stratford: 227	Mean age not reported/age range: 16–17 years	Not reported

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Canada	Clovis *et al.* [113]	1988	Cross-sectional survey	Grade 6 schoolchildren in each community. The dental health of grade 6 children in two western Canadian communities was assessed as part of a primary investigation of their beverage intake.	Wetaskiwin, Alberta (fluoridated at 1.08 ppm)	1.08	Camrose, Alberta (fluoride deficient at 0.23 ppm)	dmft, dmfs	Exposure: 89 Comparator: 115	Mean age: 11.94 years (±0.65 years)	Exposure: 48.3% Comparator: 49.6%
Canada	Ismail *et al.* [89]	1990	Cross-sectional survey	Representative sample of public and private school students aged 11–17 years who were born and lived at least the first 6 years of their life in their respective city.	Trois Rivières, Quebec: three CWF levels over time (1.0–1.3 ppm in 1970–1979; 0.6–0.7 ppm in 1980–81; and 0.9–1.0 ppm in 1982–1987)	0.6–1.3	Sherbrooke, Quebec (0.1 ppm)	DMFS, % without CDC, dental fluorosis (by public or private school, no combined data) (>0.85)	936	Mean age not reported/age range: 11–17 years	Not reported, although it was collected
Canada	Ismail *et al.* [90]	1993	Cross-sectional survey (census)	Schoolchildren in grades 5 and 6 in the two towns were included. Specific ages were not reported, but the approximate age of children in grades 5 and 6is 10—11.	Kentville, Nova Scotia (CWF at 1.1 ppm from 1976 to 1991)	1.1	Truro, Nova Scotia (fluoride deficient; <0.1 ppm)	DMFS (inter: 0.72–0.75; intra: 0.78–0.92)—	80	Age was collected but not reported	Not reported, although it was collected
Canada	Clark *et al.* [112]	1995	Cross-sectional survey	Schoolchildren aged 6–14 years	Fluoridated city of Kelowna, British Columbia (1.2 ppm)	1.2	Fluoride-deficient city of Vernon, British Columbia (<0.1 ppm)	DMFS, % difference in DMFS from control (inter: 0.72; intra: 0.83)	483	Mean age not reported/age range: 6–14 years	Not reported, although it was collected
Canada	Maupomé *et al.* [163]	2001	Retrospective/ prospective cohort study (census)	Children in 2 groups, grades 2—3 and grades 8—9 for a two timepoint study, and lifetime residents in 2 additional groups, grades 5—6 and 11—12, for a single time point study.	Comox/Courtenay, British Columbia (1985–1992: 0.92 ppm (±0.21 ppm)), Campbell River, British Columbia (1985–1992: 0.88 ppm (±0.28 ppm)), and Kamloops, British Columbia (1982 to 1996–97: 0.95 ppm (±0.27 ppm)), cited in Maupomé, 2003	0.88 (±0.28) to 0.92 (±0.21)–	'Fluoridation ended' — no level reported	DMFS (inter: 0.74; intra: 0.80)	9857 in the two timepoint study, 2,994 in the single timepoint study	Mean age of grade 2 and 3 children: 8.2–8.3 years; mean age of grade 8 and 9 children: 14.3–14.4 years	1996–97: 51%; not reported in baseline

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Canada	**McLaren *et al.*** [138]	**2017**	Cross-sectional survey	Grade 2 children (aged approximately 7 years) attending school in the public or Catholic school systems in Calgary and Edmonton. These two systems captured more than 90% of the Alberta schoolchildren in 2013–14.	Edmonton, Alberta (1967–2013: 0.61–0.82 ppm)	0.61–0.82	Calgary, Alberta (1991: 0.59–0.89 ppm; after 2011: 0.07–0.30 ppm)	DMFT, deft, % with CDC, % without CDC	Not reported	Exposure: 2004–05: mean age: 7.08 years/age range: 5–10 years; 2013–14: mean age: 7.03 years/age range: 3–13 years Comparator: 2004–05: mean age: 7.09 years/age range: 5–12 years; 2013–14: mean age: 7.07 years/age range: 4–12 years	Not reported
Canada	*McLaren et al.* [94]	*2021*	Cross-sectional survey	Grade 2 children (aged approximately 7 years) enrolled in public or separate school systems in the cities of Calgary and Edmonton; in 2018–19, over 90% of all Alberta schoolchildren were enrolled in one of these systems.	Edmonton (CWF at 0.5–0.7 ppm from 2013–2019), Calgary (CWF 1967, 0.59–0.89 ppm 1991–2011), and from May 2011–2019 0.1-0.3 ppm	0.5–0.7	0.1-0.3 ppm	DMFT, DMFS, deft, defs, mean deft of ≥1, % with CDC, dental fluorosis (≥0.80 most of the time)	Exposure: 2,600, of whom 799 were permanent residents Comparator: 2,649, of whom 918 were permanent residents	Mean age not reported; children were aged approximately 7 years	Not reported, although it was collected

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Chile	Villa *et al.* [100]	1998	Cross-sectional survey	Children aged 7, 12, and 15 years attending public or private schools who were lifelong residents of one of the five areas.	San Felipe, Valparaíso (CWF since 1986 at 0.93 ppm)	0.93	Rancagua, O'Higgins (0.07 ppm), Santiago, Región Metropolitana (0.21 ppm (natural)), La Serena, Coquimbo (0.55 ppm (natural)), and Iquique, Tarapacá (1.10 ppm (natural))	DMFT, dmft, % without CDC, dental fluorosis (≥0.91)	2,431	Mean age not reported; children were aged 7, 12, and 15 years	51.2%
Cuba	Künzel [93]	1982	Cross-sectional survey	Children resident in study area	CWF elevated fluoride to a concentration of 0.7 ppm (±0.1 ppm); CWF levels varied between 1974 and 1979, with a mean of 0.61 ppm in 1974 and 0.78 ppm in 1979.	0.7 (±0.1)	Natural content of 0.05–0.10 ppm	DMFT, reduction in dental caries, % with CDC	1973: 258 children; 1980: 356 children	Mean age not reported/age range: 6–13 years	Not reported
Cuba	Künzel and Fischer [135]	2000	Cross-sectional survey	All children aged 6–13 years attending primary and secondary schools and who were born in the community were included.	The natural fluoride concentration of 0.05–0.10 ppm was raised to 0.70 ppm (average concentration of 0.79 ppm, with monthly variations between 0.57 and 1.64 ppm)	0.8	Various fluoride concentrations, with monthly variations between 0.57 and 1.64 ppm	DMFT, DMFS	414	Mean age not reported/age range: 7–13 years	Not reported
England, UK	Beal and James [109]	1971	Cross-sectional survey	Children aged 5 years; only children attending those schools that participated in the examination each year of the study were included.	Balsall Heath and Northfield in Birmingham (CWF introduced in 1964 at 1 ppm)	1.0	Dudley (fluoride deficient, with naturally occurring fluoride levels ranging from 0.02 to 0.09 ppm)	dft, % without CDC, % with CDC, % CDC reduction	2,218	Mean age: 5.5 years	Not reported

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
England, UK	Jackson *et al.* [128]	1975 b	Cross-sectional survey (census)	All children aged 5 years attending three infant school sites and a random sample of children aged 5 years from a larger site.	Workington and Cockermouth (1.0 ppm)	1.0	Carlisle and Penrith (<0.1 ppm)	dmft	236	Workington and Cockermouth 5.2 years, Carlisle and Penrith 5.1 years	Not reported
England, UK	**Rugg-Gunn *et al.*** [147]	**1977**	Cross-sectional survey	Caucasian schoolchildren aged 5 years who were continuous residents.	Urban Newcastle upon Tyne was fluoridated in 1968–69 (1.0 ppm) and rural Prudhoe, Ovingham, and Corbridge were fluoridated in 1969 (1.0 ppm)	1.0	Urban Ashington (<0.1 ppm); and rural Alnwick, Amble, and Rothbury (<0.1 ppm)	deft, defs, % without CDC	680	Mean age not reported; children were aged 5 years	49.9%
England, UK	Jackson *et al.* [127]	1980	Cross-sectional survey	Children aged 5 years who had continuously lived in the chosen districts.	Guiseley, Yeadon, and Rawdon (0.9 ppm)	0.9	Horsforth and Pudsey (0.1 ppm)	dmft, d/m/f, total dental caries in primary teeth	388	Mean age not reported; children were aged 5 years	Not reported
England, UK	Beal and Clayton [108]	1981	Cross-sectional survey	Children aged 5, 8, and 12 years who had continuity of residence.	Scunthorpe (CWF between 0.85 and 0.90 ppm)	0.85–0.90	The natural fluoride concentration in Corby was 0.35 ppm	DMFT, dmft	Not reported (approximately 200 in each of the three age groups, i.e. 600 total)	Mean age not reported; children were aged 5, 8, and 12 years	Not reported
England, UK	*Rugg-Gunn et al.* [148]	*1981*	Cross-sectional survey	Children aged 5 years who had lived in the chosen area throughout their lives.	Children examined in 1975–76 in Newcastle upon Tyne (1.0 ppm)	1.0	Houghton (natural fluoride concentration of 0.2 ppm); Sunderland/South Tyneside (natural fluoride concentration of 0.5 ppm); and Ashington (<0.1 ppm)	deft, defs	941	Newcastle upon Tyne: mean age: 5.6 years Sunderland/South Tyneside: mean age: 5.5 years Houghton: mean age: 5.6 years Ashington: mean age: 5.5 years	Not reported

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
England, UK	Hardwick *et al.* [122]	1982	Retrospective/ prospective cohort study	Schoolchildren aged 12 years	Alsager, Middlewich, and Nantwich areas of Cheshire before and after the introduction of CWF (1.0 ppm), yearly for 4 years	1.0	Northwich (<0.1 ppm)	DMFT, DMFS, % CDC reduction	343	Mean age: 12 years, 4 months	Not reported
England, UK	*French et al.* [117]	*1984*	Cross-sectional survey	Children aged 5 years, who had been continuously resident in their 'school's locality and whose parents consented, were examined.	Newcastle upon Tyne (1.0 ppm)	1.0	Northumberland water containing less than 0.1 ppm of fluoride	dmft, dmfs	1,069	Mean age not reported; children were aged 5 years	Exposure: 52% Comparator: 55%
England, UK	*Rugg-Gunn et al.* [146]	*1988*	Cross-sectional survey	5-year-old Caucasian schoolchildren who were continuous residents of their respective areas.	Newcastle upon Tyne (1.0 ppm since 1968–69). Data collection occurred in January and February 1987.	1.0	Ashington, Blyth, Morpeth, and Newbiggin, South Northumberland (<0.1 ppm)	deft, defs	693	Mean age not reported; children were aged 5 years	Exposure: 52% Comparator: 50%
England, UK	Mitropoulos *et al.* [139]	1988	Cross-sectional survey	Children aged 14 years who attended state-maintained schools in the two selected health districts.	South Birmingham (1.0 ppm)	1.0	Bolton (<0.1 ppm)	DMFT	Total: 509 Exposure: 234 Comparator: 275	Mean age: 14.4 years	Not reported
England, UK	Murray *et al.* [141]	1991	Cross-sectional survey	Children aged 15–16 years from all three locations.	Hartlepool (1.0–1.3 ppm); Newcastle upon Tyne (1.0 ppm)	1.0–1.3 –	Middlesbrough (<0.1 ppm)	DMFS, DMFT, % without CDC	1,374	Mean age: 15.8 years	Not reported
England, UK	Booth *et al.* [110]	1992	Cross-sectional survey	Children aged 3 years who had lived in the respective areas their whole lives.	Huddersfield (1.0 ppm)	1.0	Dewsbury (<0.3 ppm)	dmft	238	Mean age not reported; children were aged 3 years	Not reported
England, UK	*Evans et al.* [116]	*1995*	Cross-sectional survey	Children of white ethnicity aged 5 years who had lived continually in their respective areas.	Newcastle upon Tyne (0.9–1.0 ppm)	0.9–1.0	Morpeth, Ashington, Newbiggin, and Blyth, South Northumberland (<0.1 ppm)	dmft, dmfs, % with CDC	932	Exposure: mean age: 5.51 years Comparator: mean age: 5.50 years	Exposure: 49% Comparator: 49%

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
England and Wales, UK	**Ellwood and 'O'Mullane** [115]	1995	Cross-sectional survey	Pupils in the third year of their secondary school education and who were lifetime residents of their respective areas.	Lifetime residents of Anglesey, North Wales (0.7 ppm)	0.7	Lifetime residents of Chester, England and Bala, North Wales (<0.1 ppm)	DMFS (>0.81)	Exposure: 196 Comparator: 267	Mean age: 14.1 years	Not reported
England, UK	*Evans et al.* [66]	*1996*	Cross-sectional survey	Children aged 5 years	Newcastle upon Tyne (1.0 ppm)	1.0	Southeast Northumberland (<0.1 ppm)	dmft	662	Exposure: mean age: 5.49 years Comparator: mean age: 5.50 years	Not reported
England and Wales, UK	*Ellwood and 'O'Mullane* [88]	*1996*	Cross-sectional survey	Schoolchildren in the third year of their secondary school education who were lifetime residents of their respective areas.	North Wales (0.7 ppm)	0.7	Chester (England) and Bala (North Wales) (<0.1 ppm)	DMFS, dental fluorosis	Exposure: 196 Comparator: 267	Mean age: 14.1 years (±0.3 years)	Not reported
England, UK	Gray and Davies-Slowik [119]	2001	Cross-sectional survey	Not reported	Dudley, Sedgley, Coseley; Brierley Hill, Kingswinford and Halesowen, towns in the Borough of Dudley (1.0 ppm)	1.0	Stourbridge, Borough of Dudley (<0.3 ppm)	% dmft=0	Exposure: 2,614 Comparator: 419	Not reported	Not reported

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
England, UK	Goodwin *et al.* [58]	2022	Retrospective/ prospective cohort study	Lifetime residents of Cumbria, divided into two distinct recruited populations: (1) a birth cohort (aged 0–5 years, examined at the ages of 3 and 5 years), and (2) an older school cohort (aged 5–11 years).	West Cumbria (fluoridated)	0.9	Carlisle, Barrow-in-Furness, Eden and South Lakeland Districts (usually <0.2 ppm)	DMFT, dmft– (0.75–1.0)	2,636 (West Cumbria 1,444, Carlisle, Barrow-in-Furness, Eden and South Lakeland Districts 1,192)	Mean Age: Birth cohort: West Cumbria 4.88 Carlisle, Barrow-in-Furness, Eden and South Lakeland Districts 4.79 Older cohort: West Cumbria 10.80, Carlisle, Barrow-in-Furness, Eden and South Lakeland Districts 10.80	Birth cohort: 47.6% Older cohort: 44.5%
Finland	**Parviainen *et al.*** [145]	1977	Cross-sectional survey	Schoolchildren aged 13–15 years who visited municipal dental clinics across three towns with varied fluoride levels.	Kuopio (CWF at 1.0 ppm since 1959)	1.0	Jyväskylä (0.2 ppm) and Hamina (natural fluoride content of 2.5–5.0 ppm)	DMFS (decayed or filled permanent surfaces (DFS) analyses only due to very few missing teeth in either group)	Not reported	Mean age: 14 years	45%
Finland	Hausen *et al.* [123]	1981	Retrospective/ prospective cohort study	7–16-year-old children who were assessed in dental health centres over the course of 1 year.	Artificially fluoridated tap water (1.0–1.2 ppm)	1.0–1.2	Fluoride-deficient water (0.0–0.2 ppm), local fluoride preventives, mainly fluoride rinses	DMFT, DMFP (proximal), % new dental caries	2,778	Mean age not reported/age range: 7–16 years	Not reported (data adjusted for age and sex)

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Finland	*Parviainen et al.* [144]	*1985*	Cross-sectional survey	Schoolchildren aged 13–15 years across three towns with varied fluoride levels.	Kuopio (CWF at 1.0 ppm since 1959)	1.0	Jyväskylä (0.2 ppm) and Hamina (natural fluoride content of 2.5–5.0 ppm)	DFS	Not reported	Mean age: 14 years	50.7%
Finland	Linkosalo [137]	1986	Cross-sectional survey	Schoolchildren aged 7, 11, and 15 years who were lifelong residents in fluoridated and fluoride-deficient towns in Finland.	Kuopio (CWF at 1.0 ppm since 1959) and where no topical fluoride interventions were performed during the study period.	1.0	Pieksämäki (0.0–0.1 ppm); all children used a 0.2% fluoride rinse solution, issued for low-fluoride areas.	DMFT, DMFS (reported for each tooth surface; 0.76–1.00)	Not reported	Mean age not reported; children were aged 7, 11, and 15 years	Not reported
Finland	**Seppä *et al.*** [153]	**1996**	Cross-sectional survey	12-year-old children in two Finnish towns.	Kuopio (1.0 ppm since CWF began in 1959 until it was discontinued in 1992)	1.0	Jyväskylä (0.1 ppm)	DMFS	Total: 154 Kuopio: 77 Jyväskylä: 77	Mean age: 12 years	Not reported
Finland	*Seppä et al.* [152]	*1998*	Cross-sectional survey	Random samples of all children aged 6, 9, 12, and 15 years were compared in 1992 and 1995 (after CWF was discontinued).	Kuopio (1.0 ppm since CWF began in 1959 until it was discontinued in 1992; 0.1 ppm after CWF was discontinued)	1.0	Jyväskylä (0.1 ppm)	DMFS (inter: 0.82–0.90; intra: 0.83–0.92)–	1992 550 1995 1198	1992: 7.2 years; 1995: 8.7 years	Not reported
Finland	*Seppä et al.* [150]	*2000 a*	Cross-sectional survey	Children were compared in 1992, 1995, and 1998 in Kuopio and un-fluoridated Jyväskylä.	Kuopio (1.0 ppm since CWF began in 1959 until it was discontinued in 1992; 0.1 ppm after CWF was discontinued)	1.0	Jyväskylä (0.1 ppm)	DMFS, dmfs, % without CDC—(inter: 0.77–0.90; intra: 0.72–0.92, over the 3 timepoints)	1992: 688 1995: 1,484 1998: 1,530	1992: 8.92 years 1995: 8.99 years 1998: 9.09 years	Not reported
Finland	*Seppä et al.* [151]	*2000 b*	Cross-sectional survey	Independent random samples of all children aged 3, 6, and 9 years in 1992 and 1995 after CWF was discontinued in Kuopio, and in non-fluoridated Jyväskylä.	Kuopio (1.0 ppm since CWF began in 1959 until it was discontinued in 1992; 0.1 ppm after CWF was discontinued)	1.0	Jyväskylä (0.1 ppm)	dmfs, mean difference–(inter: 0.86–0.94; intra: 0.88–0.91, over the 2 timepoints)	1992: 688 1995: 1,484	1992: 7.2 years 1995: 8.7 years	Not reported

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Finland	*Seppä et al.* [154]	*2002*	Cross-sectional survey (census)	In 1992, 1995, and 1998, independent random samples of children aged 3, 6, 9, 12, and 15 years in Kuopio (tap water fluoridated at 1.0 ppm from 1959 to 1992; fluoride concentration after CWF ended is 0.1 ppm) and Jyväskylä (natural fluoride concentration of 0.1 ppm).	Kuopio (1.0 ppm since CWF began in 1959 until it was discontinued in 1992; 0.1 ppm after CWF was discontinued)	1.0	Jyväskylä (0.1 ppm)	Placement of a filling (proxy) for particular teeth, no full mouth data	1,503	Mean age not reported; children were aged 3, 6, 9, 12, and 15 years	Not reported (data adjusted for age and sex)
Germany	**Künzel** [133]	**1968**	Cross-sectional survey	Children aged 6–15 years and lifetime residents.	Karl-Marx-Stadt (now Chemnitz) (CWF at 1.0 ppm since 1959)	1.0	Plauen (0.12–0.16 ppm)	DMFT	Not reported	Mean age not reported/age range: 6–15 years	Not reported, although it was collected
Germany	*Künzel* [134]	*1980*	Cross-sectional survey	Kindergarten children aged 3–8 years and schoolchildren aged 6–15 years.	Karl-Marx-Stadt (now Chemnitz) (CWF at 1.0 ppm since 1959). From 1973 until 1977, the fluoride concentration varied between 0.66 and 0.92 ppm. In 1978, the optimal value of 1.0 ppm (±0.1 ppm) was restored.	1.0	Plauen (0.2 ppm)	DMFT, dft	6–15-year-olds: 20,000; 3–8-year-olds: 12,000	Mean age not reported; children were aged 6–15 years and 3–8 years	Not reported
Germany	*Künzel and Fischer* [132]	*1997*	Cross-sectional survey	Schoolchildren aged 6–15 years	Karl-Marx-Stadt (now Chemnitz) (CWF at 1.0 ppm from 1959 to 1990)	0.9–1.1	Chemnitz (formerly Karl-Marx-Stadt) after CWF ended in 1990 (naturally occurring fluoride concentration is 0.12 ppm) and Plauen (0.12–0.16 ppm)	DMFT, DMFS, % without CDC (inter: 0.95; intra: 0.89–92.7)–	Chemnitz: 219,594 Plauen: 66,582	Mean age not reported/age range: 6–15 years	Not reported

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Germany	Künzel *et al.* [162]	2000	Cross-sectional survey	Schoolchildren aged 8–9, 12–13, and 15–16 years, examined repeatedly over the course of 20 years.	Spremberg had CWF from 1972 to 1993, with monthly average fluoride concentrations of 1.14–1.20 ppm for 1980–81, but fluoride-enriched water never reached the domestic consumers. This fact emerged in 1981. Problems were solved in 1982–83 and the CWF became effective (0.8–1.0 ppm). CWF ceased at the end of 1993; the natural fluoridation level –of the municipality's water is 0.12–0.19 ppm.	0.8–1.0, with intermittent major fluctuations	Zittau had CWF from 1975 to 1993, with a fluoride concentration of 0.9 ppm in 1980–1983. Due to technical problems, the concentration was maintained at ±10% until 1993, when CWF ceased (natural – fluoridation level is 0.12–0.19 ppm).	DMFT and DMFS, % without CDC, % with CDC, % CDC — reduction/increase (inter: 88.9–97.6%; intra: 91.4–97.5%; not Kappa)	Exposure: 9,042 Comparator: 6,232	Mean age not reported; children were aged 8–9, 12–13, and 15–16 years	Not reported
Ireland	Lemasney *et al.* [136]	1984	Cross-sectional survey	5-year-old and 11-year-old schoolchildren who were lifetime residents of their respective areas.	Limerick had CWF since 1966 (0.8–1.0 ppm), but the supply was interrupted from April 1975 to May 1976.	0.8–1.0	Fluoride-deficient water in Ireland has a fluoride concentration of ≤0.3 ppm.	DMFT, dmft, % without CDC, % reduction/increase (inter: 0.96–0.98; intra: 0.98–1.00)—	575	5-year-olds: 5 years, 2 months 11-year-olds: 11 years, 6 months	5-year-olds: 51% 11-year-olds: 50%

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Ireland	**’O’Mullane *et al.*** [143]	**1986**	Cross-sectional survey	5-, 8-, 12-, and 15-year-old schoolchildren living in the sample health board areas in 1984 compared with children pre-fluoridation (1961–1963).	Full CWF at 0.8–1.0 ppm since birth; may have had exposure to fluoride tablets or mouth rinses.	0.8–1.0	Fluoride-deficient areas (≤0.3 ppm) (35% of the population in 1984), no fluoride tablets or mouth rinses	DMFT, DMFS, dmft, dmfs, % without CDC (>0.95 correlation coefficients)	Baseline (1961–63): 26,043 Final (1984): 3,209 (5- and 12-year-olds only)	Exposure: 5-year-olds: 4.7, 8-year-olds: 7.9 years; 12-year-olds: 11.9 years; 15-year-olds: 14.8 years Comparator: 5-year-olds: 4.8 years; 8-year-olds: 7.9 years; 12-year-olds: 11.9 years; 15-year-olds: 15.0 years	Exposure: 5-year-olds: 49.5%, 8-year-olds: 54.6%, 12-year-olds: 58.8%, 15-year-olds:65.7% Comparison: 5-year-olds: 46%, 8-year-olds: 50.0%, 12-year-olds: 46.5%, 15-year-olds: 52.4%
Ireland	*’O’Mullane et al.* [142]	*1988*	Cross-sectional survey	5-, 8-, 12-, and 15-year-old schoolchildren living in the sample areas in 1984 compared with children in fluoride-deficient areas in 1984 and in 1961 and 1963.	Between 1964 and 1972, all major urban domestic water supplies were fluoridated. In 1986, 65% of domestic water supplies were fluoridated to 0.8–1.0 ppm.	0.8–1.0	Fluoride-deficient water in Ireland has a fluoride concentration of ≤0.3 ppm.	DMFT, dmft (>0.95 correlation coefficients)	1984: 5,970 1961 and 1963: 43,918	Exposure: 5-year-olds: 4.7 years; 8-year-olds: 7.9 years; 12-year-olds: 11.9 years; 15-year-olds: 14.8 years Comparator: 5-year-olds: 4.8 years; 8-year-olds: 7.9 years; 12-year-olds: 11.9 years; 15-year-olds: 15.0 years	Not reported

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Ireland	Whelton *et al.* [53]	2004	Cross-sectional survey	5-, 8-, 12-, and 15-year-old schoolchildren living in the Republic of Ireland.	–0.8–1.0 ppm	0.8–1.0	Fluoride-deficient water in Ireland has a fluoride concentration of ≤0.3 ppm.	DMFT, dmft, Visual DMFT, visual dmft, dental fluorosis	Total: 17,851 (5-year-olds: 6,661; 8-year-olds: 3,769; 12-year-olds: 3,886; 15-year-olds: 3,535)	5-year-olds: 5.3 years; 8-year-olds: 8.4 years; 12-year-olds: 12.4 years; 15-year-olds: 15.2 years	50% (5-year-olds: 51%; 8-year-olds: 50%; 12-year-olds: 49%; 15-year-olds: 50%)
Ireland	Mullen *et al.* [140]	2012	Cross-sectional survey	16-year-olds	Estimated from percentage lifetime exposure to CWF using the history of residency since birth using a four-point scale to score each month using recorded ppm levels: 1 (<0.3 ppm (imputed as 0.0 ppm)), 2 (0.3–0.7 ppm (imputed as 0.5 ppm)), 3 (0.7 and above (imputed as 1.0 ppm)), 4 (unknown) and then overall percentage banded into four categories, no exposure, low, medium and high. High group used as intervention group.	0.7–1.0	Estimated from percentage lifetime exposure to CWF using the history of residency since birth No exposure group used as comparator (<0.3 ppm (imputed as 0.0 ppm)	DMFT, dmft (>0.80)	Total: 1,403 Exposure: 719 Comparator: 684	Exposure: 16.41 years Comparator: 16.51 years	54%

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Ireland	James *et al.* [52]	2021	Cross-sectional survey	Random sample of 5-year-old schoolchildren in counties Dublin, Cork, and Kerry in 2014; follow-up at age 8 years in 2017.	Counties Dublin, Cork, and Kerry: 2002: 0.8–1.0 ppm; 2017: 0.6–0.8 ppm	2002: 0.8–1.0 ppm; 2017: 0.6–0.8 ppm	Fluoride-deficient counties Cork and Kerry (≤0.3 ppm)	dmft, d(visual caries in enamel and dentine)mft (in canines, first and second primary molars) >0, odds ratio (OR) for dental caries, dental fluorosis (intra: 0.86–1.00 in 2002; 0.77–1.00 in 2017)	Exposure: Dublin: 679 (2002), 707 (2017); counties Cork and Kerry with CWF: 332 (2002), 376 (2017) Comparator: counties Cork and Kerry without CWF 233 (2002); 772 (2017)	Exposure: Dublin: 8.3 years (2002), 8.2 years (2017); counties Cork and Kerry with CWF: 8.4 years (2002), 8.3 years (2017) Comparator: counties Cork and Kerry without CWF 8.5 years (2002), 8.4 years (2017)	Exposure: Co Dublin: 47% (2002), 54% (2017); counties Cork and Kerry with CWF: 55% (2002), 53% (2017) Comparator: counties Cork and Kerry without CWF 56% (2002), 51% (2017)
Malaysia	Mohd Nor *et al.* [97]	2018	Cross-sectional survey	Schoolchildren aged 9 years (born in 2006) and 12 years (born in 2003), and lifelong residents were included in the final analysis.	Negeri Sembilan had CWF since 1972 at 0.7 ppm; this was reduced to 0.5 ppm in December 2005.	0.7 from 1972, reduced to 0.5 in 2005	Kelantan (described and confirmed as fluoride deficient (0 ppm))	DMFT	1,155	Mean age not reported; children were aged 9 and 12 years	56.5%
Netherlands	**Backer Dirks *et al.*** [4]	**1961**	Cross-sectional survey	Children aged 7–15 years. Only children who had been born and had lived in their respective areas ever since (except for holidays) and had used the tap water supply were included in the study.	Tiel: CWF since 1953 (1.1 ppm)	1.1	Culemborg: fluoride deficient (0.1 ppm)	Decayed surfaces, individual surfaces only, approximal surface by X-ray only	200	Mean age not reported/age range: 7–15 years	50%

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Netherlands	*Groeneveld* [120]	*1985*	Retrospective/ prospective cohort study	Children were followed from the age of 7 years until they were aged 18 years. Data from Backer Dirks *et al.*'s 1961 study were used. All children were born in 1953, the same year CWF in Tiel started.	Tiel, with children having used fluoridated water from birth (1.1 ppm)	1.1	Culemborg (0.1 ppm)	Dental caries by number of buccal, approximal, and all surfaces, % reduction in dental caries by surface	Exposure: 93 Comparator: 103, examined longitudinally	Mean age not reported; children were aged 7, 9, 11, 13, 15, and 18 years	Not reported
Netherlands	*Kalsbeek et al.* [131]	*1993*	Cross-sectional survey	Children aged 15 years	Tiel: CWF since 1953 (1.1 ppm); children aged 15 years in 1968–69 had used fluoridated water from birth (1.1 ppm)	1.1	Tiel post-CWF (1979–1988); Culemborg (fluoride deficient, 0.1 ppm)	DMFT, DMFS, all carious surfaces (0.89, 0.99, 0.99, and 0.91 for DS, filled surfaces, DFS, and total dental caries lesions, respectively)	Exposure: 285 Comparator: Tiel: 1979/80; 369, 1981/82: 368, 1983/84: 376, 1985/86: 356, 1987/88: 297 Culemborg 1979/80; 246, 1981/82: 221, 1983/84: 281, 1985/86: 244, 1987/88: 241	Mean age not reported; children were aged 15 years	Not reported
Netherlands	*Weerheijm et al.* [161]	*1997*	Cross-sectional survey	Children aged 15 years (data from Backer Dirks *et al.*'s 1961 study were used).	Tiel: CWF since 1953 (1.1 ppm); children had used fluoridated water from birth	1.1	Culemborg: fluoride deficient (0.1 ppm)	DS, FS, recurrent DS (inter: 0.90; intra: 0.83–0.85)	515	Mean age not reported; children were aged 15 years	Not reported
New Zealand	de Liefde and Herbison [114]	1985	Cross-sectional survey	Children aged 9 years in fluoridated and fluoride-deficient towns in New Zealand.	Hastings (1.0 ppm)	1.0	Napier and nearby towns and rural area (0.2 ppm)	DMFT	666	Mean age: 9 years, 8 months	Not reported (little sex variation)
New Zealand	**Treasure and Dever** [159]	**1992**	Cross-sectional survey	Children aged 5 years (having had a fifth birthday but not a sixth), with continuity of residence (excluded if outside the urban area).	Ashburton, Canterbury and Dunedin, Otago, which are both fluoridated to a concentration of 1.0 ppm	1.0	Oamaru, Otago, which has never been fluoridated	dmft, dmfs, % without CDC	342	Mean age not reported; children were aged 5 years	Exposure: 52% Comparator: 47%

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
New Zealand	*Treasure and Dever* [160]	*1994*	Cross-sectional survey	14-year-old schoolchildren in fluoridated and non-fluoridated areas in New Zealand.	Dunedin, Otago (1.0 ppm) and Ashburton, Canterbury (1.0 ppm)	1.0	Oamaru, Otago (never fluoridated), Timaru, Canterbury (fluoridation ceased in 1985)	DMFT and DMFS	413	Mean age not reported; children were aged 14 years	Exposure: 51% Comparators: Timaru, Canterbury: 59%; Oamaru, Otago: 42%
New Zealand	Ministry of Health [96]	2010	Cross-sectional survey	In households, one adult aged ≥15 years and one child aged 0–14 years (if any) were randomly selected for the survey.	Average fluoride concentration around 0.8–0.9 ppm in fluoridated areas	0.8–0.9	Average fluoride concentration around 0.15 ppm in fluoride-deficient areas	DMFT/S, dmft/s (mixed dentition data only), % without CDC, mean difference (MD), mean ratio, dental fluorosis (≥0.78 ICC)	3,196 (987 children and 2,209 adults)	Mean age not reported/age range: children: 0–14 years; adults: ≥15 years	Children: 48% Adults aged 18 years or over: 61%
Scotland, UK	Stephen *et al.* [155]	1987	Cross-sectional survey (census)	5–6-year-old children living in Wick	1.0 ppm in Wick (CWF from 1974 to 1979)	1.0	0.02 ppm in Wick in 1979 (following cessation of CWF)	dmft, dmfs, % without CDC, % difference, canine and molars only (Intra: no significant difference found for dmft *p*=0·926 or dmfs *p*=0· 934)	232	Mean age not reported; children were aged 5–6 years	Not reported

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Singapore	Wong *et al.* [101]	1970	Cross-sectional survey	Chinese and Malay children in two age groups (aged 7–8 years and aged 8–9 years) were selected by random sampling from primary schools in various parts of the island.	Fluoridation was phased in between 1956–1958, the entire water supply of Singapore was fluoridated as of January 1958. The fluoride concentration was 0.7 ppm.	0.7	Before fluoridation, the fluoride concentration was 0.2 ppm.	DMFT, def	2,200 up until 1965, and 1,100 thereafter	Exposure: 7–8-year-olds: 7.5–7.7 years; 8–9-year-olds: 8.4–8.6 years Comparator: 7–8-year-olds: 7.6–7.7 years; 8–9-year-olds: 8.4–8.6 years	Not reported
Taiwan	**Hsieh *et al.*** [124]	**1972**	Cross-sectional survey (census)	Children aged 3–15 years living in either village.	Chung-Hsing New Village prior to fluoridation: 0.07 ppm (baseline)	0.07	Tsao-tun (now Caotun) (0.08 ppm)	DMFT, deft, d/e/f, D/M/F, % with CDC	Exposure: 5,118 Comparator: 5,298	Mean age not reported/age range: 3–15 years	Exposure: 49.5% Comparator: 46.2%
Taiwan	*Hsieh et al.* [125]	*1979*	Cross-sectional survey (census)	Children aged 3–15 years who were continuous residents of their respective areas. All non-lifetime residents were excluded.	Chung-Hsing New Village: 0.6 ppm since 1972	0.6	Tsao-tun (now Caotun) (0.08 ppm)	DMFT, df, % change	Exposure: 4,150 Comparator: 4,060	Mean age not reported/age range: 3–15 years	Exposure: 49.1% Comparator: 48.7%
Taiwan	*Guo et al.* [121]	*1984*	Cross-sectional survey (census)	Children aged 3–15 years who were born in or continuous residents of their respective areas. All non-lifetime residents were excluded.	Chung-Hsing New Village: 0.6 ppm	0.6	Tsao-tun (now Caotun) (0.08 ppm)	DMFT, df	Exposure: 2,995 Comparator: 4,438	Mean age not reported/age range: 3–15 years	Exposure: 49.8% Comparator: 49.9%
Taiwan	*Hsieh et al.* [126]	*1986*	Cross-sectional survey (census)	Children aged 3–15 years who were born in or continuous residents of their respective areas. All non-lifetime residents were excluded.	Chung-Hsing New Village: 0.6 ppm	0.6	Tsao-tun (now Caotun) (0.08 ppm)	DMFT, df, % df, % with 1 or more dental caries, % change	Exposure: 3,459 Comparator: 4,610	Mean age not reported/age range: 3–15 years	Exposure: 46.9% Comparator: 50.8%
USA	**Ast *et al.*** [105]	**1950**	Cross-sectional survey (census)	Children aged 6–12 years with continuous residence in their respective cities.	Newburgh, New York: CWF since 1945 (1.0–1.2 ppm)	1.0–1.2	Kingston, New York's water supply remains fluorine free.	DMFT	Exposure: ~3,400 Comparator: ~2,800	Mean age not reported/age range: 6–12 years	Not reported

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
USA	*Ast et al.* [104]	*1951*	Cross-sectional survey (census)	All 5–12-year-old children present at school on days of examination; residents of study areas with no period of residency required.	Newburgh, New York: CWF since 1945 (1.0–1.2 ppm)	1.0–1.2	Kingston, New York (<0.1 ppm)	DMFT, % without CDC in first molars, % D/F/M, df, % primary dental caries, % without CDC in primary teeth	5,078	Mean age not reported/age range: 5–12 years	Not reported
USA	***Arnold et al.*** [103]	**1953**	Cross-sectional survey	Children aged 4–16 years who were continuous residents in their respective areas.	Grand Rapids, Michigan: CWF since 1945 (0.9–1.1 ppm)	0.9–1.1	Muskegon, Michigan (<0.2 ppm until July 1951, 1.0 ppm from 1952 to 1954) and Aurora, Illinois (natural fluoride concentration of 1.2 ppm)	DMFT, deft	1951: Exposure: 4,590 Comparator: 2,192	Mean age not reported/age range: 4–16 years	Not reported
USA	*Ast and Chase* [107]	*1953*	Cross-sectional survey (census)	All elementary school age children (5–12 years) in both cities.	Newburgh, New York: CWF since 1945 (1.2 ppm)	1.2	Kingston, New York (0.1 ppm)	DMFT	Approximately 3,200 children in each city	Mean age not reported/age range: 6–12 years	Not reported
USA	*Ast et al.* [106]	*1955*	Cross-sectional survey	Children aged 6–10 years (in grades 1–5) in the selected schools.	Limited to those who had used Newburgh, New York water since the introduction of sodium fluoride (fluoride concentration of 1.0–1.2 ppm)	1.0–1.2	Kingston, New York (<0.15 ppm)	DMFT, % without CDC in primary teeth, % difference	Exposure: 382 Comparator: 374	Mean age not reported/age range: 6–10 years	Not reported
USA	*Arnold et al.* [84]	*1956*	Cross-sectional survey	Kindergarten and schoolchildren aged 4–16 years who had used city water supplies continuously since birth.	Grand Rapids, Michigan: CWF since 1945 (1.0 ppm (range: 0.9–1.1 ppm))	0.9–1.1	Muskegon, Michigan (<0.2 ppm until July 1951, 1.0 ppm from 1952 to 1954) and Aurora, Illinois (natural fluoride concentration of 1.2 ppm)	deft, DMFT, % primary and permanent teeth without CDC	1954: Exposure: 5,148 Comparator: 2,923	Mean age not reported/age range: 4–16 years	Not reported

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
USA	Szpunar and Burt [99]	1988	Cross-sectional survey	6–12-year-old schoolchildren	Redford, Michigan (CWF at 1.0 ppm)	1.0	Natural fluoride: Richmond, Michigan (1.2 ppm), Cadillac, Michigan (0.0 ppm), and Hudson, Michigan (0.8 ppm); fluoride mouth rinses	DMFT and DMFS, % without CDC (0.92)	380 of 556 included in analysis Exposure: 249 Comparator: 131 (Cadillac only (0.0 ppm))	Mean age not reported/age range: 6–12 years	Exposure: 49% Comparator: 57%
USA	*Kumar et al.* [91]	*1989*	Cross-sectional survey	7–14-year-old schoolchildren. Children with orthodontic bands or only deciduous teeth, or who were not lifetime residents of their respective cities, were excluded.	Newburgh, New York: CWF at 1.0 ppm except for a 3-year period from 1978 to 1981	1.0	Kingston, New York (0.3 ppm)	DMFT	884 included in analysis	Mean age not reported/age range: 7–14 years	Not reported, although it was collected
USA	*Kumar et al.* [92]	*1998*	Cross-sectional survey	Schoolchildren in grades 1–8 (aged 7–14 years) who had been lifelong residents of their respective cities.	Newburgh, New York: CWF since 1945 at 1.0 ppm (±0.2 ppm) except for a 3-year interruption between 1978 and 1981	0.8–1.2	Kingston, New York (<0.3 ppm)	DMFS (by poor or non-poor; no combined data) (>0.87)	1,493	Mean age not reported/age range: 7–14 years	Exposure: 51.0% Comparator: 49.2%
USA	Gillcrist *et al.* [118]	2001	Cross-sectional survey	Children aged 5–11 years residing in 62 of 119 East Tennessee communities, attending public elementary schools during the 1996–97 school year.	'Optimally fluoridated communities' (1.0 ppm)	1.0	Fluoride-deficient communities (<0.3 ppm)	DMFS, dfs	Exposure: 10,495 Comparator: 6,761	Exposure: mean age: 8.0 years Comparator: mean age: 8.2 years	Exposure: 48.0% Comparator: 47.7%
Wales, UK	**Jackson *et al.*** [130]	**1975a**	Cross-sectional survey	5- and 15-year-olds living in Anglesey and in Bangor and Caernarfon.	Anglesey (0.9 ppm)	0.9	Bangor and Caernarfon (<0.1 ppm)	DMFT, DMFS, dmft, dmfs, restorative index	Exposure: 5-year-olds: 153; 15-year-olds: 88 Comparator: 5-year-olds: 145; 15-year-olds: 97	Mean age not reported; children were aged 5 and 15 years	Not reported

Country	Author*	Year	Study design (design effect, if reported)	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Dental caries outcome measurement (and agreement, if reported†)	Sample in analysis as reported by authors	Mean age/age range	Percentage female
Wales, UK	*Jackson et al.* [129]	*1985*	Cross-sectional survey	Children aged 5, 12, and 15 years who were continuous residents of Anglesey (Welsh: Môn) and Gwynedd (Welsh: Arfon)	Anglesey (Welsh: Môn) (0.9 ppm)	0.9	Gwynedd (Welsh: Arfon) (0.01 ppm)	DMFT, dmft, d/m/f, restorative index, % difference	Exposure: 556 Comparator: 329	Mean age not reported; children were aged 5, 12, and 15 years	Not reported
Wales, UK	Seaman *et al.* [149]	1989	Cross-sectional survey	5-year-old children	Anglesey (0.8 ppm)	0.8	Mainland Gwynedd County (<0.1 ppm)	dmft, % without CDC, % with CDC, MD (0.86)	Exposure: 260 Comparator: 546	Mean age: 5.5 years	Not reported
Wales, UK	Thomas and Kassab [156]	1992	Cross-sectional survey	Mothers attending a maternity hospital who were permanent residents (had not lived outside the specific area for more than 2 years).	Anglesey (0.9 ppm)	0.9	Mainland Gwynedd County (<0.1 ppm)	DMFT, DMFS	1,083	Exposure: <20-year-olds: 18.10 years; 20–24-year-olds: 22.07 years; 25–29-year-olds: 26.63 years; 30–32-year-olds: 30.70 years Comparator: <20-year-olds: 18.10 years; 20–24-year-olds: 22.17 years; 25–29-year-olds: 26.9 years; 30–32-year-olds: 30.94 years	100%

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

†Intra = the agreement between different examiners, Inter = the agreement of one examiners' repeated measurements

3.1.3 Study quality: dental caries

3.1.3.1 Primary dentition

With regard to design and implementation, the quality assessment of the 52 papers reporting cross-sectional surveys (34 studies) and 1 retrospective/prospective cohort paper/study reporting on the primary dentition (Table 10) indicated that 3 papers/studies were of high quality [52,94,98], 19 papers (12 studies) were of moderate quality [53,58,66,83,96,100,110,116,121,124–126,129,142,143,146,157–159], and 31 papers (24 studies) were of low quality [84,86,87,93,95,101–104,106–109,111,117–119,127,128,130,133,134,136,138,144,147–151,155] (Table 10; also see Appendix H of Section 6). The total number of studies exceeds 35 here as one study with 6 linked papers had three papers with moderate quality [66,116,146] and three papers with low quality [117,147,148], one study with two linked papers had one paper with moderate quality [83] and one paper with low quality [102], a second study also with two linked papers had one paper with moderate quality [129]and one paper with low quality [130], and finally one study with two linked papers had one paper with high quality [94]and one paper with low quality [138]. For high and moderate quality papers, the main weaknesses in quality assessment were an inability to complete a follow-up due to study design and an incomplete control for the five groups of confounding factors. The low quality studies had significant weaknesses in most areas including eligible population, participation rate, inclusion criteria, inability to complete a follow-up, and confounding, and it was not possible to fully trust the findings.

3.1.3.2 Permanent dentition

With regard to design and implementation, the quality assessment of the 64 papers reporting cross-sectional surveys (40 studies) and 5 papers reporting retrospective/prospective cohort studies (4 individual papers/studies [58,122,123,163] and one paper [120] linked to other papers reporting cross-sectional surveys in one study) reporting on the permanent dentition (Table 11) indicated that 3 papers/studies were of high quality [94,98,163], 21 papers (17 studies) were of moderate quality [53,58,83,89,90,96,97,100,105,121,122,124–126,129,135,140,142,143,156,160], and 45 papers (29 studies) were of low quality [4,84–88,91–93,95,99,101–104,106–108,111–115,118,120,123,130–134,136–139,141,144,145,151–154,161,162,164] (Table 11; also see Appendix H of Section 6). The total number of studies exceeds 44 studies here as one study with 6 linked papers had one paper with moderate quality [105] and 5 papers with low quality [91,92,104,106,107], one study with 3 linked papers had one paper with moderate quality [83] and two papers with low quality [85,102], one study with two linked papers had one paper with moderate quality [129]and one paper with low quality [130], a second study with two linked papers had one paper with moderate quality [135] and one paper with low quality [93], and finally one study with two linked papers had one paper with high quality [94] and one paper with low quality [138]. For high and moderate quality papers, the weaknesses in quality assessment were an inability to complete a follow-up due to study design and an incomplete control all five groups of confounding factors. The low quality papers had significant weaknesses in most areas including eligible population, participation rate, inclusion criteria, inability to complete a follow-up, and confounding, and it was not possible to fully trust the findings.

Table 10 Quality assessment of primary dentition papers

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
Medcalf [95]	1975	Australia	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Carr [111]	1976	Australia	Cross-sectional survey	Cannot determine	0.0	No	0.0	No	0.0	Not applicable	0.0	Some	0.0	**0.0**	**Low**
Cortes *et al.* [87]	1996	Brazil	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Silva *et al.* [98]	2021	Brazil	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Extensive	1.0	**4.0**	**High**
Tiano *et al.* [157]	**2009a**	Brazil	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Extensive	1.0	**3.0**	**Moderate**
Tiano et al. [158]	*2009b*	Brazil	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Extensive	1.0	**3.0**	**Moderate**
Brown [102]	**1951**	Canada	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Connor [86]	1963	Canada	Cross-sectional survey	Yes	1.0	No	0.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
McLaren *et al.* [138]	**2017**	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Brown et al [83]	*1960*	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
McLaren et al. [94]	*2021*	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Extensive	1.0	**4.0**	**High**
Villa *et al.* [100]	1998	Chile	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	None	0.0	**3.0**	**Moderate**
Künzel [93]	1982	Cuba	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
Beal and James [109]	1971	England, UK	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Jackson *et al.* [128]	1975b	England, UK	Cross-sectional survey	Not reported	0.0	Yes	1.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Rugg-Gunn *et al.* [147]	**1977**	England, UK	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Jackson *et al.* [127]	1980	England, UK	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Beal and Clayton [108]	1981	England, UK	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Rugg-Gunn et al. [148]	*1981*	England, UK	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
French et al. [117]	*1984*	England, UK	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Rugg-Gunn et al. [146]	*1988*	England, UK	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Booth *et al.* [110]	1992	England, UK	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Evans et al. [116]	*1995*	England, UK	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Evans et al. [66]	*1996*	England, UK	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Gray and Davies-Slowik [119]	2001	England, UK	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Goodwin *et al.* [58]	2022	England, UK	Retrospective/prospective cohort study	Yes	1.0	Yes	1.0	Yes	1.0	No	0.0	Some	0.0	**3.0**	**Moderate**

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
Parviainen et al. [144]	*1985*	Finland	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	**1.5**	**Low**
Seppä et al. [150]	*2000a*	Finland	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	**2.5**	**Low**
Seppä et al. [151]	*2000b*	Finland	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	**2.5**	**Low**
Künzel [133]	**1968**	Germany	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Künzel [134]	*1980*	Germany	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Lemasney *et al.* [136]	1984	Ireland	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
O'Mullane *et al.* [143]	**1986**	Ireland	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
O'Mullane et al. [142]	*1988*	Ireland	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Whelton *et al.* [53]	2004	Ireland	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
James *et al.* [52]	2021	Ireland	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Yes	1.0	Partial	0.5	**4.5**	**High**
Treasure and Dever [159]	**1992**	New Zealand	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Ministry of Health [96]	2010	New Zealand	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Stephen *et al.* [155]	1987	Scotland, UK	Cross-sectional survey	Not reported	0.0	No	0.0	Not applicable as census study	1.0	Not applicable	0.0	None	0.0	**1.0**	**Low**
Wong *et al.* [101]	1970	Singapore	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
Hsieh [124]	**1972**	Taiwan	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Hsieh et al. [125]	*1979*	Taiwan	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Guo et al. [121]	*1984*	Taiwan	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Hsieh et al. [126]	*1986*	Taiwan	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Ast et al. [104]	*1951*	USA	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	Not applicable as census	1.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Arnold *et al.* [103]	**1953**	USA	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Ast and Chase [107]	*1953*	USA	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Ast et al. [106]	*1955*	USA	Cross-sectional survey	Cannot determine	0.0	Cannot determine	0.0	No	0.0	Not applicable	0.0	Some	0.0	**0.0**	**Low**
Arnold et al. [84]	*1956*	USA	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Gillcrist *et al.* [118]	2001	USA	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Jackson *et al.* [130]	**1975a**	Wales, UK	Cross-sectional survey	No	0.0	Yes	1.0	Yes	1.0	Not applicable	0.0	None	0.0	**2.0**	**Low**
Jackson et al. [129]	*1985*	Wales, UK	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	None	0.0	**3.0**	**Moderate**
Seaman *et al.* [149]	1989	Wales, UK	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	None	0.0	**2.0**	**Low**

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

† See quality assessment instrument in Appendix E of Section 6

Table 11 Quality assessment of permanent dentition papers

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
Medcalf [95]	1975	Australia	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Carr [111]	1976	Australia	Cross-sectional survey	Cannot determine	0.0	No	0.0	No	0.0	Not applicable	0.0	Some	0.0	**0.0**	**Low**
Riordan [164]	1991	Australia	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	**2.5**	**Low**
Cortes *et al.* [87]	1996	Brazil	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Silva *et al.* [98]	2021	Brazil	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Extensive	1.0	**4.0**	**High**
Brown [102]	**1951**	Canada	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Brown et al. [83]	*1960*	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Connor [86]	1963	Canada	Cross-sectional survey	Yes	1.0	No	0.0	Not applicabl e as census study	1.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Brown and Poplove [85]	*1965*	Canada	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Clovis *et al.* [113]	1988	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Ismail *et al.* [89]	1990	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
Ismail *et al.* [90]	1993	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Clark *et al.* [112]	1995	Canada	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Maupomé *et al.* [163]	2001	Canada	Retrospective/prospective cohort study	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	No	0.0	Partial	0.5	**3.5**	**High**
McLaren *et al.* [138]	**2017**	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
McLaren et al. [94]	*2021*	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Extensive	1.0	**4.0**	**High**
Villa *et al.* [100]	1998	Chile	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Künzel [93]	1982	Cuba	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Künzel and Fischer [135]	2000	Cuba	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Beal and Clayton [108]	1981	England, UK	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
Hardwick *et al.* [122]	1982	England, UK	Retrospective/prospective cohort study	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	No	0.0	Some	0.0	**3.0**	**Moderate**
Mitropoulos *et al.* [139]	1988	England, UK	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Murray *et al.* [141]	1991	England, UK	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Ellwood and O'Mullane [115]	**1995**	England and Wales, UK	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Ellwood and O'Mullane [88]	*1996*	England, Wales, UK	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	None	0.0	**1.0**	**Low**
Goodwin *et al.* [58]	2022	England, UK	Retrospective/prospective cohort study	Yes	1.0	Yes	1.0	Yes	1.0	No	0.0	Some	0.0	**3.0**	**Moderate**
Parviainen *et al.* [145]	**1977**	Finland	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Hausen *et al.* [123]	1981	Finland	Retrospective/prospective cohort study	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	**1.5**	**Low**
Parviainen et al. [144]	*1985*	Finland	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	**1.5**	**Low**

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
Linkosalo [137]	1986	Finland	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Seppä *et al.* [153]	**1996**	Finland	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	**1.5**	**Low**
Seppä et al. [152]	*1998*	Finland	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	**2.5**	**Low**
Seppä et al. [150]	*2000a*	Finland	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	**2.5**	**Low**
Seppä et al. [154]	*2002*	Finland	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Künzel [133]	**1968**	Germany	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Künzel [134]	*1980*	Germany	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Künzel and Fischer [132]	*1997*	Germany	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Künzel *et al.* [162]	2000	Germany	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Lemasney *et al.* [136]	1984	Ireland	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
O'Mullane *et al.* [143]	**1986**	Ireland	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
O'Mullane et al. [142]	*1988*	Ireland	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Whelton *et al.* [53]	2004	Ireland	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Mullen *et al.* [140]	2012	Ireland	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Mohd Nor *et al.* [97]	2018	Malaysia	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Backer Dirks *et al.* [4]	**1961**	Netherlands	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Groeneveld [120]	*1985*	Netherlands	Retrospective/prospective cohort study	Cannot determine	0.0	Yes	1.0	No	0.0	Cannot determine	0.0	Some	0.0	**1.0**	**Low**
Kalsbeek et al. [131]	*1993*	Netherlands	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Weerheijm et al. [161]	*1997*	Netherlands	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
de Liefde and Herbison [114]	1985	New Zealand	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
Treasure and Dever [160]	*1994*	New Zealand	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Ministry of Health [96]	2010	New Zealand	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Wong *et al.* [101]	1970	Singapore	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	None	0.0	**1.0**	**Low**
Hsieh [124]	**1972**	Taiwan	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Hsieh et al. [125]	*1979*	Taiwan	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Guo et al. [121]	*1984*	Taiwan	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Hsieh et al. [126]	*1986*	Taiwan	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
Ast *et al.* [105]	**1950**	USA	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable as census study	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**
Ast et al. [104]	*1951*	USA	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	Not applicable as census	1.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Arnold *et al.* [103]	**1953**	USA	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Ast and Chase [107]	*1953*	USA	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Ast et al. [106]	*1955*	USA	Cross-sectional survey	Cannot determine	0.0	Cannot determine	0.0	No	0.0	Not applicable	0.0	Some	0.0	**0.0**	**Low**
Arnold et al. [84]	*1956*	USA	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Szpunar and Burt [99]	1988	USA	Cross-sectional survey	No	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Kumar et al. [91]	*1989*	USA	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**
Kumar et al. [92]	*1998*	USA	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**1.0**	**Low**
Gillcrist *et al.* [118]	2001	USA	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	**2.0**	**Low**

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
Jackson *et al.* [130]	**1975a**	Wales, UK	Cross-sectional survey	No	0.0	Yes	1.0	Yes	1.0	Not applicable	0.0	None	0.0	**2.0**	**Low**
Jackson et al. [129]	*1985*	Wales, UK	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	None	0.0	**3.0**	**Moderate**
Thomas and Kassab [156]	1992	Wales, UK	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicabl e as census	1.0	Not applicable	0.0	Some	0.0	**3.0**	**Moderate**

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

† See quality assessment instrument in Appendix E of Section 6

3.1.4 Study findings: dental caries

3.1.4.1 Primary dentition: inclusion and exclusion at data extraction stage

A total of 53 papers (35 studies) reported outcomes relating to the primary dentition; as outlined earlier (3.1.3.1), this analysis has focused on the four most relevant, commonly reported, and comparable outcomes: dmft (44 papers/32 studies) [52,53,58,66,84,86,87,93–96,98,100–103,108–111,116,121,124–130,133,134,136,138,142,143,146–150,155,157–159], dmfs (18 papers/11 studies) [66,92,102,116,117,128,130,142,143,146–148,150,151,155,157–159], the percentage of children without cavitated dental caries (% without CDC) (27 papers/22 studies) [58,83,86,95,96,100,104,106–110,117–119,127,136,138,142,143,146–149,155,157,159], and the percentage of children with cavitated dental caries (% with CDC) (10 papers/7 studies) [52,58,66,94,98,116,121,124,126,157]. Some or all data from 22 of these papers (18 studies) [66,84,86,95,102–104,106,107,109,111,118,124,128,130,133,134,138,142,150,155,158] could not be extracted or used for a variety of reasons (Table 12Table 12).

Table 12 Primary dentition papers for which data could not be extracted

Authors*	Year	Reason for exclusion at data extraction stage	Outcome(s)
Arnold et al. [103]	1953	dmft cannot be extracted; data reported as number of dmft, not rate	dmft
Arnold et al. [84]	1956	Data for dft only	dmft
Ast *et al.* [104]	**1951**	Canine and molar primary teeth only	% without CDC
Ast et al. [106]	*1955*	Canine and molar primary teeth only	% without CDC
Beal and James [109]	1971	Data presented separately for two intervention groups; total cannot be calculated	dmft
Brown [102]	**1951**	Data for dft and dfs only	dmft, dmfs
Carr [111]	1976	Comparator group inadequate/no control for time; comparator used data from a pre-CWF survey of the same population setting that was conducted 10 years earlier	dmft
Connor [86]	1963	Comparator group inadequate/no control for time; comparator was the same population 7-years earlier, data for dft only	dmft, % without CDC
Evans *et al.* [66]	1996	Same data as Evans *et al.* 1995 [116]	dmft, % with CDC
Gillcrist *et al.* [118]	2001	Data for dfs only	dmfs
Hsieh [124]	**1972**	Data are the baseline data used in Guo *et al.* 1984 [121]	dmft, % with CDC
Jackson *et al.* [130]	**1975a**	Data for dfs only	dmfs
Jackson *et al.* [128]	1975b	Data for dfs only	dmfs
Künzel [133]	**1968**	Data for dft only	dmft
Künzel [134]	*1980*	Data for dft only	dmft
McLaren *et al.* [138]	**2017**	Comparator had CWF for all but 2 years; presents mixed dmft and DMFT data	dmft, % without CDC
Medcalf [95]	1975	Data for dft only	dmft
O'Mullane et al. [142]	*1988*	Same data as O'Mullane *et al.* 1986 [143]	dmft, dmfs
Seppä et al. [150]	*2000a*	Data for dmfs could not be extracted, as they were presented in figures only; % without CDC was presented with dmfs and DMFS data combined	dmfs, % without CDC
Stephen *et al.* [155]	1987	Comparator group inadequate/no control for time; comparator used data from the same population setting 5-years earlier, canine and molar primary teeth only	dmft, dmfs
Tiano et al. [158]	*2009b*	Same data as Tiano *et al.* 2009a {Citation}	dmft, dmfs

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

Of the papers for which data in relation to the primary dentition could be extracted and considered for analysis, 28 papers (24 studies) reported on dmft

[52,53,58,87,93,94,96,98,100,101,108,110,116,121,126–128,130,136,143,147,149,157,159]; all of the intervention participants in these papers had lifetime exposure to CWF, except in one paper, which reported on 6–8-year-olds who were aged 0–2 years when CWF was introduced [93]. A further two papers (two studies) did not provide standard deviation (SD) data [87,101]. Of the papers for which data could be extracted and considered for analysis that reported on dmfs (11 papers/8 studies) [92,116,117,130,143,146,146,147,151,157,159], the percentage of children without cavitated dental caries (20 papers/17 studies) [58,83,95,96,100,108–110,117–119,127,136,143,146–149,157,159], and the percentage of children with cavitated dental caries, (8 papers/7 studies) [52,58,94,98,116,121,126,157], all of the intervention participants had lifetime exposure to CWF. Two papers (2 studies) did not provide SD data for the dmfs outcome [92,143], 17 papers (14 studies) did not provide 95% confidence intervals (CIs) for the percentage of children without cavitated dental caries [58,95,96,100,108–110,117,127,136,143,146–149,157,159], and 4 papers (4 studies) did not provide 95% CIs for the percentage of children with cavitated dental caries [52,58,98,157]. All these papers have been excluded from our analysis (Table 13). The analysis of the remaining 28 papers (22 studies) is presented in Section 3.1.4.3.1 [52,53,58,83,94,96,98,100,108,110,117–119,121,126–130,136,143,146–149,151,157,159].

Table 13 Primary dentition papers for which data could not be included in the analysis

Author*	Year of publication	Reason for exclusion	Outcome(s)
Beal and Clayton [108]	1981	No 95% CI provided	% without CDC
Cortes *et al*. [87]	1996	No SD data provided	dmft
French et al. [117]	*1984*	No 95% CI provided	% without CDC
Goodwin *et al.* [58]	2022	No 95% CI provided	% without CDC, % with CDC
Jackson *et al.* [127]	1980	No 95% CI provided	% without CDC
James *et al.* [52]	2021	No 95% CI provided	% with CDC
Kumar et al. [92]	*1998*	No SD data provided	dmfs
Künzel [93]	1982	CWF group did not have lifetime exposure	dmft
Lemasney *et al.* [136]	1984	No 95% CI provided	% without CDC
Ministry of Health [96]	2010	No 95% CI provided	% without CDC
O'Mullane *et al.* [143]	**1986**	No SD data provided	dmfs
O'Mullane et al. [142]	*1988*	No 95% CI provided	% without CDC
Rugg-Gunn *et al*. [147]	**1977**	No 95% CI provided	% without CDC
Rugg-Gunn et al. [148]	*1981*	No 95% CI provided	% without CDC
Rugg-Gunn et al. [146]	*1988*	No 95% CI provided	% without CDC
Seaman *et al.* [149]	1989	No 95% CI provided	% without CDC
Silva *et al.* [98]	2021	No 95% CI provided	% with CDC
Tiano *et al*. [157]	**2009a**	No 95% CI provided	% without CDC, % with CDC
Treasure and Dever [159]	**1992**	No 95% CI provided	% without CDC
Villa *et al*. [100]	1998	No 95% CI provided	% without CDC
Wong *et al*. [101]	1970	No SD data provided	dmft

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

3.1.4.2 Permanent dentition: inclusion and exclusion at data extraction stage

A total of 69 papers (44 studies) reported outcomes in relation to the permanent dentition. Once again, we have focused on the four most relevant, commonly reported, and comparable outcomes: DMFT (51 papers/36 studies) [53,58,83–87,91,93–108,111,113,114,121–126,129–135,135,136,138–143,156,160,164], DMFS (26 papers/21 studies) [4,88–90,99,102,112,113,115,118,122,123,130,131,135,141–145,150,152,153,160,161,163], the percentage without cavitated dental caries (26 papers/21 studies) [58,83–86,88,90,93,96,99,100,102,108,115,118,132,135–139,141–143,160,164], and the percentage with cavitated dental caries (13 papers/10 studies) [58,94,98,101,107,120–126,154]. Some or all data from 26 of these papers could not be extracted or used for a variety of reasons (Table 14).

Of the papers in relation to the permanent dentition for which data could be extracted, 39 papers (30 studies) reported DMFT [53,58,83–85,91,93–102,105,106,108,113,114,121,122,125,126,129–131,133–136,139–141,143,156,160,162], of which 30 papers (26 studies) reported that the intervention participants had lifetime exposure to CWF [53,83–85,94–100,106,113,114,121,125,126,129–131,134–136,139–141,143,156,160,162]; the remaining 9 papers (8 studies) reported that the intervention participants were aged 0–12 years when CWF was introduced, and the age range of these participants was between 6 and 16 years [58,91,93,101,102,105,108,122,133]. A further 14 papers (11 studies) did not report SD data [58,84,91,93,95,96,99,101,102,105,106,108,122,133].

Of the 16 papers (15 studies) reporting on DMFS for which data could be extracted, 11 papers (11 studies) reported that the intervention participants had lifetime exposure to CWF [90,99,115,118,130,131,135,141,143,144,160]. Of the remaining five papers, three papers (three studies) reported that the intervention participants were aged 3–12 years when CWF was introduced, and the age range of these participants was between 6 and 16 years [102,113,122]. The other two papers (one study) reported on the cessation of water fluoridation for the final 2 and 3 years of the study for participants aged 12 years [152,153]. A further eight papers (seven studies) did not provide SD data [99,102,113,122,143,144,152,153].

Of the 20 papers (17 studies) reporting the percentage of participants without cavitated dental caries for which data could be extracted, 15 papers (14 studies) reported that the intervention participants had lifetime exposure to CWF [83,85,86,90,96,99,100,115,118,135,136,139,141,143,160]; one of these papers clarified that 10–12% of participants in both groups had some periods with or without exposure to CWF [90]. The remaining five papers (five studies) reported that the intervention participants were aged 3–8 years when CWF was introduced, and the age range of these participants was between 8 and 16 years [58,84,93,102,108]. A further 15 papers (15 studies) did not provide 95% CIs [58,84,93,96,99,100,102,108,115,135,136,139,141,143,160].

Of the eight papers (seven studies) reporting the percentage of participants with cavitated dental caries for which data could be extracted, five papers (four studies) reported that the intervention participants had lifetime exposure to CWF [94,98,107,121,126]. The remaining three papers (three studies) reported that the intervention participants were aged 0–16 years when CWF was introduced, and the age range of these participants was between 7 and 16 years [58,101,122]. Four papers (four studies) did not provide 95% CIs [83,85,107].

Table 14 Permanent dentition papers for which data could not be extracted

Authors*	Year	Reason for exclusion at data extraction stage	Outcome(s)
Arnold *et al.* [103]	**1953**	Data reported the number with DMFT rather than the mean	DMFT
Ast *et al.* [104]	**1951**	Data presented as decayed, missing, or filled permanent teeth (DMF) rates per 100 erupted teeth	DMFT
Ast and Chase [107]	*1953*	Data presented as DMF rates per 100 erupted teeth	DMFT
Backer Dirks *et al.* [4]	**1961**	Decayed teeth individual surfaces only, no full-mouth data	DMFS
Carr [111]	1976	Comparator group inadequate/no control for time; comparator used data from a pre-CWF survey of the same population setting that was conducted 10 years earlier	DMFT
Clark *et al.* [112]	1995	Decayed, missing, or filled permanent teeth surfaces including level of cavitation to enamel (D_{1-2}MFS) – not cavitation only	DMFS
Connor [86]	1963	Comparator group inadequate/no control for time; comparator data was the same population setting 7 years earlier	DMFT, % without CDC
Cortes *et al.* [87]	1996	Data for six index teeth only	DMFT
Ellwood and O'Mullane [88]	*1996*	Same data as Ellwood and O'Mullane (1995) [115]	DMFS, % without CDC
Groeneveld [120]	*1985*	Cavitation classification was different for different surfaces, so data could not be combined or used	% with CDC
Hausen *et al.* [123]	1981	Level of fluoride exposure was unclear; comparator group used fluoride rinse	DMFT, DMFS, % with CDC
Hsieh [124]	**1972**	Data were the same as baseline data used in Guo *et al.* 1984 [121]	DMFT, % with CDC
Hsieh et al. [125]	*1979*	Same data as Hsieh (1972) [124]	% with CDC
Ismail *et al.* [89]	1990	Data were presented for two separate groups for each population, so could not be combined	DMFS
Jackson *et al.* [130]	**1975a**	Same baseline data as Jackson *et al.* 1985 [129]	DMFT
Künzel and Fischer [132]	*1997*	Comparator had 4 years with CWF, intervention had some periods with low fluoride	DMFT, % without CDC
Linkosalo [137]	1986	Data for first molars only	% without CDC
Maupomé *et al.* [163]	2001	Comparator had CWF for 5 of 8 years at baseline	DMFS
McLaren *et al.* [138]	**2017**	Comparator had CWF for 7 of the 9 years of the study; the average age of participants was 7 years, but ages ranged from 5 to 13 years; presented mixed dmft and DMFT data	DMFT, % without CDC
O'Mullane et al. [145]	*1988*	Data were the same as O'Mullane *et al.* (1986 [143]	DMFT, % without CDC
Parviainen *et al.* [145]	1977	Data could not be extracted, as they were presented in figures only	DMFS
Riordan [164]	1991	Varied fluoride exposure: 84–90% of intervention group had 7.5–12 years' exposure (participants were aged 12 years), and 20–25% of comparator group were using other fluoride therapies for short periods	DMFT, % without CDC
Seppä et al. [150]	*2000a*	Data for DMFS could not be extracted, as they were presented in figures only; comparator group inadequate/no control for time – compared a population before and after CWF had ceased	DMFS, % without CDC
Seppä et al. [154]	*2002*	Data could not be extracted due to the way they were presented: placement of first filling was used as a proxy for dental caries	% with CDC
Weerheijm et al. [161]	*1997*	Used data from Backer Dirks *et al.* (1961), but reported data for occlusal surfaces only [4]	DMFS

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

Only papers with some participants with lifetime exposure to CWF and with SD or 95% CI data were included in our analysis; 29 of the 69 papers providing data in relation to outcomes for permanent dentition were excluded from analysis for these reasons (Table 15). The analysis of the remaining 30 papers (24 studies) [53,83,85,90,94,97,98,100,102,107,113–115,118,121,125,126,129–131,134–136,139–141,143,156,160,162] is presented in Section 3.1.4.3.2.

Table 15 Permanent dentition papers for which data could not be included in the analysis

Authors*	Year	Reason for exclusion	Outcome(s)
Arnold *et al*. [84]	**1956**	No SD or 95% CI data provided	DMFT, % without CDC
Ast *et al*. [105]	**1950**	CWF group did not have lifetime exposure	DMFT
Ast and Chase [107]	*1953*	CWF group did not have lifetime exposure	DMFT
Ast et al. [106]	*1955*	No SD data provided	DMFT
Ast et al. [104]	*1951*	CWF group did not have lifetime exposure	DMFT
Beal and Clayton [108]	1981	CWF group did not have lifetime exposure	DMFT, % without CDC
Brown [102]	1951	CWF group did not have lifetime exposure	DMFT, DMFS, % without CDC
Clovis *et al*. [113]	1988	CWF group did not have lifetime exposure	DMFS
Ellwood and O'Mullane [115]	**1995**	No 95% CI data provided	% without CDC
Goodwin *et al*. [58]	2022	CWF group did not have lifetime exposure	DMFT, % without CDC, % with CDC
Hardwick *et al*. [122]	1982	CWF group did not have lifetime exposure	DMFT, DMFS, % with CDC
Kumar et al. [91]	*1989*	CWF group did not have lifetime exposure	DMFT
Künzel [93]	1982	CWF group did not have lifetime exposure	DMFT, % without CDC
Künzel [133]	**1968**	CWF group did not have lifetime exposure	DMFT
Künzel and Fischer [135]	2000	No 95% CI data provided	% without CDC
Lemasney *et al*. [136]	1984	No 95% CI data provided	% without CDC
Medcalf [95]	1975	No SD data provided	DMFT
Ministry of Health [96]	2010	No SD or 95% CI data provided	DMFT, % without CDC
Mitropoulos *et al*. [139]	1988	No 95% CI data provided	% without CDC
Murray *et al*. [141]	1991	No 95% CI data provided	% without CDC
O'Mullane et al. [143]	*1986*	No SD or 95% CI data provided	DMFS, % without CDC
Parviainen et al. [144]	*1985*	No SD data provided	DMFS
Seppä et al. [153]	*1996*	CWF group did not have lifetime exposure	DMFS
Seppä et al. [152]	*1998*	CWF group did not have lifetime exposure	DMFS
Silva *et al*. [98]	2021	No 95% CI data provided	% with CDC
Szpunar and Burt [99]	1988	No SD or 95% CI data provided	DMFT, DMFS, % without CDC
Treasure and Dever [160]	*1994*	No 95% CI data provided	% without CDC
Villa *et al*. [100]	1998	No 95% CI data provided	% without CDC
Wong *et al*. [101]	1970	CWF group did not have lifetime exposure	DMFT, % with CDC

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

3.1.4.3 Narrative study findings for included studies, by dentition and by outcome

3.1.4.3.1 Primary dentition

Where possible, data were extracted for children aged 5–6 years, as this is the age at which the World Health Organization (WHO) recommends the assessment of dental caries in the primary dentition [36].

3.1.4.3.1.1 Decayed, missing, or filled primary teeth (dmft) with SD

Twenty-four papers (19 studies) provided some dmft with SD data or were census studies; the papers reported data for children aged 3–15 years. Only data for the dmft of 5–8-year-olds will be presented in our analysis of the dmft outcome, as this is the age group with the most primary teeth and without excess influence of other determinants of dental caries [52,53,58,94,96,98,100,108,110,116,117,121,126–129,136,143,147–149,157,159].

Five papers (four studies) presented dmft data from baseline and follow-up in CWF areas compared with fluoride-deficient areas, all of which compared different populations of children at the two time points [52,108,121,126,129] (Table 16). Two of these papers (two studies) reported a CWF level of 0.8–1.0 ppm [108,129]; one paper reported a CWF level of 0.8–1.0, which then dropped to 0.6–0.8 ppm [52], and the remaining two linked papers reported a CWF level of 0.6 ppm [121,126]. All the fluoride-deficient comparator groups had a CWF level of <0.35 ppm. Three of the five papers (two studies) used the WHO 2013 index to measure the dmft [52,121,126], and the other two papers used the Jackson *et al.* 1973 index [108,129]. Four papers (three studies) reported data for 5-year-olds [108,126,129], and the fifth paper reported data for 8-year-olds [52]. The follow-up periods ranged from 7 to 12 years. All of the studies were completed after 1975: one commenced in 1968 [108], two studies (three papers) commenced between 1972 and 1974 [121,126,129], and one commenced in 2002 [52]. The two papers using the Jackson et al., 1973 index reported a final percentage difference of 48.42% and 55.00% in dmft in favour of CWF [108,129]. The two studies (three papers) using the WHO 2013 index reported a mean difference in dmft; the two linked papers showed a reduction in dmft of 3.0 and 3.5 after 9 and 12 years, respectively, in favour of CWF [121,126], and the most recent paper, by James *et al.* (2021), showed a difference in dmft of 0.8 in favour of CWF [52]. One paper had a high quality rating [52]; two papers (one study) had a moderate quality rating [121,126]; and two papers had a low quality rating [108,129].

The final time point data for the 5 papers (4 studies) described above, and a further 19 papers (16 studies) presented mean difference and SD data for a single time point comparing children with lifetime exposure to CWF with children living in fluoride-deficient areas (Table 17). All papers were cross-sectional surveys except one [58], which was a retrospective/prospective cohort study. The CWF levels were 0.8–1.0 ppm in 19 papers (15 studies) [52,53,58,96,100,108,110,116,117,127–129,136,143,146–149,159], 0.6–0.8 ppm in 2 papers (2 studies) [94,157], and 0.5–0.6 ppm in the remaining 3 papers (2 studies) [98,121,126]. The CWF levels for the comparator populations were <0.3 ppm for all the papers. We used the data for 5-year-olds from 19 papers (15 studies) [53,58,96,98,108,116,117,121,126–129,136,143,146–149,159]; 2 papers (2 studies) presented data for 7-year-olds [94,100], 1 paper presented data for 8-year-olds [52], and the remaining 2 papers (2 studies) [110,157] presented data for children aged 3 years and for children aged up to 36 months, respectively.

Eight papers (seven studies) [52,53,94,100,121,126,143,157] used the WHO index for measuring dmft; four papers (four studies) used the Jackson *et al.,* 1973 index [108,127–129]; four papers (one study) used the Backer-Dirks *et al.,* 1961 index [117,146–148]; three papers (three studies) used the Palmer *et al.,* 1984 index [110,149,159]; two papers (two studies) used the British Association for the Study of Community Dentistry (BASCD) index [58,116], one paper/study each used the Australian Institute of Health and Welfare's 2004–06 National Survey of Adult Oral Health (ANS) index [96], and the Downer *et al*., 1997 index [136]; and one paper/study did not name the index used [98]. Despite the range of indices used, all the papers reported dmft scores with dental caries at the visual level only. All the studies were undertaken and reported after 1975: 14 papers (10 studies) [108,110,117,121,126–129,136,143,146–149] were undertaken between 1975 and 1989, and 10 papers (10 studies) were undertaken between 1990 and 2019 [52,53,58,94,96,98,100,116,157,159]. Eight papers (eight studies) reported the percentage difference between the groups, which ranged from 40% to 62% in favour of CWF [108,116,117,127,129,136,143,146]. Seventeen papers (14 studies) reported the difference in dmft, one of which also reported the percentage difference [146]; the difference in dmft scores ranged from 0.1 to 3.7 [52,53,58,94,96,98,100,110,121,124,128,146–149,157,159].

The quality rating of 3 of the papers (3 studies) was high [52,94,98]; a further 13 papers (11 studies) had a moderate rating [53,58,96,100,110,116,121,126,129,143,146,157,159]; and the remaining 8 papers (6 studies) were rated as low quality [108,117,127,128,136,147–149].

Table 16 Decayed, missing, or filled primary teeth (dmft), baseline and follow-up studies

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline mean dmft – CWF	Baseline SD – CWF	Final mean dmft – CWF	Final SD – CWF	Final total participants– CWF	Baseline mean dmft – no F	Baseline SD – no F	Final mean dmft – no F	Final SD – no F	Final total participants – no F	Final difference in mean dmft or percentage †	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
Ireland	James *et al.* [52]	2021	8	0.8–1.0, then 0.6–0.8	1.8	2.2	1.9	2.4	704	3.5	3.1	2.7	2.8	770	0.8	WHO	High	Not reported	Yes
Wales, UK	*Jackson et al.* [129]	*1985*	5	0.99	2.83	0.261	1.58	0.174	219	4.58	0.338	3.55	0.328	128	55% [or 1.97]	Jackson *et al.*, 1973	Moderate	Not reported	Not reported
England, UK	Beal and Clayton [108]	1981	5	0.85–0.90	4.29	0.25	1.8	0.19	170	4.28	0.25	3.49	0.27	180	48.42% [or 1.69]	Jackson et al., 1973	Low	Not reported	Not reported
Taiwan	*Hsieh et al.* [126]	*1986*	5	0.6–0.7	6.5	4.4	5.1	3.8	226	6.4	4.2	8.6	4	319	3.5	WHO	Moderate	N/A: census	Yes
Taiwan	*Guo et al.* [121]	*1984*	5	0.6	6.5	4.4	5.5	4.3	345	6.4	4.2	8.5	4.6	387	3	WHO	Moderate	N/A: census	Yes

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

† Our preference was for dmft, where not reported percentage was used a HRB hand calculated mean difference in dmft in [square brackets]. Primary study author calculated percentage differences are in (round brackets)

SD = standard deviation; no F = no fluoride; N/A = not applicable

Table 17 Decayed, missing, or filled primary teeth (dmft), from studies where single-time-point data were available

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline mean dmft – CWF	Baseline SD – CWF	Final dmft – CWF	Final SD – CWF	Final total participants – CWF	Baseline mean dmft – no F	Baseline SD – no F	Final dmft – no F	Final SD – no F	Final total participants– no F	Final difference in mean dmft or percentage †	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
Brazil	*Silva et al.* [98]	*2021*	5	0.5–0.6	N/A	N/A	1.53	2.47	161	N/A	N/A	3.54	4.1	169	2.01	NR	High	Yes	Yes
Brazil	**Tiano *et al.*** [157]	**2009a**	1–1.5	0.60–0.75	N/A	N/A	0.57	1.91	30	N/A	N/A	0.68	1.83	38	0.11	WHO	Moderate	NR	Yes
Canada	*McLaren et al.* [94]	*2021*	7	0.5–0.7	N/A	N/A	2	1.7-2.3 CI	799	N/A	N/A	3.2	2.9-3.4 CI	918	1.2	WHO	High	Yes	Yes
Chile	Villa *et al.* [100]	1998	7	0.93	N/A	N/A	1.72	2.33	129	N/A	N/A	3.67	3.54	158	1.95	WHO	Moderate	Implied	NR
England UK	Jackson *et al.* [128]	1975 b	5	1.0	N/A	N/A	2.38	0.304 SE‡	106	N/A	N/A	4.4	0.349 SE†	130	2.02	Jackson *et al.*, 1973	Low	N/A: census	NR
England, UK	*Rugg-Gunn et al.* [147]	*1977*	5	1.0	N/A	N/A	2.4	2.73	212	N/A	N/A	6.1	4.03	132	3.7	Backer-Dirks *et al.*, 1961	Low	NR	NR
England, UK	Jackson *et al.* [127]	1980	5	0.9	N/A	N/A	1.23	0.1462	190	N/A	N/A	3.28	0.2543	198	62% [or 2.05]	Jackson *et al.*, 1973	Low	NR	Yes
England, UK	Beal and Clayton [108]	1981	5	0.85–0.90	4.29	0.25	1.8	0.19	170	4.28	0.25	3.49	0.27	180	48.42% [or 1.69]	Jackson *et al.*, 1973	Low	NR	NR
England, UK	*Rugg-Gunn et al.* [148]	*1981*	5	1.0	N/A	N/A	2.5	2.79	438	N/A	N/A	6.1	4.03	132	3.6	Backer-Dirks *et al.*, 1961	Low	NR	Yes
England, UK	*French et al.* [117]	*1984*	5	1.0	N/A	N/A	1.41	2.21	533	N/A	N/A	3.37	3.65	536	58% [or 1.96]	Backer-Dirks *et al.*, 1961	Low	NR	Yes
England, UK	*Rugg-Gunn et al.* [146]	*1988*	5	1.0	N/A	N/A	1.81	2.56	457	N/A	N/A	3.9	4.22	370	2.09 (54%)	Backer-Dirks *et al.*, 1961	Moderate	NR	Yes
England, UK	Booth *et al.* [110]	1992	3	1.0	N/A	N/A	0.3	1	121	N/A	N/A	0.74	2	107	0.44	Palmer *et al.*, 1984	Moderate	NR	NR

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline mean dmft – CWF	Baseline SD – CWF	Final dmft – CWF	Final SD – CWF	Final total participants – CWF	Baseline mean dmft – no F	Baseline SD – no F	Final dmft – no F	Final SD – no F	Final total participants– no F	Final difference in mean dmft or percentage †	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
England, UK	**Evans *et al*.** [116]	**1995**	5	0.90–1.0	N/A	N/A	1.33	0.1	496	N/A	N/A	2.41	0.1	436	45%	BASCD	Moderate	NR	NR
England, UK	Goodwin *et al.* [58]	2022	5	0.9	N/A	N/A	1.06	2.16	699	N/A	N/A	1.18	2.41	911	0.12	BASCD	Moderate	NR	Yes
Ireland	Lemasney *et al.* [136]	1984	5	0.8–1.0	N/A	N/A	2.46	3.27	169	N/A	N/A	3.83	3.75	98	36% [or 1.37]	Downer	Low	NR	Yes
Ireland	**O'Mullane *et al.*** [143]	**1986**	5	0.8–1.0	N/A	N/A	1.8	2.8	869	5.6	NR	3	3.7	836	40% [or 1.9]	WHO	Moderate	Implied	Yes
Ireland	Whelton *et al.* [53]	2004	5	0.8–1.0	N/A	N/A	1	2.1	3,616	N/A	N/A	1.7	2.1	2,160	0.7	WHO	Moderate	Implied	Yes
Ireland	James *et al.* [52]	2021	8	0.8–1.0, then 0.6–0.8	1.8	2.2	1.9	2.4	704	3.5	3.1	2.7	2.8	770	0.9	WHO	High	NR	Yes
New Zealand	**Treasure and Dever** [159]	**1992**	5	1.0	N/A	N/A	1.06	1.75	107	N/A	N/A	2.91	3.82	67	1.85	Palmer *et al.*, 1984	Moderate	Implied	Yes
New Zealand	Ministry of Health [96]	2010	5	0.8–0.9	N/A	N/A	1.8	0.1	NR (population study)	N/A	N/A	2.2	0.1	NR (population study)	0.4	ANS	Moderate	Yes	Yes
Taiwan	*Guo et al.* [121]	*1984*	5	0.6	6.5	4.4	5.5	4.3	345	6.4	4.2	8.5	4.6	387	3	WHO	Moderate	N/A: census	Yes
Taiwan	*Hsieh et al.* [126]	*1986*	5	0.6–0.7	6.5	4.4	5.1	3.8	226	6.4	4.2	8.6	4	319	3.5	WHO	Moderate	N/A: census	Yes
Wales, UK	*Jackson et al.* [129]	*1985*	5	0.99	2.83	0.261	1.58	0.174	219	4.58	0.338	3.55	0.328	128	55% [or 1.97]	Jackson *et al.*, 1973	Moderate	NR	NR
Wales, UK	Seaman *et al.* [149]	1989	5	0.8	N/A	N/A	0.8	1.43	260	N/A	N/A	2.26	3.17	546	1.46	Palmer *et al.*, 1984	Low	Implied	NR

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for are subsequent papers. Authors of unique papers are presented in normal font.
† Our preference was for dmft, where not reported percentage was used a HRB hand calculated mean difference in dmft in [square brackets]. Primary study author calculated percentage differences are in (round brackets)
‡ When the standard deviation was not reported the SE was used if available.
SD = standard deviation; no F = no fluoride; NR = not reported; SE = standard error; N/A = not applicable

3.1.4.3.1.2 Decayed, missing, or filled primary surfaces (dmfs) with SD

No papers presented acceptable baseline and follow-up data for CWF areas compared with fluoride-deficient areas for the dmfs outcome.

Eight papers (four studies) presented data for a single time point comparing children who had lifetime exposure to CWF with children living in fluoride-deficient areas [116,117,146–148,151,157,159] (Table 18). Six of these papers reported data for 5-year-olds, five of which were linked and reported on the CWF city of Newcastle upon Tyne compared with the fluoride-deficient area of Ashington and surrounding towns in England between the years of 1977 and 1995 [116,117,146–148].

A sixth paper reporting on 5-year-olds compared the New Zealand CWF town of Ashburton with the town of Oamaru, which has never been fluoridated; only the data in this paper for lifetime residents were used in our analysis [159]. A seventh paper reported on 6-year-olds prior to the cessation of CWF in the town of Kuopio in Finland compared with the fluoride-deficient town of Jyväskylä; two other age groups were reported, but we used only the data for lifetime residents in the CWF group for the single time point before CWF ceased [151]. The CWF level in all 7 papers was 1.0 ppm [117,146–148,150,151,159]. The CWF level for the comparator populations was ≤0.1 ppm for all six papers, except one which described the comparator area as 'never fluoridated' [159].

Of these first seven papers, four linked papers used the Backer-Dirks *et al*., 1961 index [117,146–148]; the three others used the BASCD [116]; Moller and Poulsen, 1966 [151]; and Palmer *et al*., 1984 [159] indices. All papers reported dmfs with dental caries at the visual level only; one paper also used dental radiographs [151]. The studies were undertaken between 1976 and 1994. The five linked papers reported a difference in dmfs of between 2.97 and 8.0 in favour of CWF, with the difference reducing over the years between 1976 and 1994 [116,117,146–148]. Another study reported a difference in mean dmfs of 3.17 in favour of CWF [159]. The final study conducted in Finland reported a difference in mean dmfs of 1.21 in favour of the fluoride-deficient area [151]; in this CWF cessation study, the baseline data, before CWF was discontinued, was used. The mean dmfs in the control fluoride-deficient group was lower. The authors do not provide any explanation for this finding which would be contrary to the findings of other similar studies. The quality rating for three papers (two studies) was moderate [116,146,159], and the remaining four papers (two studies) had a low quality rating [117,147,148,151].

The eighth paper [157] presented data for children aged 6–36 months and compared the municipality of Gabriel Monteiro (which had a CWF level of 0.60–0.75 ppm) with the fluoride-deficient (0.40 ppm) municipality of Clementina in Brazil. Both the WHO and American Dental Association (ADA) Caries Classification System (CCS) indices were used to record levels of cavitated and early dental caries respectively; however, only the data using the WHO index for dmfs was used in our analysis. The percentage of teeth with and without dental caries at the cavitation level were also recorded and reported, however, no CIs were reported for this data. Tiano *et al* (2009a) also stated that the parents in the CWF municipality reported that only 54.5% of the children consumed water from the public supply. This study was undertaken in 2006; however, the effect of toothpaste in this population is likely to be minimal and variable, as its use and the practice of oral hygiene for many of the children did not commence until after they were aged 12 months. There was a difference in the mean dmfs of 0.13 in favour of CWF. As the CWF levels, the age profile, and the level of dental caries recorded in this paper differs from the seven other papers, no comparison is made between them. The quality rating for this paper was low [157].

Table 18 Decayed, missing, or filled primary surfaces (dmfs), from studies where single-time-point data were available

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline mean dmfs – CWF	Baseline SD dmfs – CWF	Final mean dmfs – CWF	Final SD dmfs – CWF	Final total participants– CWF	Baseline mean dmfs – no F	Baseline SD dmfs – no F	Final mean dmfs – no F	Final SD dmfs – no F	Final total participants– no F	Final difference in mean dmfs or percentage †	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
Brazil	**Tiano *et al.*** [157]	**2009a**	1–2	0.60–0.75	N/A	N/A	1	3.56	30	N/A	N/A	1.13	4.26	38	0.13	WHO	Low	NR	Yes
England, UK	**Rugg-Gunn et al.** [147]	**1977**	5	1.0	N/A	N/A	3.6	4.98	212	N/A	N/A	11.6	9.54	132	8	Backer-Dirks *et al.*, 1961	Low	NR	NR
England, UK	*Rugg-Gunn et al.* [148]	*1981*	5	1.0	N/A	N/A	4.1	5.76	438	N/A	N/A	11.6	9.54	132	7.5	Backer-Dirks *et al.*, 1961	Low	NR	Yes
England, UK	*French et al.* [117]	*1984*	**5**	1.0	N/A	N/A	2.14	4.13	533	N/A	N/A	5.7	7.19	536	3.56 (62%)	Backer-Dirks *et al.*, 1961	Low	NR	Yes
England, UK	*Rugg-Gunn et al.* [146]	*1988*	5	1.0	N/A	N/A	2.81	4.77	457	N/A	N/A	7	9.28	370	4.19 (60%)	Backer-Dirks *et al.*, 1961	Moderate	NR	Yes
England, UK	**Evans *et al.*** [116]	**1995**	5	0.90–1.0	N/A	N/A	2.8	0.1	496	N/A	N/A	5.77	0.1	436	2.97 (52%)	BASCD	Moderate	NR	NR
Finland	*Seppä et al.* [151]	*2000b*	6	1.0	N/A	N/A	2.53	3.1	49	N/A	N/A	1.32	2.51	66	(+) 1.21	Moller and Poulsen, 1966	Low	NR	Yes
New Zealand	**Treasure and Dever** [159]	**1992**	5	1.0	N/A	N/A	**1.52**	2.65	107	N/A	N/A	**4.69**	7.03	67	3.17	Palmer *et al.*, 1984	Moderate	Implied	Yes

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

† Our preference was for dmfs, where not reported percentage was used a HRB hand calculated mean difference in dmfs in [square brackets]. Primary study author calculated percentage differences are in (round brackets)

SD = standard deviation; no F = no fluoride; NR = not reported

3.1.4.3.1.3 Percentage of children without cavitated dental caries in the primary dentition with 95% CI

Four papers (four studies) provided data that could be considered for analysis for this outcome [83,105,118,119].

Two studies presented both baseline and follow-up data in CWF areas compared with fluoride-deficient areas with 95% CI data, both of which compared different populations of children at the two time points (Table 19) [83,119].

Brown *et al.* (1960) [83] reported data for two Canadian cities: Brantford, Ontario, which had had CWF (at a concentration of 1.0–1.2 ppm) since 1945, and Sarnia, Ontario, which was described as 'fluorine-free'. It also reported data for another city (Stratford, Ontario, which had a natural fluoride level of 1.3 ppm), which are not considered in this review. We have used the data for children aged 9–11 years, as these were the children with the longest exposure to CWF during primary tooth development; the paper also reported data for 12–14-year-olds. The study had a follow-up period of 12 years (1948–1959). The dental caries index used was not reported. The study reported a 6.87-percentage-point increase in the percentage of children without cavitated dental caries in the primary dentition from baseline in the CWF group compared with a 0.73-percentage-point increase in the fluoride-deficient group over the 12-year period. There was a difference of 7.47 percentage points in favour of CWF at the final time point. The quality rating for the study was moderate [83].

Gray and Davies-Slowik (2001) [119] reported data for a number of towns in England within a single health authority area, four of which had CWF at 1.0 ppm: Dudley; Sedgley and Coseley; Brierley Hill and Kingswinford; and Halesowen. The paper also reported data for one fluoride-deficient town, Stourbridge, which had <0.3 ppm of fluoride in the water. The children were aged 5 years, and the study had a follow-up period of 8 years, from 1988–89 to 1996–97. The dental caries index used was the BASCD index. The study reported increases of 22.8 (95% CI: 20.2–25.5), 20.5 (95% CI: 17.8–23.3), 12.1 (95% CI: 9.6–14.7), and 11.0 (95% CI: 8.4–13.6) percentage points in the percentages of children without cavitated dental caries in the primary dentition from baseline in the four CWF areas compared with an 8.8-percentage-point (95% CI: 6.1–11.6) decrease in the fluoride-deficient group over an 8-year period. There was a difference of between 4.3 and 14.8 percentage points in favour of the four CWF areas at the final time point. The quality rating for the study was low [119].

Three studies reported data with 95% CIs for a single time point comparing CWF areas with fluoride-deficient areas (*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

† When the standard deviation was not reported the SE was used if available.

No F = no fluoride; SE = standard error; NR = not reported

Table 20) [83,118,119]. In addition to the two studies described above [83,119], one other study (Gillcrist *et al*., 2001) [118] was undertaken in public elementary schools in East Tennessee, USA during the 1996–97 school year. The areas with CWF had 1.0 ppm fluoride and those without had <0.3 ppm fluoride in the water. The children were aged 5–11 years. The dental caries index used was the ADA CCS index. The study reported a 7-percentage-point difference in favour of CWF for the percentage of 5–11-year-olds without cavitated dental caries in the primary dentition. The quality rating for the study was low.

In summary, the two studies presenting baseline and follow-up data with CIs for CWF areas compared with fluoride-deficient areas looked at two different age groups, used two different indices to measure dental caries, and followed up over different periods; therefore, the results could not be aggregated [83,119].

Using the final follow-up data as a single time point, one of these three studies [119] presented data using the BASCD index with 95% CIs for four CWF areas compared with one fluoride-deficient area for 5-year-olds. There was a difference of between 4.3 and 14.8 percentage points in favour of the four CWF areas at the final time point. The quality rating for the study was low [119].

The three other papers presented single-time-point data for the selected age groups; one of these was was Ast and Chase (1953), one of these was the Brown *et al.* (1960) follow-up study described earlier, which examined 9–11-year-olds, and the other one was Gillcrist *et al.* (2001), which examined 5–11-year-olds. Brown *et al.* (1960) did not report the criteria used to measure dental caries, whereas Ast and Chase (1953) used the WHO index and Gillcrist *et al.* (2001) used the ADA CCS index, but all studies recorded dmft using similar examination criteria and recorded dental decay at the visual cavitation level only. Both had similar water fluoridation levels. Two studies were carried out before 1975 (which is regarded as a cut-off date to differentiate between the periods before and after the widespread use of fluoride toothpaste), and the other was carried out after this date. All studies reported a difference in favour of CWF (28, 7 and 7.47 percentage points) in relation to the percentage of children without cavitated dental caries for children aged between 5 and 11 years at a single time point. The quality rating of the three studies was low [83,107,118].

3.1.4.3.1.4 Percentage of children with cavitated dental caries in the primary dentition with 95% CI

Four papers (three studies) provided data that could be considered for analysis for this outcome [94,116,121,126].

Two papers (one study) presented both baseline and follow-up data in CWF areas compared with fluoride-deficient areas; both were census studies, so the 95% CI was assumed to be 0.1 (*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

† When the standard deviation was not reported the SE was used if available.

No F = no fluoride; SE = standard error; NR = not reported

Table 21) [121,126]. The two papers, Guo *et al.* (1984) and Hsieh *et al.* (1986), are linked and report on the effect of CWF after 9 and 12 years (1972–1984) on children in Taiwan aged between 3 and 15 years. Here, we report the data for 5-year-olds in relation to the primary dentition only. Data for the permanent dentition will be reported later in the analysis (Section 3.1.4.3.2). The CWF concentration in Chung-Hsing New Village was 0.6 ppm, and the natural fluoride concentration in Tsao-tun (now Caotun) was 0.08 ppm. The WHO index was used over the 12 years of the study. The baseline percentage of children with cavitated dental caries was very high in both groups (89.6% compared with 91.7%); there was a 3.2-percentage-point reduction in the percentage of children with cavitated dental caries in the CWF group after 9 years; however, the percentage of children with cavitated dental caries increased in the fluoride-deficient group after 9 years (by 3.4 percentage points) and in both groups after 12 years (by 10 percentage points in the CWF group, and by 8 percentage points in the no fluoride (no F) group). After 9 years, there was an 8.7-percentage-point lower level of cavitated dental caries in the CWF population (86.4% for the CWF area compared with 95.1% for the fluoride-free area), which dropped to a 0.1-percentage-point difference after 12 years (99.6% for the CWF area compared with 99.7% for the fluoride-free area). The quality rating of both papers was moderate.

The final follow-up data for the 5-year-olds in these two papers [121,126] and for two other papers (two studies) [94,116] reported data with 95% CIs for a single time point comparing CWF areas with fluoride-deficient areas (*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

No F = no fluoride; N/A = not applicable

Table 22). The first additional study [94], compared grade 2 schoolchildren (aged approximately 7 years) in the CWF city of Edmonton (0.5–0.7 ppm) with children of the same age born after CWF cessation in the city of Calgary, which had ceased CWF in 2011, after which the level of fluoride in the public water supply dropped from a range of 0.6–0.9 ppm to a range of 0.07–0.30 ppm. The data presented are for a subset of lifelong residents only. The WHO index was used to measure dental caries. There was a 16.3-percentage-point difference in relation to the percentage of children with cavitated dental caries in favour of the city with CWF compared with the city that had ceased CWF (44.5% compared with 60.8%). The second additional study [116], compared 5-year-olds in the CWF city of Newcastle upon Tyne upon Tyne (0.9–1.0 ppm) compared with the non-fluoridated towns of Morpeth, Ashington, Newbiggin, and Blyth in Northumberland (<0.1 ppm). The dental caries index used was the BASCD index. There was a 16-percentage-point difference in favour of CWF (39% compared with 55%). The quality rating of all four papers (three studies) was moderate.

In summary, four papers (three studies) presented data with 95% CIs for the percentage of children aged 5–7 years with cavitated dental caries in the primary dentition. The percentage point difference between the CWF and fluoride-deficient groups ranged from 0.10 to 16.3 in favour of CWF groups. The two linked papers published in the 1980s had considerably higher percentages of children with cavitated dental caries in both groups [121,126] compared with the papers published in 1995 and 2021 [94,116] (86.4–99.7% compared with 39.0–60.8%). The percentage point differences were greatest in the two studies with the lower percentage of children with cavitated dental caries (16.0% (Evans *et al.*, 1995) and 16.3% (McLaren *et al.*, 2021)) [94,116].

Table 19 Percentage of children without cavitated dental caries in the primary dentition, baseline and follow-up studies

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline % without CDC – CWF	Baseline 95% CI – CWF	Final % without CDC – CWF	Final 95% CI – CWF	Final total partici pants– CWF	Baseline % without CDC – no F	Baseline 95% CI – no F	Final % without CDC – no F	Final 95% CI – no F	Final total partici pants– no F	Final percent age point differe nce	Index	Quality rating	Cluster sampling adjustme nt	Identific ation of determi nants
USA	*Ast and Chase* [107]	*1953*	5	1.2	NR	0.1	56.2	0.1	217	NR	0.1	28.2	0.1	140	28	NR	Low	N/A	No
Canada	*Brown et al.* [83]	*1960*	9–11	1.0–1.2	34.96	1.96 SE†	41.83	2.20 SE†	502	33.63	1.98 SE†	34.36	2.08 SE†	521	7.47	NR	Moderate	NR	Yes
England, UK	Gray and Davies-Slowik [119]	2001	5	1.0	57.0 49.0 62.0 69.0	56.5–59.4 48.4–51.3 61.6–64.2 68.5–71.2	79.8 69.5 74.1 80.0	79.4–82.0 69.1–71.7 73.8–76.2 79.6–82.2	2614	74	73.5–76.2	65.2	64.6–67.5	419	14.6 4.3 8.9 14.8	BASCD	Low	NR	NR

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

† When the standard deviation was not reported the SE was used if available.

No F = no fluoride; SE = standard error; NR = not reported

Table 20 Percentage of children without cavitated dental caries in the primary dentition, from studies where single-time-point data were available

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline % without CDC – CWF	Baseline 95% CI – CWF	Final % without CDC – CWF	Final 95% CI – CWF	Final total participants – CWF	Baseline % without CDC – no F	Baseline 95% CI – no F	Final % without CDC – no F	Final 95% CI – no F	Final total participants – no F	Final percentage point difference	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
Canada	*Brown et al.* [83]	*1960*	9–11	1.0–1.2	34.96	1.96 SE†	41.83	2.20 SE†	502	33.63	1.98 SE†	34.36	2.08 SE†	521	7.47	NR	Moderate	NR	Yes
USA	*Ast and Chase* [107]	*1953*	5	1.2	NR	0.1	NR	0.1	196	NR	0.1	NR	0.1	160	56	NR	Low	N/A	Yes
England, UK	Gray and Davies-Slowik [119]	2001	5	1.0	57.0 49.0 62.0 69.0	56.5–59.4 48.4–51.3 61.6–64.2 68.5–71.2	79.8 69.5 74.1 80.0	79.4–82.0 69.1–71.7 73.8–76.2 79.6–82.2	2,614	74	73.5–76.2	65.2	64.6–67.5	419	14.6 4.3 8.9 14.8	BASCD	Low	NR	NR
USA	Gillcrist *et al.* [118]	2001	5–11	1.0	NR	NR	42.00	39–44	10,495	NR	NR	35	32–37	6,761	7	ADA CCS	Low	Implied	Yes

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

† When the standard deviation was not reported the SE was used if available.

No F = no fluoride; SE = standard error; NR = not reported

Table 21 Percentage of children with cavitated dental caries in primary dentition, baseline and follow-up studies

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline % with CDC – CWF	Baseline 95% CI – CWF	Final % with CDC – CWF	Final 95% CI – CWF	Final total participants – CWF	Baseline % with CDC – no F	Baseline 95% CI – no F	Final % with CDC – no F	Final 95% CI – no F	Final total participants – no F	Final percentage point difference	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
Taiwan	*Guo et al.* [121]	*1984*	5	0.6	89.60	0.1	86.40	0.1	345	91.70	0.1	95.10	0.1	387	8.70	WHO	Moderate	N/A: census	Yes
Taiwan	*Hsieh et al.* [126]	*1986*	5	0.6–0.7	89.60	0.1	99.6	0.1	226	91.70	0.1	99.7	0.1	319	0.10	WHO	Moderate	N/A: census	Yes

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

No F = no fluoride; N/A = not applicable

Table 22 Percentage of children with cavitated dental caries in primary dentition, from studies where single-time-point data were available

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline % with CDC – CWF	Baseline 95% CI – CWF	Final % with CDC – CWF	Final 95% CI – CWF	Final total participants – CWF	Baseline % with CDC – no F	Baseline 95% CI – no F	Final % with CDC – no F	Final 95% CI – no F	Final total participants – no F	Final percentage point difference	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
Canada	*McLaren et al.* [94]	*2021*	~7	0.5–0.7	NR	NR	44.5	44.5–49.2	799	NR	NR	60.8	57.0–64.5	918	16.3	WHO	Moderate	Yes	Yes
England, UK	**Evans *et al*.** [116]	**1995**	5	0.9–1.0	NR	NR	39	0.1	496	NR	NR	55	±0	436	16	BASCD	Moderate	N/A: census	NR
Taiwan	*Guo et al.* [121]	*1984*	5	0.6	89.60	0.1	86.40	0.1	345	91.70	0.1	95.10	0.1	387	8.70	WHO	Moderate	N/A: census	Yes
Taiwan	*Hsieh et al.* [126]	*1986*	5	0.6–0.7	89.60	0.1	99.6	0.1	226	91.70	0.1	99.7	0.1	319	0.10	WHO	Moderate	N/A: census	Yes

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

No F = no fluoride; NR = not reported; N/A = not applicable

3.1.4.3.2 Permanent dentition

3.1.4.3.2.5 Decayed, missing, or filled permanent teeth (DMFT) with SD

The 25 papers (21 studies) concerning lifetime exposure to CWF and SD data are included in this analysis [53,83,85,94,97,98,100,113,114,121,125,126,129–131,134–136,139–141,143,156,160,162].

Five papers (three studies) presented both baseline and follow-up data in CWF areas compared with fluoride-deficient areas, all of which compared different populations of children at the two time points (Table 23) [83,121,125,126,129]. Three of these papers [121,125,126] are linked and report on the effect of CWF in Taiwan after 6, 9, and 12 years. Two of these three papers (which were described earlier (Section 3.1.4.3.1.4, Table 28) in relation to the percentage of children with cavitated dental caries in primary teeth,) reported on the 9- and 12-year data on 10-year-olds [121,126]; the third [125] was the earliest report (after 6 years' exposure to CWF). We have extracted the data for 6-year-olds in this third paper, as this was the oldest age group with lifetime exposure to CWF. One paper [83] from Canada reported on 9–11-year-olds after 12 years' exposure to CWF, and one paper from Wales, UK [129] reported on 15-year-olds after 9 years' exposure to CWF. The level of fluoridation in the public water supply in the CWF areas in Taiwan was 0.6 ppm and was between 0.99 and 1.20 ppm in the other two countries. In the fluoride-deficient areas, four papers (two studies) reported that the level of fluoridation in the public water supply was between 0.08 and 0.10 ppm [121,125,126,129], and the fifth paper [83] described the drinking water as 'fluorine-free'.

Two of the linked Taiwan-based papers [121,126] showed a small increase in DMFT between the baseline and final time points in the CWF groups after 9 and 12 years (0.4 and 0.8); the other three papers (three studies) [83,125,129] showed a decrease in DMFT ranging from 0.10 to 2.55 after between 6 and 12 years. The direction of the differences in the fluoride-deficient groups matched the CWF groups, except in the third Taiwan-based paper [125], which showed an increase in DMFT in the fluoride-deficient group. The increases in the three Taiwanese papers (one study) [121,125,126] ranged from 0.2 to 3.5 DMFT; the decrease in DMFT in the other two studies [83,129] ranged from 0.53 to 3.75. All five papers (three studies) showed a difference between the final groups in favour of CWF, with a lower mean DMFT of between 0.20 and 2.96 [83,121,125,126,129].

There were 25 papers (21 studies) presenting mean DMFT and SD data for a single time point comparing participants with lifetime exposure to CWF with participants living in fluoride-deficient areas (Table 24); all were cross-sectional surveys. The CWF levels were 0.8–1.0 ppm in 18 papers (16 studies) [53,83,85,100,113,114,129–131,134–136,139,141,143,156,160,162], 0.6–0.7 ppm in 4 papers (2 studies) [121,125,126,140], and 0.5–0.6 ppm in 2 papers (2 studies) [97,98]; in the final paper, the level of fluoridation in the public water supply ranged from 0.59 to 0.89 ppm [94]. The level of fluoridation in the public water supply for the comparator populations was ≤0.3 ppm for all papers [53,94,97,98,100,113,114,121,125,126,129–131,134–136,139–141,143,156,162], except for three papers (two studies) [83,85,160] which described the water as 'never fluoridated' or 'fluorine-free'. Where possible, we used the data for 12-year-olds, or the closest age to this age with lifetime exposure to CWF. Seven papers (seven studies) presented data for 12-year-olds [53,97,98,100,126,143,162], six papers (five studies) presented data for 14–16-year-olds [129–131,139,140,160], and six papers (six studies) presented data for 6–11-year-olds [94,114,121,125,134,136]. The remaining six papers (five studies) [83,85,113,135,141,156] presented data for age groups ranging from 6 to 32 years.

Twelve papers (10 studies) used the WHO index for measuring DMFT [53,94,97,100,113,114,121,125,126,135,143,162]; 3 papers (3 studies) used the Palmer *et al.*, 1984 index [141,156,160]; 2 papers (1 study) used the Jackson *et al.*, 1973 index [129,130]; two papers (two studies) used the Downer *et al.*, 1979 [136,139] index ; one paper used the BASCD [116]; and 5 papers (4 studies) did not name the index used [83,85,98,131,134]. Despite the range of indices used, all the papers reported DMFT scores with dental caries at the visual level only. One paper also used dental radiographs [131]. The papers were published between 1960 and 2021; 3 of the studies (4 papers) were undertaken prior to 1975 [83,85,130,131], 14 studies (16 papers) were undertaken between 1975 and 1997 [100,113,114,121,125,126,129,134–136,139,141,143,156,160,162], and 5 studies (5 papers) were undertaken between 2002 and 2018 [53,94,97,98,140]. Four papers (four studies) reported the final percentage difference between the groups, which ranged from 21.0% to 54.2% in favour of CWF [121,143,156,162]. The change in mean DMFT was reported or calculated for all the papers; all reported a difference in favour of CWF, and the difference in mean DMFT scores ranged from 0.07 to 6.70.

The quality rating for 2 papers (2 studies) was high [94,98]; 13 papers (10 studies) had a moderate quality rating [53,83,97,100,121,125,126,129,135,140,143,156,160]; and 10 papers (10 studies) had a low quality rating [85,113,114,130,131,134,136,139,141,162].

Table 23 Decayed, missing, or filled permanent teeth (DMFT), baseline and follow-up studies

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline mean DMFT – CWF	Baseline SD – CWF	Final mean DMFT – CWF	Final SD – CWF	Final total partici pants– CWF	Baseline mean DMFT – no F	Baseline SD – no F	Final mean DMFT – no F	Final SD – no F	Final total partici pants – no F	Final difference in mean DMFT or percentage †	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
Canada	*Brown et al.* [83]	*1960*	9–11	1.0–1.2	4.07	0.09	1.52	0.08	502	4.21	0.11	3.68	0.10	521	2.16	NR	Moderate	NR	Yes
Taiwan	*Hsieh et al.* [125]	*1979*	6	0.6	0.2	0.6	0.1	0.4	312	0.1	0.4	0.3	0.7	238	0.2	WHO	Moderate	N/A	Yes
Taiwan	*Guo et al.* [121]	*1984*	10	0.6	0.7	1.3	1.1	1.5	310	0.8	1.5	2.4	2	436	1.3	WHO	Moderate	N/A	Yes
Taiwan	*Hsieh et al.* [126]	*1986*	12	0.6	1.1	1.7	1.9	2.4	329	0.8	1.5	4.3	3.6	458	2.4	WHO	Moderate	N/A	Yes
Wales, UK	*Jackson et al.* [129]	*1985*	15	0.99	6.37	0.37	4.73	0.28	141	11.44	0.59	7.69	0.42	86	2.96	Jackson *et al.*, 1973	Moderate	NR	NR

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* if they are subsequent papers. Authors of unique papers are presented in normal font.

† Our preference was for DMFT, where not reported percentage was used a HRB hand calculated mean difference in DMFT in [square brackets]. Primary study author calculated percentage differences are in (round brackets)

SD = standard deviation; no F = no fluoride; NR = not reported; N/A = not applicable

Table 24 Decayed, missing, or filled permanent teeth (DMFT), from studies where single-time-point data were available

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline mean DMFT – CWF	Baseline SD – CWF	Final mean DMFT – CWF	Final SD – CWF	Final total participants – CWF	Baseline mean DMFT – no F	Baseline SD – no F	Final mean DMFT – no F	Final SD – no F	Final total participants – no F	Final difference in mean DMFT or percentage †	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
Brazil	Silva *et al.* [98]	2021	12	0.5–0.6	N/A	N/A	1.53	1.81	178	N/A	N/A	2.63	3.02	184	1.1	NR	High	Yes	Yes
Canada	Clovis *et al.* [113]	1988	11–12	1.08	N/A	N/A	2.26	2.43	53	N/A	N/A	2.43	2.11	77	0.17	WHO	Low	NR	Yes
Canada	*Brown et al.* [83]	*1960*	9–11	1.0–1.2	4.07	0.093	1.52	0.08	502	4.21	0.11	3.68	0.10	521	2.16	NR	Moderate	NR	Yes
Canada	*Brown and Poplove* [85]	*1965*	16–17	1.0–1.2	N/A	N/A	4.74	0.18	356	N/A	N/A	10.44	0.22	482	5.7	NR	Low	NR	NR
Canada	*McLaren et al.* [94]	*2021*	7	0.5–0.7	N/A	N/A	0.19	0.13, 0.24 (95% CIs)	791	N/A	N/A	0.26	0.20, 0.33 (95% CIs)	912	0.07	WHO	High	Yes	Yes
Chile	Villa *et al.* [100]	1998	12	0.93	N/A	N/A	1.28	1.65	152	N/A	N/A	3.1	2.65	155	1.82	WHO	Moderate	Implied	NR
Cuba	Künzel and Fischer [135]	2000	10–11	0.8	N/A	N/A	1.1	1.51	126	N/A	N/A	3.1	1.79	85	2	WHO	Moderate	NR	NR
England, UK	Mitropoulos *et al.* [139]	1988	14	1.0	N/A	N/A	2.26	2.46	234	N/A	N/A	3.79	3.22	275	1.53	Downer *et al.*, 1979	Low	NR	NR
England, UK	Murray *et al.* [141]	1991	15–16	1.0	N/A	N/A	2.7	0.13	349	N/A	N/A	3.4	0.16	347	0.7	Palmer *et al., 1984*	Low	NR	Yes
Germany	*Künzel* [134]	*1980*	10	1.0	N/A	N/A	1.3	1.41	164	N/A	N/A	3.1	1.95	272	1.8	NR	Low	N/A	Yes
Germany	*Künzel et al.* [162]	*2000*	12	0.8–1.0	N/A	N/A	2.47	2.06	337	N/A	N/A	4.65	1.77	472	2.18 (46.9%)	WHO	Low	NR	Yes
Ireland	Lemasney *et al.* [136]	1984	11	0.8–1.0	N/A	N/A	2.12	1.97	182	N/A	N/A	3.63	2.79	126	1.51	Downer et al., 1979	Low	NR	Yes
Ireland	**O'Mullane *et al.*** [143]	**1986**	12	0.8–1.0	N/A	N/A	2.6	2.3	749	4.7	NR	3.3	2.5	755	0.7 (21%)	WHO	Moderate	Implied	Yes
Ireland	Whelton *et al.* [53]	2004	12	0.8–1.0	N/A	N/A	1.1	1.4	2,090	N/A	N/A	1.3	1.7	747	0.2	WHO	Moderate	Implied	Yes

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline mean DMFT – CWF	Baseline SD – CWF	Final mean DMFT – CWF	Final SD – CWF	Final total participants – CWF	Baseline mean DMFT – no F	Baseline SD – no F	Final mean DMFT – no F	Final SD – no F	Final total participants – no F	Final difference in mean DMFT or percentage †	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
Ireland	Mullen *et al.* [140]	2012	16	0.7	N/A	N/A	2.42	2.12, 2.73 (95% CIs)	823	N/A	N/A	3.61	3.36, 3.86 (95% CIs)	253	1.19	BASCD	Moderate	NR	Yes
Malaysia	Mohd Nor *et al.* [97]	2018	12	0.5	N/A	N/A	0.47	0.97	294	N/A	N/A	1.31	1.81	301	0.84	WHO	Moderate	NR	Yes
Netherlands	*Kalsbeek et al.* [131]	*1993*	15	1.1	N/A	N/A	7.4	4	285	N/A	N/A	14.1	5.7	261	6.7	NR	Low	NR	Yes
New Zealand	de Liefde and Herbison [114]	1985	9	1.0	N/A	N/A	1.7	1.6	191	N/A	N/A	2.4	1.9	237	0.7	WHO	Low	NR	Yes
New Zealand	**Treasure and Dever** [160]	**1994**	14	1.0	N/A	N/A	2.33	2.16	134	N/A	N/A	4.52	3.7	48	2.19	Palmer *et al., 1984*	Moderate	Implied	Yes
Taiwan	*Hsieh et al.* [125]	*1979*	6	0.6	0.2	0.6	0.1	0.4	312	0.1	0.4	0.3	0.7	238	0.2	WHO	Moderate	N/A	Yes
Taiwan	*Guo et al.* [121]	*1984*	10	0.6	0.7	1.3	1.1	1.5	310	0.8	1.5	2.4	2	436	1.3 (54.2%)	WHO	Moderate	N/A	Yes
Taiwan	*Hsieh et al.* [126]	*1986*	12	0.6	1.1	1.7	1.9	2.4	329	0.8	1.5	4.3	3.6	458	2.4	WHO	Moderate	N/A	Yes
Wales, UK	**Jackson *et al.*** [130]	**1975a**	15	0.9	N/A	N/A	6.37	0.37	88	N/A	N/A	11.44	0.59	97	5.07	Jackson *et al.*, 1973	Low	NR	NR
Wales, UK	*Jackson et al.* [129]	*1985*	15	0.99	6.37	0.365	4.73	0.28	141	11.44	0.59	7.69	0.424	86	2.96	Jackson *et al.*, 1973	Moderate	NR	NR
Wales, UK	Thomas and Kassab [156]	1992	18–32	0.8	N/A	N/A	9.48	0.31 SE‡	170	N/A	N/A	13.62	0.23 SE†	479	4.14 (30.4%)	Palmer *et al., 1984*	Moderate	NR	No

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* if they are subsequent papers. Authors of unique papers are presented in normal font.

† Our preference was for DMFT, where not reported percentage was used a HRB hand calculated mean difference in DMFT in [square brackets]. Primary study author calculated percentage differences are in (round brackets)

‡ When the standard deviation was not reported the SE was used if available.

SD = standard deviation; no F = no fluoride; NR = not reported; N/A = not applicable; SE = standard error

3.1.4.3.2.6 Decayed, missing, or filled permanent surfaces (DMFS) with SD

No papers presented both baseline and follow-up DMFS data in CWF areas compared with fluoride-deficient areas.

Six papers (six studies) presented DMFS data for a single time point comparing some participants who had lifetime exposure to CWF with participants living in fluoride-deficient areas [115,118,131,135,141,160] (Table 25).

Three papers/studies reported data for 14- or 15-year-olds [115,131,160]; the remaining three papers/studies reported data for age groups ranging from 5 to 16 years [118,135,141]. The CWF level in all six papers/studies was between 0.7 and 1.0 ppm. The level of fluoridation in the public water supply for the comparator populations was <0.3 ppm for all the papers/studies except one, which described the population as 'never fluoridated'. Two papers/studies used the Palmer *et al*., 1984 index [141,160]; one paper/study each used the ADA CCS [118], the Stephen *et al.*, 1988 [115], and the WHO indices [135]; and one did not report the index used [131]. All papers/studies recorded dental caries at the visual level only; one paper/study also used dental radiographs [131]. Five of the studies were undertaken between 1989 and 1997 [115,118,135,141,160]; the baseline data from the final study, as the only group with some participants with lifetime exposure to CWF, were collected in 1968 [131]. One paper/study reported a 25% difference between the final groups in favour of CWF [118]. The difference in mean DMFS between CWF areas and fluoride-deficient areas was reported or calculated for all the papers: all reported a difference in favour of CWF, and the difference in DMFS scores ranged from 0.25 to 16.9. The quality rating for two papers was moderate [135,160], and the remaining four papers had a low quality rating [115,118,131,141].

Table 25 Decayed, missing, or filled permanent surfaces (DMFS), from studies where single-time-point data were available

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline mean DMFS – CWF	Baseline SD – CWF	Final mean DMFS – CWF	Final SD – CWF	Final total participants – CWF	Baseline mean DMFS – no F	Baseline SD – no F	Final mean DMFS – no F	Final SD – no F	Final total participants – no F	Final difference in mean DMFS or percentage †	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
Cuba	Künzel and Fischer [135]	2000	10–11	0.8	N/A	N/A	1.5	2.21	126	N/A	N/A	4.8	3.76	85	3.3	WHO	Moderate	NR	NR
England, UK	Murray *et al.* [141]	1991	15–16	1.0	N/A	N/A	3.7	0.69	349	N/A	N/A	6.2	0.38	347	2.5	Palmer *et al., 1984*	Low	NR	Yes
England and Wales, UK	**Ellwood and O'Mullane** [115]	**1995**	14	0.7	N/A	N/A	3.18	3.92	196	N/A	N/A	4.18	4.56	267	1.00	Stephen *et al.*, 1988	Low	NR	Yes
Netherlands	*Kalsbeek et al.* [131]	*1993*	15	1.1	N/A	N/A	10.8	7.7	285	N/A	N/A	27.7	14.6	261	16.9	NR	Low	NR	Yes
New Zealand	**Treasure and Dever** [160]	**1994**	14	1.0	N/A	N/A	2.97	3.08	134	N/A	N/A	6.19	6.41	48	3.22	Palmer *et al., 1984*	Moderate	Implied	Yes
USA	Gillcrist *et al.* [118]	2001	5–11	1.0	N/A	N/A	0.77	0.65, 0.88 (95% CI)	10,495	N/A	N/A	1.02	0.90, 1.13 (95% CI)	6,761	0.25 (25%)	ADA CCS	Low	Implied	Yes

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

† Our preference was for DMFS, where not reported percentage was used a HRB hand calculated mean difference in DMFS in [square brackets]. Primary study author calculated percentage differences are in (round brackets)

SD = standard deviation; no F = no fluoride; NR = not reported

3.1.4.3.2.7 Percentage of participants without cavitated dental caries in the permanent dentition with 95% CI

Three papers (two studies) provided data for the outcome of percentage of participants without cavitated dental caries in the permanent dentition [83,85,118].

One paper [83] presented both baseline and follow-up data for the percentage of participants without cavitated dental caries in the permanent dentition in a CWF area compared with a fluoride-deficient area and compared different populations of children at the two time points over a 12-year time period (1948–1959) (Table 26). Brown *et al.* (1960) reported data for two Canadian cities: Brantford, Ontario, which had CWF (at a concentration of 1.0–1.2 ppm) since 1945, and Sarnia, Ontario, which was described as 'fluorine-free'. The paper also reported data for another city (Stratford, Ontario, which had a natural fluoride level of 1.3 ppm), which are not considered in this review. We reported primary dentition data for children aged 9–11 years from this paper earlier (Section 3.1.4.3.1.3). Here, we present the data for 12–14-year-olds in relation to the permanent dentition. The dental caries index used was not reported. The paper reported a 17.51-percentage-point increase in the percentage of children without cavitated dental caries in the permanent dentition from baseline in the CWF group compared with a 1.65-percentage-point increase in the fluoride-deficient group over a 12-year period. The quality rating for the study was moderate [83].

Using the final time point follow-up data from the Brown *et al.* (1960) paper and single-time-point data from two other papers, we compared participants with lifetime exposure to CWF with participants living in fluoride-deficient areas [83,85,118] (No F = no fluoride; NR = not reported

Table 27).

The three papers (two studies) reported data for participants aged 5–17 years (No F = no fluoride; NR = not reported

Table 27). One of the two linked papers was the Brown *et al.* (1960) paper detailed above, which reported on 12–14-year-olds. The other linked paper, Brown and Poplove (1965), was undertaken in the same population settings but reported on 16–17-year-olds 4 years later [83,85]. The dental caries index used was not reported in either paper, but both reported dental caries at the visual level. There was a 16.42-percentage-point difference for the 12–14-year-olds in favour of CWF and an 11.39-percentage-point difference for the 16–17-year-olds in favour of CWF. The quality rating for the paper on 12–14-year-olds was moderate, and the quality rating for the paper on 16–17-year-olds was low.

The final paper was undertaken in East Tennessee, USA, and compared 5–11-year-olds in CWF communities (1.0 ppm) with those in fluoride-deficient communities (<0.3 ppm). The dental caries index used was the ADA CCS index. There was a 4-percentage-point difference in favour of CWF. The quality rating of this paper was low [118].

All three papers reporting data for the outcome of percentage of participants without cavitated dental caries in the permanent dentition showed a percentage point difference in favour of CWF. However, the percentage point differences in the papers [83,85] reporting on the study undertaken before 1975 (16.42 and 11.39) were considerably higher than the percentage point difference for the study [118] undertaken in 1996 (4.00).

Table 26 Percentage of participants without cavitated dental caries in the permanent dentition, baseline and follow-up study

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline % without CDC – CWF	Baseline 95% CI – CWF	Final % without CDC – CWF	Final 95% CI – CWF	Final total participants – CWF	Baseline % without CDC – no F	Baseline 95% CI – no F	Final % without CDC – no F	Final 95% CI – no F	Final total participants – no F	Final percentage point difference	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
Canada	*Brown et al.* [83]	*1960*	12–14	1.0–1.2	1.18	0.447	18.69	1.74	503	0.62	0.353	2.27	0.68	485	16.42	NR	Moderate	NR	Yes

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

No F = no fluoride; NR = not reported

Table 27 Percentage of participants without cavitated dental caries in the permanent dentition, from studies where single-time-point data were available

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline % without CDC – CWF	Baseline 95% CI – CWF	Final % without CDC – CWF	Final 95% CI – CWF	Final total participants – CWF	Baseline % without CDC – no F	Baseline 95% CI – no F	Final % without CDC – no F	Final 95% CI – no F	Final total participants – no F	Final percentage point difference	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
Canada	*Brown et al.* [83]	*1960*	12–14	1.0–1.2	1.18	0.45	18.69	1.74	503	0.62	0.35	2.27	0.68	485	16.42	NR	Moderate	NR	Yes
Canada	*Brown and Poplove* [85]	*1965*	16–17	1.0–1.2	NR	NR	11.8	1.71	356	NR	NR	0.41	0.291	482	11.39	NR	Low	NR	NR
USA	Gillcrist *et al.* [118]	2001	5–11	1.0	NR	NR	78	76, 80	10,495	NR	NR	74	72, 76	6,761	4	ADA CCS	Low	Implied	Yes

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

No F = no fluoride; NR = not reported

3.1.4.3.2.8 Percentage of participants with cavitated dental caries in the permanent dentition with 95% CI

Four papers (three studies) provided some data for the outcome of percentage of participants with cavitated dental caries in the permanent dentition [94,107,121,126].

Two linked papers [121,126], presented the percentage of participants with cavitated dental caries in the permanent dentition at baseline and follow-up in CWF areas compared with fluoride-deficient areas and compared the different populations of participants at the two time points. Both were reporting on a census study, so the 95% CI was assumed to be 0.1 (Table 28). The two papers [121,126] reported on the effect of CWF in two cities in Taiwan after 10 and 12 years of CWF exposure (1971–1984). We reported the data for 5-year-olds in relation to primary dentition earlier (Section 3.1.4.4.6). Here, we only report on 10-year-olds after 10 years and 12-year-olds after 12 years, as these were the oldest ages with lifetime exposure to CWF at the final time point, having been born in 1971, the year CWF was introduced. The concentration of fluoride in the fluoridated water supply in Chung-Hsing New Village was 0.6 ppm, and the natural concentration of fluoride in the water in Tsao-tun (now Caotun) was 0.08 ppm. The WHO index was used to record cavitated dental caries over the 12 years.

The difference between the baseline and final time points for the percentage of participants with cavitated dental caries in the CWF group was 10.2 and 11.2 percentage points higher for the 10- and 12-year-olds, respectively. For the fluoride-deficient groups, the difference between the baseline and final time points was 42.3 and 39.7 percentage points higher for the 10- and 12-year-olds, respectively. After 10 years and 12 years, there was a 32.6- and 23.3-percentage-point difference in favour of the CWF groups for the percentage of 10- and 12-year-old participants with cavitated dental caries, respectively. The quality rating of both papers was moderate [121,126].

Of the four papers (three studies) presenting data for a single time point comparing participants who had lifetime exposure to CWF with participants living in fluoride-deficient areas, one paper [94] reported a 95% CI and another two papers [121,126] were reporting on the census study detailed above. The final paper [107], also a census study, did not present any time point data for either group, but presented only the percentage point difference between the two groups (*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

No F = no fluoride; N/A = not applicable

Table 29).

In addition to the two papers reporting on 10- and 12-year-olds in the census study detailed above [121,126], the two other papers (two studies) reported on 7-year-olds in Canada [94] and on 6–12-year-olds in the USA [107]. Only the data for the 6-year-olds from this second paper were used, as this was the only age group in that paper with lifetime exposure to CWF [107]. The level of fluoridation in the public water supply in the CWF groups was between 0.60 and 0.82 ppm in three papers (two studies) [94,121,126] and was 1.2 ppm in the fourth [107]. Three of the four papers (two studies) used the WHO index [94,121,126] to record dental caries; the fourth [107] did not report the index used, but all recorded dental caries at the visual level. The percentage point differences ranged from 3 to 56 percentage points in favour of CWF; the study with the smallest difference was undertaken in 2019 [94], and the study with the greatest difference was undertaken in 1946 [107]. The quality rating for one paper (one study) was high [94], two papers (one study) were rated as moderate quality [121,126], and the fourth paper/study was rated as low quality [107].

See Appendix I of Section 6 for a feasibility assessment of the outcome data for meta-analysis.

Table 28 Percentage of participants with cavitated dental caries in the permanent dentition, baseline and follow-up studies

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline % with CDC – CWF	Baseline 95% CI – CWF	Final % with CDC – CWF	Final 95% CI – CWF	Final total participants – CWF	Baseline % with CDC – no F	Baseline 95% CI – no F	Final % with CDC – no F	Final 95% CI – no F	Final total participants – no F	Final percentage point difference	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
Taiwan	*Guo et al.* [121]	*1984*	10	0.6	37.9	0.1	48.1	0.1	310	38.4	0.1	80.7	0.1	436	32.6	WHO	Moderate	N/A	Yes
Taiwan	*Hsieh et al.* [126]	*1986*	12	0.6	48.7	0.1	59.9	0.1	329	43.5	0.1	83.2	0.1	458	23.3	WHO	Moderate	N/A	Yes

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

No F = no fluoride; N/A = not applicable

Table 29 Percentage of participants with cavitated dental caries in the permanent dentition, from studies where single-time-point data was available

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Baseline % with CDC – CWF	Baseline 95% CI – CWF	Final % with CDC – CWF	Final 95% CI – CWF	Final total participants – CWF	Baseline % with CDC – no F	Baseline 95% CI – no F	Final % with CDC – no F	Final 95% CI – no F	Final total participants– no F	Final percentage point difference	Index	Quality rating	Cluster sampling adjustment	Identification of determinants
Canada	*McLaren et al.* [94]	*2021*	7	0.5–0.7	N/A	N/A	12.4	9.6, 15.9	791	N/A	N/A	15.4	12.4, 18.9	912	3	WHO	High	Yes	Yes
Taiwan	*Guo et al.* [121]	*1984*	10	0.6	37.9	0.1	48.1	0.1	310	38.4	0.1	80.7	0.1	436	32.6	WHO	Moderate	N/A	Yes
Taiwan	*Hsieh et al.* [126]	*1986*	12	0.6	48.7	0.1	59.9	0.1	329	43.5	0.1	83.2	0.1	458	23.3	WHO	Moderate	N/A	Yes
USA	*Ast and Chase* [107]	*1953*	6	1.2	NR	0.1	NR	0.1	196	NR	0.1	NR	0.1	160	56	NR	Low	N/A	Yes

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

No F = no fluoride; N/A = not applicable; NR = not reported

3.1.4.4 Synthesis of dental caries in a CWF area compared with a fluoride-deficient area or baseline

3.1.4.4.1 Introduction

For the purposes of this analysis, we have presented the findings by individual paper rather than by study, as some of the papers within a study series had different characteristics, for example different age profiles or different exposure times to CWF.

3.1.4.4.2 Feasibility assessment for meta-analysis

We completed a feasibility assessment in order to determine if we should complete a meta-analysis on the effect of CWF on dental caries for each outcome (dmft/DMFT, dmfs/DMFS, and the percentage with or without cavitated dental caries in either the primary or permanent dentition). At the data tabulation phase, we excluded any paper/study that: had not provided variance data for the statistical measures such as SDs for means or CIs for prevalence estimates; did not have author-defined lifetime exposure to the fluoride concentration of interest or did not control for lifetime exposure; or had not collected data for the intervention and comparator groups in different years (see Table 12 and Table 13 in Section **Error! Reference source not found.**, and Table 14 and Table 15 in Section **Error! Reference source not found.**).

Our parameters for the feasibility assessment for single time point analysis were study design, participant age, CWF level, the assessment measure, and adjustment for named confounders. In addition, where data were available for two time points, we also considered length of follow-up. Where meta-analyses of outcomes were possible, we present a series of forest plots including sensitivity analyses and subgroup analyses as appropriate. The certainty of the evidence has been determined from the GRADE gradings. The gradings and justifications for the GRADE criteria are presented in Appendix 10.

3.1.4.4.3 Mean decayed, missing, or filled primary teeth (dmft)

The feasibility assessment for meta-analysis of the dmft outcome indicated that of the 24 included papers. One of the papers did not report the number of 5-year-olds in the study population [96]; another paper focused on a population of children aged 18–36 months, and the fluoride concentration in the water supply of the comparator population was unclear [157], and another paper focused on children aged 3 years [110] (Appendix I of Section 6, Table 11). Therefore, we excluded these three papers from further analysis, leaving 21 papers. 8 had a low quality rating with regard to the design and conduct of the study [112,121,128,129,136,147–149] (Appendix H of Section 6, Table 10)

Of the 21 remaining papers, 3 papers were census studies and therefore did not require a variance measure (although we provided a notional measure of 0.1 for SDs to facilitate computerised statistical analysis) [116,121,126], and 18 papers provided mean and SDs dmft scores [52,53,58,94,98,100,108,117,127–129,136,143,146–149,159].

Five of the 21 papers reported data for two time points and were included in the meta-analysis of baseline and follow-up studies [52,108,121,126,129]. All of the 21 remaining papers were included in the single-time-point meta-analysis [52,53,58,94,98,100,108,116,117,121,126–129,136,143,146–149,159].

The studies in the papers included in the two meta-analyses were undertaken in Brazil (one paper) [98], Canada (one paper) [94], Chile (one paper) [100], England, UK (nine papers) [58,112,116,121,128,129,146–148], Ireland (four papers) [52,53,136,142] , New Zealand (one paper) [159], Taiwan (two papers) [121,126], and Wales, UK (two paper) [129,149] between 1975 and 2022. Four papers reported a CWF level of between 0.6 and 0.8 ppm [94,98,121,126], and sixteen papers reported a CWF level of between 0.8 ppm and 1.0 ppm [53,58,100,108,116,117,127–129,136,143,146–149,159]; the final paper reported a CWF level of 0.8–1.0 ppm at baseline and 0.6–0.8 ppm at the final time point [52].

The participants were 5-year-olds in 18 papers [53,58,98,108,116,117,121,126–129,136,143,146–149,159], 7-year-olds in 2 papers [94,100], and 8-year-olds in 1 paper [52].

Figure 4 presents standardised MD (±SDs) for dental caries measured using dmft in CWF areas compared with fluoride-deficient. The most reliable single-time-point pairwise random effects meta-analysis is a sensitivity analysis of 18 papers, with 3 outlier papers removed because their findings were not compatible other included papers, i.e. results were greater than four standard deviations from the standardised MD (Figure 5). The results of the meta-analysis indicate a statistically significant effect of CWF on dmft, providing low certainty evidence that exposure to artificially fluoridated water reduced dental caries in the primary dentition (standardised mean difference; SMD -0.65, 95% CI: -0.87 to - 0.44; 18 papers). The very high level of heterogeneity on the model (I^2 = 97.1%) is partly due to study quality and level of fluoride in the CWF group. In subgroup analyses, there was no difference in effectiveness by CWF level (Figure 6), and the high and moderate quality papers had results closer to the line indicating no difference in effectiveness (Figure 7). Therefore, there is very low certainty evidence that the mean difference for dmft equates to just over one-half additional healthy tooth per child aged 5–8 years in the CWF area compared with similar children in the fluoride-deficient area at a single time point.

Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Jackson et al. 1975b	2.38	3.1300	106	4.40	3.9800	130	4.8%	−0.56 [−0.82; −0.29]
Rugg−Gunn et al. 1977	2.40	2.7300	212	6.10	4.0300	132	4.8%	−1.12 [−1.36; −0.89]
Jackson et al. 1980	1.23	0.1462	190	3.28	0.2543	198	4.7%	−9.81 [−10.54; −9.09]
Beal and Clayton 1981	1.80	0.1900	170	3.49	0.2700	180	4.7%	−7.19 [−7.76; −6.61]
Rugg−Gunn et al. 1981	2.50	2.7900	438	6.10	4.0300	132	4.8%	−1.15 [−1.36; −0.95]
French et al. 1984	1.41	2.2100	533	3.37	3.6500	536	4.8%	−0.65 [−0.77; −0.53]
Guo et al. 1984	5.50	4.3000	345	8.50	4.6000	387	4.8%	−0.67 [−0.82; −0.52]
Lemansey et al. 1984	2.46	3.2700	169	3.83	3.7500	98	4.8%	−0.40 [−0.65; −0.14]
Jackson et al. 1985	1.58	0.1740	219	3.55	0.3280	128	4.7%	−8.11 [−8.76; −7.47]
Hsieh et al. 1986	5.10	3.8000	226	8.60	4.0000	319	4.8%	−0.89 [−1.07; −0.71]
O'Mullane et al. 1986	1.80	2.8000	869	3.00	3.7000	836	4.8%	−0.37 [−0.46; −0.27]
Rugg−Gunn et al. 1988	1.81	2.5600	457	3.90	4.2200	370	4.8%	−0.61 [−0.75; −0.47]
Seaman et al. 1989	0.80	1.4300	260	2.26	3.1700	546	4.8%	−0.53 [−0.68; −0.38]
Treasure and Dever 1992	1.06	1.7500	107	2.91	3.8200	67	4.8%	−0.67 [−0.99; −0.36]
Evans et al. 1995	1.33	0.5700	496	2.41	0.5300	436	4.8%	−1.96 [−2.11; −1.80]
Villa et al. 1998	1.72	2.3300	129	3.67	3.5400	158	4.8%	−0.64 [−0.87; −0.40]
Whelton et al. 2004	1.00	2.1000	3616	1.70	2.1000	2160	4.8%	−0.33 [−0.39; −0.28]
James et al. 2021	1.90	2.4000	704	2.70	2.8000	770	4.8%	−0.31 [−0.41; −0.20]
McLaren et al. 2021	2.00	4.3300	799	3.20	3.8600	918	4.8%	−0.29 [−0.39; −0.20]
Silva et al. 2021	1.53	2.4700	161	3.54	4.1000	169	4.8%	−0.59 [−0.81; −0.37]
Goodwin et al. 2022	1.06	2.1600	699	1.18	2.4100	911	4.8%	−0.05 [−0.15; 0.05]
Total (95% CI)			**10905**			**9581**	**100.0%**	**−1.74 [−3.03; −0.46]**

Heterogeneity: $Tau^2 = 7.8112$; $Chi^2 = 2282.89$, df = 20 ($P = 0$); $I^2 = 99\%$

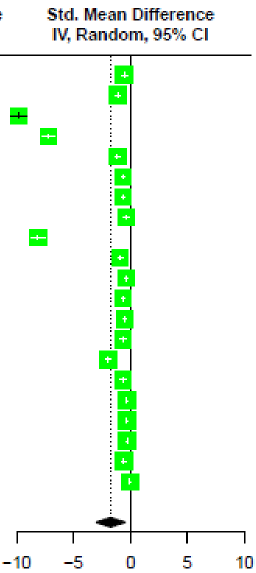


Figure 4 Forest plot of standardised MD (±SDs) for dental caries measured using dmft in CWF areas compared with fluoride-deficient

Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Jackson et al. 1975b	2.38	3.1300	106	4.40	3.9800	130	5.3%	−0.56 [−0.82; −0.29]
Rugg−Gunn et al. 1977	2.40	2.7300	212	6.10	4.0300	132	5.4%	−1.12 [−1.36; −0.89]
Rugg−Gunn et al. 1981	2.50	2.7900	438	6.10	4.0300	132	5.5%	−1.15 [−1.36; −0.95]
French et al. 1984	1.41	2.2100	533	3.37	3.6500	536	5.7%	−0.65 [−0.77; −0.53]
Guo et al. 1984	5.50	4.3000	345	8.50	4.6000	387	5.6%	−0.67 [−0.82; −0.52]
Lemansey et al. 1984	2.46	3.2700	169	3.83	3.7500	98	5.3%	−0.40 [−0.65; −0.14]
Hsieh et al. 1986	5.10	3.8000	226	8.60	4.0000	319	5.6%	−0.89 [−1.07; −0.71]
O'Mullane et al. 1986	1.80	2.8000	869	3.00	3.7000	836	5.7%	−0.37 [−0.46; −0.27]
Rugg−Gunn et al. 1988	1.81	2.5600	457	3.90	4.2200	370	5.7%	−0.61 [−0.75; −0.47]
Seaman et al. 1989	0.80	1.4300	260	2.26	3.1700	546	5.6%	−0.53 [−0.68; −0.38]
Treasure and Dever 1992	1.06	1.7500	107	2.91	3.8200	67	5.1%	−0.67 [−0.99; −0.36]
Evans et al. 1995	1.33	0.5700	496	2.41	0.5300	436	5.6%	−1.96 [−2.11; −1.80]
Villa et al. 1998	1.72	2.3300	129	3.67	3.5400	158	5.4%	−0.64 [−0.87; −0.40]
Whelton et al. 2004	1.00	2.1000	3616	1.70	2.1000	2160	5.8%	−0.33 [−0.39; −0.28]
James et al. 2021	1.90	2.4000	704	2.70	2.8000	770	5.7%	−0.31 [−0.41; −0.20]
McLaren et al. 2021	2.00	4.3300	799	3.20	3.8600	918	5.7%	−0.29 [−0.39; −0.20]
Silva et al. 2021	1.53	2.4700	161	3.54	4.1000	169	5.4%	−0.59 [−0.81; −0.37]
Goodwin et al. 2022	1.06	2.1600	699	1.18	2.4100	911	5.7%	−0.05 [−0.15; 0.05]
Total (95% CI)			**10326**			**9075**	**100.0%**	**−0.65 [−0.87; −0.44]**

Heterogeneity: $Tau^2 = 0.1790$; $Chi^2 = 587.09$, df = 17 ($P < 0.0001$); $I^2 = 97.1\%$

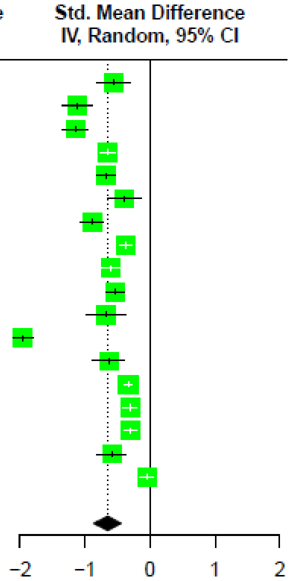


Figure 5 Forest plot of standardised MD (±SDs) for dental caries measured using dmft in CWF areas compared with fluoride-deficient areas (sensitivity analysis with three outlier papers removed)

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Fluoridation status = <0.6ppm								
Guo et al. 1984	5.50	4.3000	345	8.50	4.6000	387	5.6%	−0.67 [−0.82; −0.52]
Hsieh et al. 1986	5.10	3.8000	226	8.60	4.0000	319	5.6%	−0.89 [−1.07; −0.71]
McLaren et al. 2021	2.00	4.3300	799	3.20	3.8600	918	5.7%	−0.29 [−0.39; −0.20]
Silva et al. 2021	1.53	2.4700	161	3.54	4.1000	169	5.4%	−0.59 [−0.81; −0.37]
Total (95% CI)			**1531**			**1793**	**22.4%**	**−0.60 [−1.01; −0.20]**
Heterogeneity: $Tau^2 = 0.0586$; $Chi^2 = 42.24$, df = 3 ($P < 0.0001$); $I^2 = 92.9\%$								
Fluoridation status = 0.6−0.8ppm								
Jackson et al. 1975b	2.38	3.1300	106	4.40	3.9800	130	5.3%	−0.56 [−0.82; −0.29]
Rugg−Gunn et al. 1977	2.40	2.7300	212	6.10	4.0300	132	5.4%	−1.12 [−1.36; −0.89]
Rugg−Gunn et al. 1981	2.50	2.7900	438	6.10	4.0300	132	5.5%	−1.15 [−1.36; −0.95]
French et al. 1984	1.41	2.2100	533	3.37	3.6500	536	5.7%	−0.65 [−0.77; −0.53]
Lemansey et al. 1984	2.46	3.2700	169	3.83	3.7500	98	5.3%	−0.40 [−0.65; −0.14]
O'Mullane et al. 1986	1.80	2.8000	869	3.00	3.7000	836	5.7%	−0.37 [−0.46; −0.27]
Rugg−Gunn et al. 1988	1.81	2.5600	457	3.90	4.2200	370	5.7%	−0.61 [−0.75; −0.47]
Seaman et al. 1989	0.80	1.4300	260	2.26	3.1700	546	5.6%	−0.53 [−0.68; −0.38]
Treasure and Dever 1992	1.06	1.7500	107	2.91	3.8200	67	5.1%	−0.67 [−0.99; −0.36]
Evans et al. 1995	1.33	0.5700	496	2.41	0.5300	436	5.6%	−1.96 [−2.11; −1.80]
Villa et al. 1998	1.72	2.3300	129	3.67	3.5400	158	5.4%	−0.64 [−0.87; −0.40]
Whelton et al. 2004	1.00	2.1000	3616	1.70	2.1000	2160	5.8%	−0.33 [−0.39; −0.28]
James et al. 2021	1.90	2.4000	704	2.70	2.8000	770	5.7%	−0.31 [−0.41; −0.20]
Goodwin et al. 2022	1.06	2.1600	699	1.18	2.4100	911	5.7%	−0.05 [−0.15; 0.05]
Total (95% CI)			**8795**			**7282**	**77.6%**	**−0.66 [−0.94; −0.39]**
Heterogeneity: $Tau^2 = 0.2208$; $Chi^2 = 544.36$, df = 13 ($P < 0.0001$); $I^2 = 97.6\%$								
Total (95% CI)			**10326**			**9075**	**100.0%**	**−0.65 [−0.87; −0.44]**
Prediction interval								**[−1.57; 0.27]**

Heterogeneity: $Tau^2 = 0.1790$; $Chi^2 = 587.09$, df = 17 ($P < 0.0001$); $I^2 = 97.1\%$
Test for subgroup differences: $Chi^2 = 0.11$, df = 1 ($P = 0.7386$)

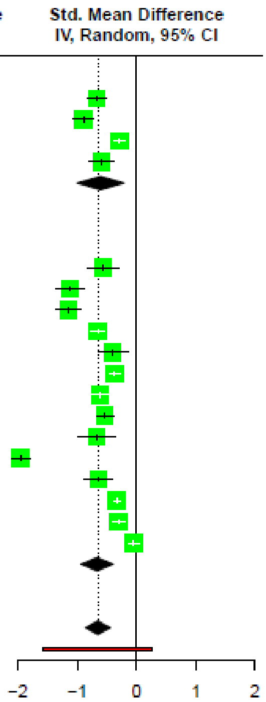


Figure 6 Forest plot of standardised MD (±SDs) for dental caries measured using dmft in CWF areas compared with fluoride-deficient areas by CWF PPM subgroup analyses

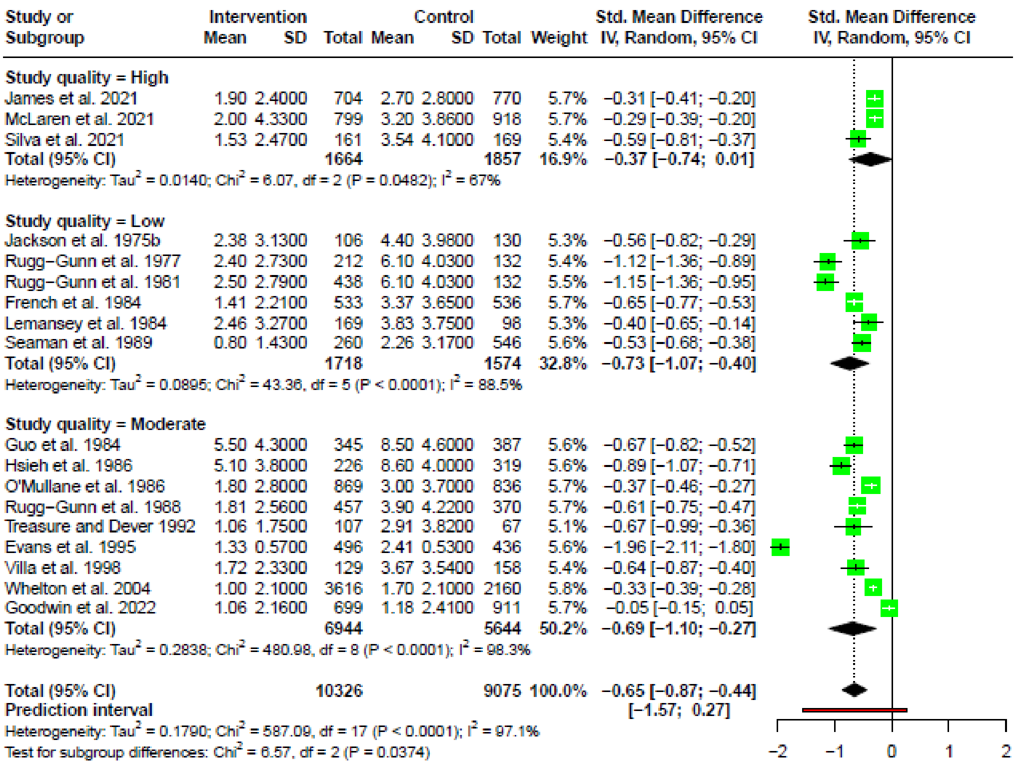


Figure 7 Forest plot of standardised MD (±SDs) for dental caries measured using dmft in CWF areas compared with fluoride-deficient areas by study quality subgroup analyses

Five of the 21 papers published between 1981 and 2021, comparing the effect of CWF in the intervention areas with the control (or fluoride-deficient) areas using the outcome mean dmft reported data for two time points [52,108,121,126,129] (Table 30). Meta-analysis was not possible for these papers as the follow-up periods were different in each study, ranging from 7–15 years. The mean difference for dmft over time in the areas with CWF was -0.1 higher to 2.49 lower (a lowering of dmft over time is a better result). The mean difference for dmft over time in the fluoride deficient areas was -2.2 higher to 1.0 lower. The follow-up periods ranged from 9 to 15 years, the children were aged between 5 and 8 years. Therefore, there is very low certainty evidence of mixed findings for dmft in children between 5 and 8 years over two time points with three papers reporting a reduction in mean dmft in the CWF area compared with the fluoride deficient area, and two papers reporting no significant difference in mean dmft.

Table 30 Difference over time for dental caries measured using dmft in CWF areas compared with fluoride-deficient areas, baseline and follow-up papers excluded from meta-analysis

Author, year, country	Age (years)	Intervention group baseline		Intervention group follow-up		Intervention Group difference	Control group baseline		Control group follow-up		Control Group difference	Years of follow-up
		Mean (SD)	N	Mean (SD)	N	*MD (SD)	Mean (SD)	N	Mean (SD)	N	MD (SD)	
Beal and Clayton 1981 [108], England	5	4.29 (0.25)	196	1.8 (0.19)	170	-3.1	4.28 (0.25)	205	3.49 (0.27)	180	-0.79	7
Guo et al. 1984 [121], Tiawan	5	6.5 (4.4)	589	5.5 (4.3)	345	1 (6.39)	6.4 (4.2)	218	8.5 (4.6)	387	-2.1 (6.39)	9
Jackson et al. 1985 [129], Wales	5	2.8 (0.3)	153	1.6 (0.2)	219	-1.2 (0.35)	4.6 (0.3)	145	3.6 (0.3)	128	-1.0 (0.42)	9
Hsieh et al. 1986 [126], Tiawan	5	6.5 (4.4)	589	5.1 (3.8)	226	-1.4 (6.28)	6.4 (4.2)	218	8.6 (4.0)	319	+2.2 (5.94)	12
James et al. 2021 [52], Ireland	8	1.8 (2.2)	679	1.9 (2.4)	704	+0.1 (3.22)	3.5 (3.1)	233	2.7 (2.8)	770	-0.8 (5.03)	15

*MD(SD) Mean difference (standard deviation)

3.1.4.4.4 Mean decayed, missing, or filled primary surfaces (dmfs)

The feasibility assessment for meta-analysis of the dmfs outcome indicated that of the eight relevant papers. Four papers had a low rating with regard to design and conduct of the studies [121,147,148,151]. One paper focused on a population of children aged 18–36 months and was not clear about the concentration of fluoride in the water supply in the comparator population [157] (Appendix I of Section 6, Table 12). Therefore, one paper was excluded from further analysis, leaving seven papers for meta-analysis.

Of the seven remaining papers, one paper was based on a census study and therefore does not require a variance measure (although we provided a notional measure of 0.1 for SDs to facilitate computerised statistical analysis) [116], while the six other papers provided means and SDs of dmfs scores [117,146–148,151,159]. Five papers were undertaken in England, UK in 1987 and 1994 [116,117,146–148], one paper in Finland [151] and the remaining paper was based on a unique study undertaken in New Zealand in 1992 [159]. The CWF level in all papers was 1.0 ppm, and all the papers were based on single-time-point studies. The participant numbers were larger in the studies in England (2,136) than in the studies in Finland (49) or New Zealand (107). We completed a pairwise meta-analysis for the seven single-time-point studies.

Seven papers of low or moderate quality, published between 1977 and 2000, compared the effect of CWF in the intervention areas with the control (or fluoride-deficient) areas using the outcome of mean dmfs and were judged suitable for pairwise random effect meta-analysis. The children included in these papers were aged between 5 and 6 years. The CWF level in all papers was 1.0 ppm so subgroup analysis was not required. All the papers were based on single-time-point studies. Figure 8 presents standardised MD (±SDs) for dental caries measured using dmfs in CWF areas compared with fluoride-deficient. The most reliable single-time-point pairwise random effects meta-analysis is a sensitivity analysis of 6 papers, with 1 outlier study removed because its finding was not compatible with other included papers (Figure 9). The results of the single-time-point pairwise random effects meta-analysis indicate a standardised MD of −0.62 (95% CI: −1.2 to −0.04; I^2: 100%; 6 papers) in favour of CWF for dmfs, and this difference is statistically significant. The I^2 value (92.6%) was high indicating substantial statistical heterogeneity. The very high level of heterogeneity on the model is partly due to study quality. The subgroup analysis examining low and moderate quality indicate that the subgroup with low quality papers had wider confidence intervals and these cross the line from effectiveness to no effectiveness (Figure 10). There is very low certainty evidence that the mean difference for dmfs equates to just over one-half additional healthy tooth surface per child aged 5–6 years in the CWF area compared with similar children in the fluoride-deficient areas at a single time point.

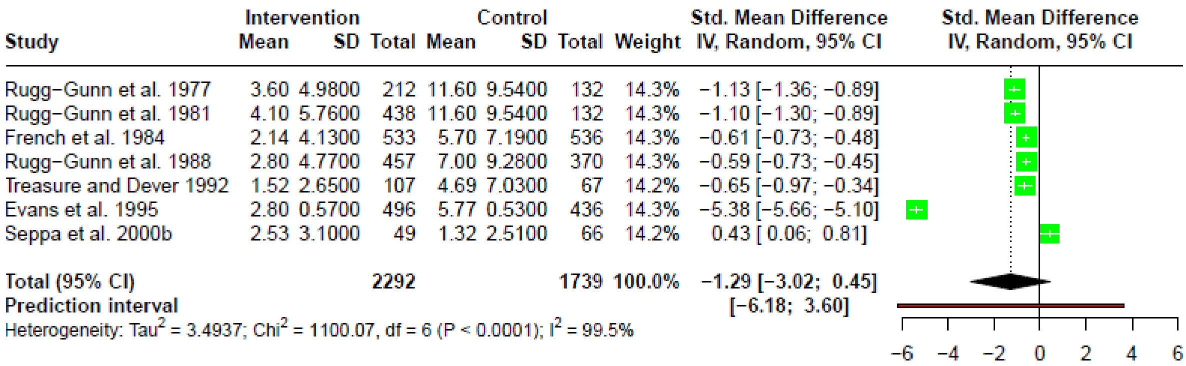


Figure 8 Forest plot of standardised MD (±SDs) for dental caries measured using dmfs in CWF areas compared with fluoride-deficient

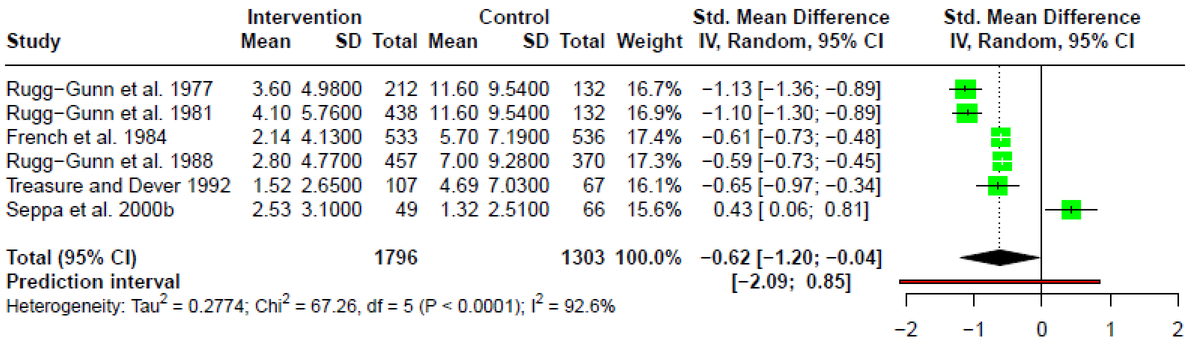


Figure 9 Forest plot of standardised MD (±SDs) for dental caries measured using dmfs in CWF areas compared with fluoride-deficient areas (sensitivity analysis with one outlier study removed)

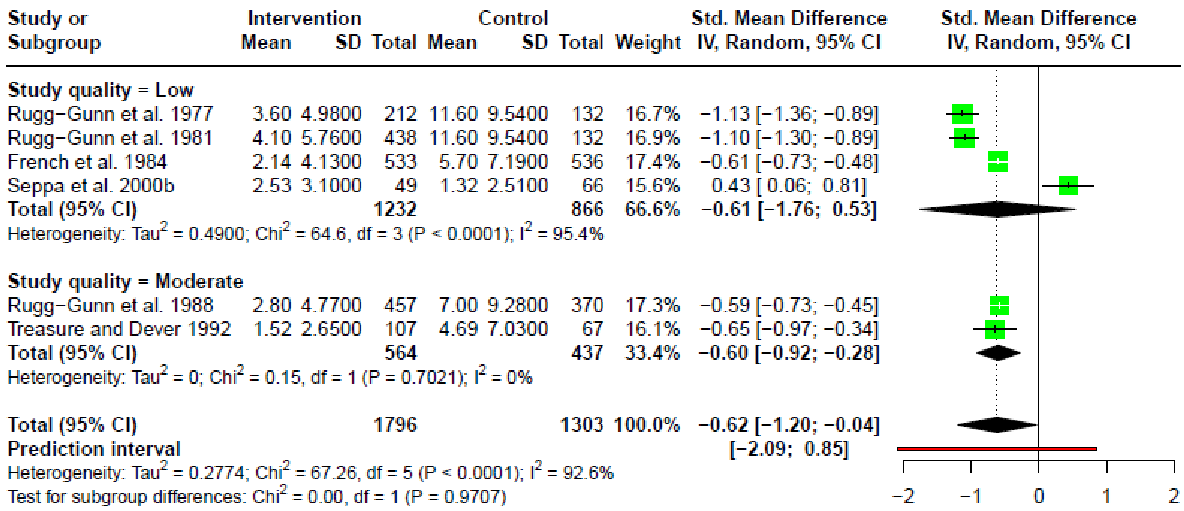


Figure 10 Forest plot of standardised MD (±SDs) for dental caries measured using dmfs in CWF areas compared with fluoride-deficient areas by study quality subgroup analyses

3.1.4.4.5 Percentage of participants without cavitated dental caries in the primary dentition

The feasibility assessment for meta-analysis of the outcome of percentage of participants without cavitated dental caries in the primary dentition indicated that the four papers measuring this outcome, were suitable for meta-analysis [40,83,105,107,111,118,119,122,123] (Appendix I of Section 6.8, Table 13).

Four papers of low or moderate quality, published between 1953 and 2001, compared the effect of CWF in the intervention and control (or fluoride-deficient) areas using the outcome of percentage of participants without cavitated dental caries in the primary dentition. The four papers were judged suitable for single-time-point meta-analysis. The children in these papers were aged 5–11 years. The CWF level was between 1.0 and 1.2 ppm in the four papers, so subgroup analysis was not required. The results of the single-time-point pairwise random effects meta-analysis indicate an odds ratio of 1.75 (95% CI: 0.87–3.51; I^2: 84.0%; 4 papers) in favour of CWF, the results are not statistically significant and have considerable heterogeneity (Figure 11). The subgroup analysis examining low and moderate quality indicate that the subgroup with low quality papers had wider confidence intervals but similar results (Figure 12). Therefore, there is very low certainty evidence that children aged 5–11 years have 1.75 higher odds of having cavity free primary teeth in the CWF area compared with the fluoride-deficient area at a single time point.

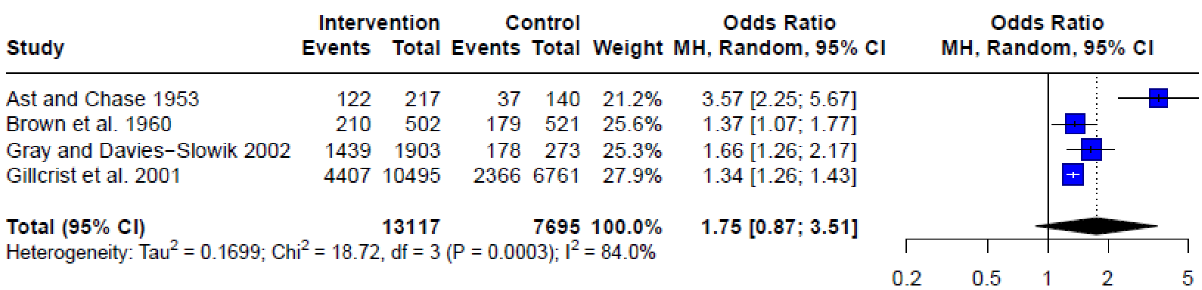


Figure 11 Forest Plot of odds ratio (MH 95% CI) of per cent without cavitated dental caries measured using dmft in CWF areas compared with fluoride-deficient areas

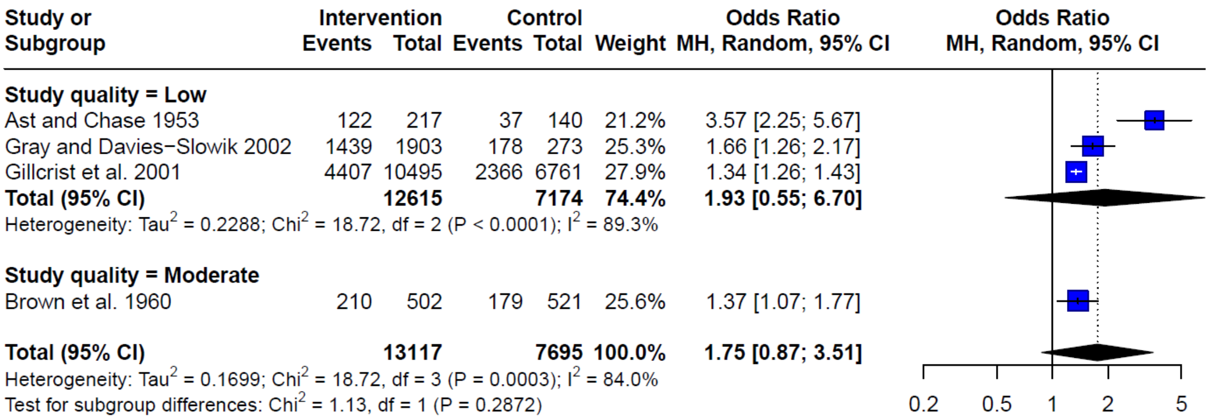


Figure 12 Forest Plot of odds ratio (MH 95% CI) of per cent without cavitated dental caries measured using dmft in CWF areas compared with fluoride-deficient areas by study quality subgroup analyses

One paper, which was of moderate quality with regard to design and conduct, reported data for two time points [83] (Table 31). The paper, which was published in 1960, compared the effect of CWF in the intervention area (1.0–1.2 ppm) compared with the control (or fluoride-deficient) areas using the outcome of percentage of participants without cavitated dental caries in the primary dentition. The data were collected in 1948 and 1959 for 9–11-year-old children living in two Canadian cities. The paper found that the percentage of 9–11-year-old children without cavitated dental caries in the primary dentition after 11 years of exposure to CWF was greater in the CWF group; the percentage of children without cavitated dental caries in the CWF group had increased by 6.87 percentage points compared with the comparator group, in which the percentage of children without cavitated dental caries had increased by only 0.73 percentage points over the 11-year period. The percentage point difference at the first time point was 1.33 (95% CI: -4.12–6.78) in favour of CWF and a 7.47 (95 % CI: 1.53–13.41) percentage-point difference in favour of CWF at the final time point, resulting in an overall percentage point difference of 6.14 in the percentage of 9–11-year-old children without cavitated dental caries in the primary dentition in favour of CWF. The result was reported by the authors to be statistically significant. The certainty of the evidence is very low. This study was undertaken before 1975 and thus without the influence of the additional effect of fluoride toothpaste. In addition, the availability of fluoride toothpaste since 1975 means that such a differential in caries between CWF and non-fluoridated areas would no longer be observed in countries where fluoride toothpaste is available and affordable.

3.1.4.4.6 Percentage of participants with cavitated dental caries in the primary dentition

The feasibility assessment for meta-analysis of the outcome of percentage of participants with cavitated dental caries in the primary dentition indicated that of the four papers examining this outcome, three papers had a moderate quality rating [116,121,126] and one paper had a high quality rating [94] with regard to design and conduct (Appendix I of Section 6.8, Table 14). Three papers were census studies and therefore did not require a variance measure (although we provided a notional measure of 0.01% for prevalence measures in order to facilitate computerised statistical analysis) [116,121,126], and one paper provided percentages and 95% CIs for participants with cavitated dental caries in the primary dentition [94].

All four papers were included in a pairwise random effects meta-analysis treating each paper as a single-time-point study [94,116,121,126]. Three papers were judged moderate quality with regard to design and conduct and one paper was judged high quality. The four papers, published between 1984 and 2021, compared the effect of CWF in the intervention and control (or fluoride-deficient) areas using the outcome of percentage of participants with cavitated dental caries in the primary dentition. The four papers were judged suitable for single-time-point meta-analysis. The children in these papers were aged 5–7 years. The CWF level was circa 0.6 ppm in one paper, 0.6 ppm–0.8 ppm in two papers and 1.0 ppm in the remaining paper, so subgroup analysis was not recommended. The results of the single-time-point pairwise random effects meta-analysis indicate an odds ratio of 0.50 (95% CI: 0.40–0.63; I^2: 0%; 4 papers) in favour of CWF, the results are statistically significant and had very low heterogeneity between studies (Figure 13). The results imply there is low certainty evidence that children aged 5–7 years have 50% lower odds of having cavitated dental caries in one or more teeth in the primary dentition in the CWF area compared with the fluoride-deficient area at a single time point.

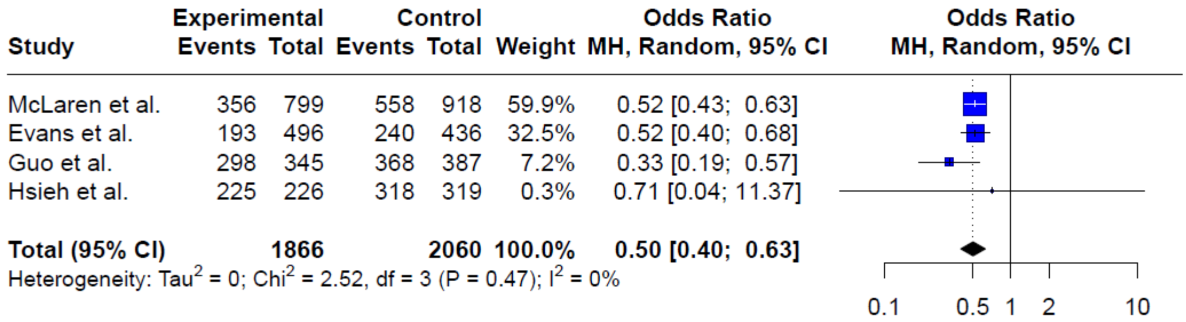


Figure 13 Forest Plot of odds ratio (MH 95% CI) of per cent with cavitated dental caries measured using dmft in CWF areas compared with fluoride-deficient areas

Two of the included papers in a census study series reported data for 5-year-olds at two time points; the lowest CWF ppm level in both papers was 0.6–0.8, a meta-analysis could not be undertaken to examine the difference over time due to an inadequate number of papers and the different follow-up periods [121,126]. The two included papers in a census study series reported data for 5-year-olds at two time points (baseline and 9 or 12 years later); the CWF level in both papers was 0.6–0.8 ppm, a meta-analysis could not be undertaken to examine the difference over time due to an inadequate number of papers and different follow-up periods (Table 32). The papers reported that the percentage of 5 year old participants with cavitated dental caries in the primary dentition was lower in the CWF groups after 9 or 12 years of CWF compared with the respective fluoride-deficient area, although the absolute rates from the two papers were very different at 8.70 (95% CI: 8.84–8.56) and 0.1 (95% CI: 0.24–0.04) percentage points difference at the final timepoint). Therefore, there is very low certainty evidence that the percentage of 5-year-olds with cavitated dental caries in the primary dentition was much lower in the first study and marginally lower in the second in the CWF area compared with the fluoride-deficient area after 9 or 12 years, respectively.

Table 31 Percentage of participants without cavitated dental caries in the primary dentition, baseline and follow-up study excluded from meta-analysis

Author * (year), country	Study design and census/cluster sample adjustment where reported	Study population age (in years)	CWF lifetime exposure (ppm)	Comparator lifetime exposure (ppm)	Dental caries outcome, proportion agreement where reported	Statistical measure and variance	Regression to adjust for confounding	Confounders	Study quality	Baseline % without CDC – CWF	Baseline SD - CWF	Baseline total participants – CWF	Final % without CDC – CWF	Final SE – CWF	Final total participants – CWF	Baseline % without CDC – no F	Baseline SD – no F	Baseline total participants – no F	Final % without CDC – no F	Final SE – no F	Final total participants– no F	Percentage point difference at final time point	Index
Brown et al. (1960) [83], Canada	Cross-sectional survey	9–11	1.0–1.2	No fluoride	Percentage of primary teeth without cavitated dental caries	%, 95% CI	No	N/A	Moderate	34.96	SE 1.956 (SD 47.712)	595	41.83	2.202	502	33.63	SE 1.977 (SD 47.242)	571	34.36	2.081	521	7.47 (95 % CI: 1.53–13.41)	NR

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

No F = no fluoride; SE = standard error (SD hand calculated); NR = not reported

Table 32 Percentage of participants with cavitated dental caries in the primary dentition, baseline and follow-up papers excluded from meta-analysis

Author * (year), country	Study design and census/cluster sample adjustment where reported	Study population age (in years)	CWF lifetime exposure (ppm)	Comparator lifetime exposure (ppm)	Dental caries outcome, proportion agreement where reported	Statistical measure and variance	Regression to adjust for confounding	Confounders	Study quality	Baseline % with CDC – CWF	Baseline 95% CI – CWF	Baseline total participants – CWF	Final % with CDC – CWF	Final 95% CI – CWF	Final total participants – CWF	Baseline % with CDC – no F	Baseline 95% CI – no F	Baseline total participants – no F	Final % CDC – no F	Final 95% CI – no F	Final total participants – no F	Percentage point difference at final time point	Index
Guo et al. (1984) [121], Taiwan	Cross-sectional census survey	5	0.6	0.08	Percentage of primary teeth with cavitated dental caries	% (variance not required for prevalence, as census)	No	Not applicable	Moderate	89.6	±0.1	589	86.4	±0.1	345	91.7	±0.1	218	95.1	±0.1	387	8.70 (95% CI: 8.84–8.56)	WHO
Hsieh et al. (1986) [126], Taiwan	Cross-sectional census survey	5	0.6–0.7	0.08	Percentage of primary teeth with cavitated dental caries	% (variance not required for prevalence, as census)	No	Not applicable	Moderate	89.6	±0.1	589	99.6	±0.1	226	91.7	±0.1	218	99.7	±0.1	319	0.1 (95% CI: 0.24–0.04)	WHO

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

No F = no fluoride, 95% CI hand calculated

3.1.4.4.7 Mean decayed, missing, or filled permanent teeth (DMFT)

The feasibility assessment for meta-analysis of the outcome of DMFT indicated that of the 25 relevant papers, 10 papers had a low quality rating with regard to design and conduct [89,117,118,129,131,134,136,139,141,162](Appendix I of Section 6, Table 15).

Of the 25 papers, 3 papers were reporting on a census study and did not require a variance measure (although we provided a notional measure of 0.1 for SDs to facilitate computerised statistical analysis) [121,125,126], and 22 papers provided means and SDs [53,83,85,94,97,98,100,113,114,128,129,131,134–136,139–141,143,156,160,162].

All 25 papers were included in a meta-analysis of single-time-point studies [53,83,85,94,97,98,100,113,114,121,125,126,128,129,131,134–136,139–141,143,156,160,162]. Five of the 25 papers reported data for two time points [83,121,125,126,129].

The 25 papers included in the meta-analyses were undertaken in Brazil (1 paper) [98], Canada (4 papers +2) [83,85,94,113], Chile (1 paper) [100], Cuba (1 paper) [135], England (+2 papers) [139,141], Germany (+2 papers) [134,162], Ireland (4 papers +1) [53,136,140,143], Malaysia (1 paper) [97], the Netherlands (+1 paper) [131], New Zealand (2 papers +1) [114,160], Taiwan (3 papers) [121,125,126], and Wales, UK (3 papers +1) [129,130,156]. Three papers [83,85,130] reported on studies that were undertaken before or during 1975, and the studies reported on in all the other papers were undertaken after 1975, specifically between 1978 and 2019. One paper reported a CWF level of 0.5 ppm [97], one paper reported a CWF level of 0.5–0.6 ppm [98], seven papers reported a CWF level of 0.6–0.8 ppm [94,121,125,126,135,140,156], and the remaining sixteen papers reported a CWF level of 0.81–1.2 ppm [53,83,100,129,143,160] [85,113,114,128,131,134,136,139,141,162]. Sixteen papers included participants aged between 6 and 12 years [53,83,94,97,98,100,113,114,121,125,126,134–136,143,162], 8 papers included participants aged between 14 and 16 years [85,129–131,139–141,160], and the final paper included pregnant women aged between 18 and 32 years [156] (Appendix I of Section 6, Table 15). The 25 papers were published between 1960 and 2021, compared the effect of CWF in the intervention and control (or fluoride-deficient) areas using the outcome of mean DMFT and were judged suitable for meta-analysis.

Figure 14 presents the standardised MD (±SDs) for dental caries measured using DMFT in CWF areas compared with fluoride-deficient areas. Four outlier papers were identified and removed due to incompatibility, leaving 21 papers (Figure 15). The results of the single-time-point meta-analysis indicate a standardised mean difference of −0.83 (95% CI: −1.27 to -0.38; I^2: 98.4%; 21 papers) in favour of CWF, the result is statistically significantly different. There is very high statistical heterogeneity in the model partly due to the wide age span, higher ppm, and study quality. In subgroup analyses, there was no difference in effectiveness by CWF level (Figure 16), and the results of high-quality papers crossed the line indicating no significant difference in effectiveness while the overall results of moderate quality papers indicated higher effectiveness (Figure 17). There is very low certainty evidence that the mean difference for DMFT equates to an average gain of almost one additional healthy tooth per person aged 6–32 years in the CWF areas compared with the fluoride-deficient areas at a single time point.

Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Brown et al. 1960	1.52	0.0750	502	3.68	0.1030	521	4.0%	−23.89 [−24.93; −22.84]
Brown and Poplove 1965	4.74	0.1800	356	10.44	0.2200	482	4.0%	−27.92 [−29.27; −26.57]
Jackson et al. 1975a	6.37	0.3700	88	11.44	0.5900	97	4.0%	−10.15 [−11.23; −9.06]
Hsieh et al. 1979	0.10	0.4000	312	0.30	0.7000	238	4.0%	−0.36 [−0.53; −0.19]
Kunzel 1980	1.30	1.4100	164	3.10	1.9500	272	4.0%	−1.02 [−1.22; −0.81]
Guo et al. 1984	1.10	1.5000	310	2.40	2.0000	436	4.0%	−0.72 [−0.87; −0.57]
Lemasney et al. 1984	2.12	1.9700	182	3.63	2.7900	126	4.0%	−0.64 [−0.88; −0.41]
de Liefde and Herbison 1985	1.70	1.6000	191	2.40	1.9000	237	4.0%	−0.39 [−0.59; −0.20]
Jackson et al. 1985	4.73	0.2750	141	7.69	0.4240	86	4.0%	−8.70 [−9.55; −7.85]
Hsieh et al. 1986	1.90	2.4000	329	4.30	3.6000	458	4.0%	−0.76 [−0.91; −0.61]
O'Mullane et al. 1986	2.60	2.3000	749	3.30	2.5000	755	4.0%	−0.29 [−0.39; −0.19]
Clovis et al. 1988	2.26	2.4300	53	2.43	2.1100	77	4.0%	−0.08 [−0.43; 0.27]
Mitropoulos et al. 1988	2.26	2.4600	234	3.79	3.2200	275	4.0%	−0.53 [−0.70; −0.35]
Murray et al. 1991	2.70	0.1300	349	3.40	0.1600	347	4.0%	−4.80 [−5.09; −4.51]
Thomas and Kassab 1992	9.48	4.0400	170	13.62	4.6000	479	4.0%	−0.93 [−1.11; −0.74]
Kalsbeek et al. 1993	7.40	4.0000	285	14.10	5.7000	261	4.0%	−1.37 [−1.56; −1.18]
Treasure and Dever 1994	2.33	2.1600	134	4.52	3.7000	48	4.0%	−0.82 [−1.16; −0.48]
Villa et al. 1998	1.28	1.6500	152	3.10	2.6500	155	4.0%	−0.82 [−1.05; −0.59]
Kunzel and Fischer 2000	1.10	1.5100	126	3.10	1.7900	85	4.0%	−1.22 [−1.52; −0.92]
Kunzel et al. 2000	2.47	2.0600	337	4.65	1.7700	472	4.0%	−1.15 [−1.30; −1.00]
Whelton et al. 2004	1.10	1.4000	2090	1.30	1.7000	747	4.0%	−0.13 [−0.22; −0.05]
Mullen et al. 2012	2.42	4.4600	823	3.61	2.0300	253	4.0%	−0.30 [−0.44; −0.15]
Mohd Nor et al. 2018	0.47	0.9700	294	1.31	1.8100	301	4.0%	−0.58 [−0.74; −0.41]
McLaren et al. 2021	0.19	0.7800	791	0.26	1.0000	912	4.0%	−0.08 [−0.17; 0.02]
Silva et al. 2021	1.53	1.8100	178	2.63	3.0200	184	4.0%	−0.44 [−0.65; −0.23]
Total (95% CI)			**9340**			**8304**	**100.0%**	**−3.51 [−6.48; −0.53]**
Prediction interval								**[−18.62; 11.61]**

Heterogeneity: $Tau^2 = 51.5671$; $Chi^2 = 5410.71$, df = 24 (P = 0); $I^2 = 99.6\%$

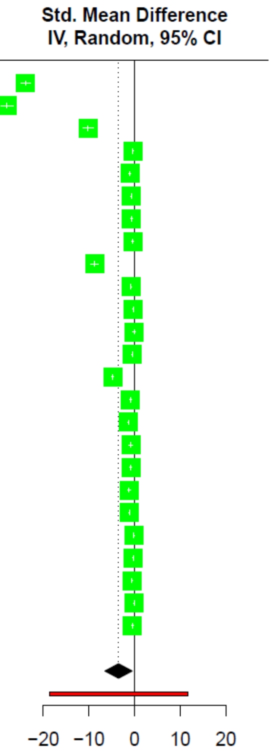


Figure 14 Forest plot of standardised MD (±SDs) for dental caries measured using DMFT in CWF areas compared with fluoride-deficient

Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Hsieh et al. 1979	0.10	0.4000	312	0.30	0.7000	238	4.8%	−0.36 [−0.53; −0.19]
Kunzel 1980	1.30	1.4100	164	3.10	1.9500	272	4.8%	−1.02 [−1.22; −0.81]
Guo et al. 1984	1.10	1.5000	310	2.40	2.0000	436	4.8%	−0.72 [−0.87; −0.57]
Lemasney et al. 1984	2.12	1.9700	182	3.63	2.7900	126	4.7%	−0.64 [−0.88; −0.41]
de Liefde and Herbison 1985	1.70	1.6000	191	2.40	1.9000	237	4.8%	−0.39 [−0.59; −0.20]
Hsieh et al. 1986	1.90	2.4000	329	4.30	3.6000	458	4.8%	−0.76 [−0.91; −0.61]
O'Mullane et al. 1986	2.60	2.3000	749	3.30	2.5000	755	4.8%	−0.29 [−0.39; −0.19]
Clovis et al. 1988	2.26	2.4300	53	2.43	2.1100	77	4.7%	−0.08 [−0.43; 0.27]
Mitropoulos et al. 1988	2.26	2.4600	234	3.79	3.2200	275	4.8%	−0.53 [−0.70; −0.35]
Murray et al. 1991	2.70	0.1300	349	3.40	0.1600	347	4.7%	−4.80 [−5.09; −4.51]
Thomas and Kassab 1992	9.48	4.0400	170	13.62	4.6000	479	4.8%	−0.93 [−1.11; −0.74]
Kalsbeek et al. 1993	7.40	4.0000	285	14.10	5.7000	261	4.8%	−1.37 [−1.56; −1.18]
Treasure and Dever 1994	2.33	2.1600	134	4.52	3.7000	48	4.7%	−0.82 [−1.16; −0.48]
Villa et al. 1998	1.28	1.6500	152	3.10	2.6500	155	4.7%	−0.82 [−1.05; −0.59]
Kunzel and Fischer 2000	1.10	1.5100	126	3.10	1.7900	85	4.7%	−1.22 [−1.52; −0.92]
Kunzel et al. 2000	2.47	2.0600	337	4.65	1.7700	472	4.8%	−1.15 [−1.30; −1.00]
Whelton et al. 2004	1.10	1.4000	2090	1.30	1.7000	747	4.8%	−0.13 [−0.22; −0.05]
Mullen et al. 2012	2.42	4.4600	823	3.61	2.0300	253	4.8%	−0.30 [−0.44; −0.15]
Mohd Nor et al. 2018	0.47	0.9700	294	1.31	1.8100	301	4.8%	−0.58 [−0.74; −0.41]
McLaren et al. 2021	0.19	0.7800	791	0.26	1.0000	912	4.8%	−0.08 [−0.17; 0.02]
Silva et al. 2021	1.53	1.8100	178	2.63	3.0200	184	4.8%	−0.44 [−0.65; −0.23]
Total (95% CI)			**8253**			**7118**	**100.0%**	**−0.83 [−1.27; −0.38]**
Prediction interval								**[−2.89; 1.24]**

Heterogeneity: $Tau^2 = 0.9361$; $Chi^2 = 1259.65$, df = 20 (P < 0.0001); $I^2 = 98.4\%$

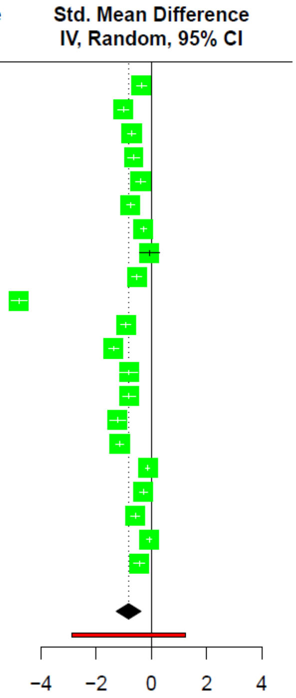


Figure 15 Forest plot of standardised MD (±SDs) for dental caries measured using DMFT in CWF areas compared with fluoride-deficient areas (sensitivity analysis with four outlier papers removed)

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Fluoridation status = <0.6ppm								
Mohd Nor et al. 2018	0.47	0.9700	294	1.31	1.8100	301	4.8%	−0.58 [−0.74; −0.41]
Fluoridation status = 0.6−0.8ppm								
Hsieh et al. 1979	0.10	0.4000	312	0.30	0.7000	238	4.8%	−0.36 [−0.53; −0.19]
Guo et al. 1984	1.10	1.5000	310	2.40	2.0000	436	4.8%	−0.72 [−0.87; −0.57]
Hsieh et al. 1986	1.90	2.4000	329	4.30	3.6000	458	4.8%	−0.76 [−0.91; −0.61]
Thomas and Kassab 1992	9.48	4.0400	170	13.62	4.6000	479	4.8%	−0.93 [−1.11; −0.74]
Kunzel and Fischer 2000	1.10	1.5100	126	3.10	1.7900	85	4.7%	−1.22 [−1.52; −0.92]
Mullen et al. 2012	2.42	4.4600	823	3.61	2.0300	253	4.8%	−0.30 [−0.44; −0.15]
McLaren et al. 2021	0.19	0.7800	791	0.26	1.0000	912	4.8%	−0.08 [−0.17; 0.02]
Silva et al. 2021	1.53	1.8100	178	2.63	3.0200	184	4.8%	−0.44 [−0.65; −0.23]
Total (95% CI)			**3039**			**3045**	**38.2%**	**−0.59 [−0.90; −0.28]**
Heterogeneity: $Tau^2 = 0.1258$; $Chi^2 = 145.75$, df = 7 ($P < 0.0001$); $I^2 = 95.2\%$								
Fluoridation status = >0.8ppm								
Kunzel 1980	1.30	1.4100	164	3.10	1.9500	272	4.8%	−1.02 [−1.22; −0.81]
Lemasney et al. 1984	2.12	1.9700	182	3.63	2.7900	126	4.7%	−0.64 [−0.88; −0.41]
de Liefde and Herbison 1985	1.70	1.6000	191	2.40	1.9000	237	4.8%	−0.39 [−0.59; −0.20]
O'Mullane et al. 1986	2.60	2.3000	749	3.30	2.5000	755	4.8%	−0.29 [−0.39; −0.19]
Clovis et al. 1988	2.26	2.4300	53	2.43	2.1100	77	4.7%	−0.08 [−0.43; 0.27]
Mitropoulos et al. 1988	2.26	2.4600	234	3.79	3.2200	275	4.8%	−0.53 [−0.70; −0.35]
Murray et al. 1991	2.70	0.1300	349	3.40	0.1600	347	4.7%	−4.80 [−5.09; −4.51]
Kalsbeek et al. 1993	7.40	4.0000	285	14.10	5.7000	261	4.8%	−1.37 [−1.56; −1.18]
Treasure and Dever 1994	2.33	2.1600	134	4.52	3.7000	48	4.7%	−0.82 [−1.16; −0.48]
Villa et al. 1998	1.28	1.6500	152	3.10	2.6500	155	4.7%	−0.82 [−1.05; −0.59]
Kunzel et al. 2000	2.47	2.0600	337	4.65	1.7700	472	4.8%	−1.15 [−1.30; −1.00]
Whelton et al. 2004	1.10	1.4000	2090	1.30	1.7000	747	4.8%	−0.13 [−0.22; −0.05]
Total (95% CI)			**4920**			**3772**	**57.0%**	**−1.00 [−1.80; −0.20]**
Heterogeneity: $Tau^2 = 1.5602$; $Chi^2 = 1092.97$, df = 11 ($P < 0.0001$); $I^2 = 99\%$								
Total (95% CI)			**8253**			**7118**	**100.0%**	**−0.83 [−1.27; −0.38]**
Prediction interval								**[−2.89; 1.24]**
Heterogeneity: $Tau^2 = 0.9361$; $Chi^2 = 1259.65$, df = 20 ($P < 0.0001$); $I^2 = 98.4\%$								
Test for subgroup differences: $Chi^2 = 1.31$, df = 2 ($P = 0.5193$)								

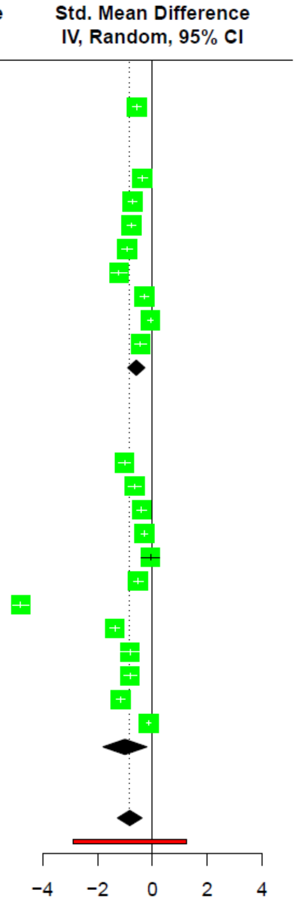


Figure 16 Forest plot of standardised MD (±SDs) for dental caries measured using DMFT in CWF areas compared with fluoride-deficient areas by CWF PPM subgroup analyses

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Study quality = High								
McLaren et al. 2021	0.19	0.7800	791	0.26	1.0000	912	4.8%	−0.08 [−0.17; 0.02]
Silva et al. 2021	1.53	1.8100	178	2.63	3.0200	184	4.8%	−0.44 [−0.65; −0.23]
Total (95% CI)			**969**			**1096**	**9.6%**	**−0.25 [−2.54; 2.05]**
Heterogeneity: $Tau^2 = 0.0586$; $Chi^2 = 9.57$, df = 1 (P = 0.0020); $I^2 = 89.5\%$								
Study quality = Low								
Kunzel 1980	1.30	1.4100	164	3.10	1.9500	272	4.8%	−1.02 [−1.22; −0.81]
Lemasney et al. 1984	2.12	1.9700	182	3.63	2.7900	126	4.7%	−0.64 [−0.88; −0.41]
de Liefde and Herbison 1985	1.70	1.6000	191	2.40	1.9000	237	4.8%	−0.39 [−0.59; −0.20]
Clovis et al. 1988	2.26	2.4300	53	2.43	2.1100	77	4.7%	−0.08 [−0.43; 0.27]
Mitropoulos et al. 1988	2.26	2.4600	234	3.79	3.2200	275	4.8%	−0.53 [−0.70; −0.35]
Murray et al. 1991	2.70	0.1300	349	3.40	0.1600	347	4.7%	−4.80 [−5.09; −4.51]
Kalsbeek et al. 1993	7.40	4.0000	285	14.10	5.7000	261	4.8%	−1.37 [−1.56; −1.18]
Kunzel et al. 2000	2.47	2.0600	337	4.65	1.7700	472	4.8%	−1.15 [−1.30; −1.00]
Total (95% CI)			**1795**			**2067**	**38.0%**	**−1.25 [−2.49; 0.00]**
Heterogeneity: $Tau^2 = 2.2088$; $Chi^2 = 759.44$, df = 7 (P < 0.0001); $I^2 = 99.1\%$								
Study quality = Moderate								
Hsieh et al. 1979	0.10	0.4000	312	0.30	0.7000	238	4.8%	−0.36 [−0.53; −0.19]
Guo et al. 1984	1.10	1.5000	310	2.40	2.0000	436	4.8%	−0.72 [−0.87; −0.57]
Hsieh et al. 1986	1.90	2.4000	329	4.30	3.6000	458	4.8%	−0.76 [−0.91; −0.61]
O'Mullane et al. 1986	2.60	2.3000	749	3.30	2.5000	755	4.8%	−0.29 [−0.39; −0.19]
Thomas and Kassab 1992	9.48	4.0400	170	13.62	4.6000	479	4.8%	−0.93 [−1.11; −0.74]
Treasure and Dever 1994	2.33	2.1600	134	4.52	3.7000	48	4.7%	−0.82 [−1.16; −0.48]
Villa et al. 1998	1.28	1.6500	152	3.10	2.6500	155	4.7%	−0.82 [−1.05; −0.59]
Kunzel and Fischer 2000	1.10	1.5100	126	3.10	1.7900	85	4.7%	−1.22 [−1.52; −0.92]
Whelton et al. 2004	1.10	1.4000	2090	1.30	1.7000	747	4.8%	−0.13 [−0.22; −0.05]
Mullen et al. 2012	2.42	4.4600	823	3.61	2.0300	253	4.8%	−0.30 [−0.44; −0.15]
Mohd Nor et al. 2018	0.47	0.9700	294	1.31	1.8100	301	4.8%	−0.58 [−0.74; −0.41]
Total (95% CI)			**5489**			**3955**	**52.4%**	**−0.61 [−0.83; −0.39]**
Heterogeneity: $Tau^2 = 0.0964$; $Chi^2 = 167.26$, df = 10 (P < 0.0001); $I^2 = 94\%$								
Total (95% CI)			**8253**			**7118**	**100.0%**	**−0.83 [−1.27; −0.38]**
Prediction interval								**[−2.89; 1.24]**
Heterogeneity: $Tau^2 = 0.9361$; $Chi^2 = 1259.65$, df = 20 (P < 0.0001); $I^2 = 98.4\%$								
Test for subgroup differences: $Chi^2 = 4.99$, df = 2 (P = 0.0823)								

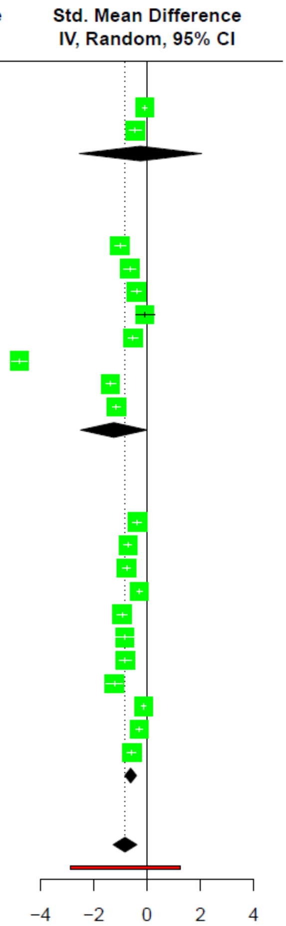


Figure 17 Forest plot of standardised MD (±SDs) for dental caries measured using DMFT in CWF areas compared with fluoride-deficient areas by study quality subgroup analyses

Five of the 21 papers of, published between 1960 and 1986, comparing the effect of CWF in the intervention areas with the control (or fluoride-deficient) areas using the outcome of mean DMFT reported data for two time points, meta-analysis was not possible as the follow-up period was different in each of the papers, ranging from 6–12 years. The participants were aged 6–15 years [83,121,125,126,129]. The CWF level was 0.6 ppm in three papers, and 0.8 ppm or higher in the remaining two papers (Table 33). The mean difference over time for DMFT in the areas with CWF was 2.55 (0.12 SD) higher to -0.8 (3.06 SD) lower, (lower mean difference equates with better outcome). The mean difference over time for DMFT in the fluoride deficient areas was 3.75 (0.73 SD) higher to -3.5 (4.42 SD) lower. Therefore, there is very low certainty evidence of mixed findings for DMFT in persons aged 6–15 years over two time points with four papers reporting a greater reduction in mean DMFT in the CWF area compared with the fluoride deficient area, and one paper reporting a greater reduction in the fluoride deficient area compared with the CWF area.

Table 33 Difference over time for dental caries measured using DMFT in CWF areas compared with fluoride-deficient areas, baseline and follow-up study excluded from meta-analysis

Authur, year, country	Age (years)	Intervention group baseline		Intervention group follow-up		Intervention Group difference	Control group baseline		Control group follow-up		Control Group difference	Years of follow-up
		Mean (SD)	N	Mean (SD)	N	MD (SMD)*	Mean (SD)	N	Mean (SD)	N	MD (SD)*	
Brown et al. 1960 [83], Canada	09-11	4.07 (0.09)	595	1.52 (0.08)	502	2.55 (0.12)	4.21 (0.11)	571	3.68 (0.10)	521	0.53 (0.12)	11
Guo et al. 1984 [121], Tiawan	10	0.7 (1.3)	346	1.1 (1.5)	310	-0.4 (2.03)	0.8 (1.5)	323	2.4 (2.0)	436	-1.6 (2.48)	6
Hsieh et al. 1979 [125], Taiwan	6	0.2 (0.6)	695	0.1 (0.4)	312	0.1 (0.69)	0.1 (0.40)	309	0.3 (0.70)	238	-0.2 (0.84)	9
Jackson et al. 1985 [129], Wales	15	6.37 (0.37)	88	4.73 (0.28)	141	1.64 (0.49)	11.44 (0.59)	97	7.69 (0.42)	86	3.75 (0.73)	12
Hsieh et al. 1986 [126], Tiawan	12	1.1 (1.7)	468	1.9 (2.4)	329	-0.8 (3.06)	0.8 (1.50)	841	4.3 (3.60)	458	-3.5 (4.42)	9

*MD (SD) Mean difference (standardised deviation)

3.1.4.4.8 Mean decayed, missing, or filled permanent surfaces (DMFS)

The feasibility assessment for meta-analysis of the DMFS outcome indicated that of the six papers that measured this outcome, two papers had a moderate quality rating with regard to design and conduct [135,160] and four papers had a low quality rating [115,118,131,141] (Appendix I of Section 6, Table 16).

The six papers were published between 1991 and 2001, compared the effect of CWF in the intervention and control (or fluoride-deficient) areas using the outcome of mean DMFS. The participants were 5–16-year-old children and all papers were single-time-point studies. Two papers reported a level of 0.6–0.8 ppm [115,135] and the remaining four papers reported a CWF level of 0.8–1.0 ppm. Figure 18 presents the standardised MD (±SDs) for dental caries measured using DMFS in CWF areas compared with fluoride-deficient. One outlier paper was removed due to incompatibility, leaving five papers (Figure 19). The results of the single-time-point meta-analysis indicate a standardised mean difference of −0.72 (95% CI: −1.46 to 0.3; I^2: 98.5%; 5 papers) in favour of CWF, the result is not statistically significantly different. There is very high statistical heterogeneity in the model partly due to the wide age span. In subgroup analyses, there was no difference by CWF level (Figure 20) or study quality (Figure 21). Therefore, there is very low certainty evidence that the mean difference for DMFS equates to an average gain of almost one additional healthy tooth surface per person aged 5–16 years in the CWF areas compared with the fluoride-deficient areas at a single time point.

Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Murray et al. 1991	3.70	0.6900	349	6.20	0.3800	347	16.6%	−4.48 [−4.76; −4.20]
Kalsbeek et al. 1993	10.80	7.7000	285	27.70	14.6000	261	16.7%	−1.46 [−1.65; −1.28]
Treasure and Dever 1994	2.97	3.0800	134	6.19	6.4100	48	16.6%	−0.76 [−1.10; −0.42]
Ellwood and O'Mullane 1995	3.18	3.9200	196	4.18	4.5600	267	16.7%	−0.23 [−0.42; −0.05]
Kunzel and Fischer 2000	1.50	2.2100	126	4.80	3.7600	85	16.6%	−1.12 [−1.42; −0.83]
Gillcrist et al. 2001	0.77	6.0100	10495	1.02	4.8200	6761	16.8%	−0.04 [−0.08; −0.01]
Total (95% CI)			**11585**			**7769**	**100.0%**	**−1.35 [−3.05; 0.35]**
Prediction interval								**[−5.84; 3.14]**

Heterogeneity: $Tau^2 = 2.6140$; $Chi^2 = 1211.74$, df = 5 ($P < 0.0001$); $I^2 = 99.6\%$

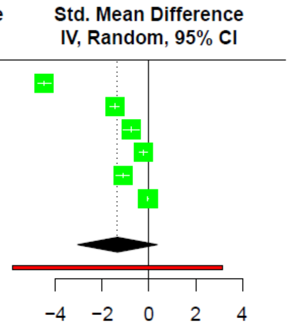


Figure 18 Forest plot of standardised MD (±SDs) for dental caries measured using DMFS in CWF areas compared with fluoride-deficient

Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Kalsbeek et al. 1993	10.80	7.7000	285	27.70	14.6000	261	20.3%	−1.46 [−1.65; −1.28]
Treasure and Dever 1994	2.97	3.0800	134	6.19	6.4100	48	19.2%	−0.76 [−1.10; −0.42]
Ellwood and O'Mullane 1995	3.18	3.9200	196	4.18	4.5600	267	20.3%	−0.23 [−0.42; −0.05]
Kunzel and Fischer 2000	1.50	2.2100	126	4.80	3.7600	85	19.5%	−1.12 [−1.42; −0.83]
Gillcrist et al. 2001	0.77	6.0100	10495	1.02	4.8200	6761	20.8%	−0.04 [−0.08; −0.01]
Total (95% CI)			**11236**			**7422**	**100.0%**	**−0.72 [−1.46; 0.03]**
Prediction interval								**[−2.53; 1.09]**

Heterogeneity: $Tau^2 = 0.3511$; $Chi^2 = 274.72$, df = 4 ($P < 0.0001$); $I^2 = 98.5\%$

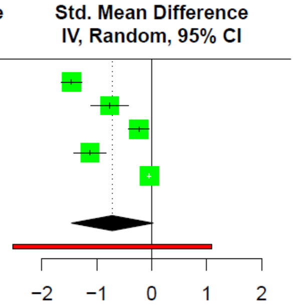


Figure 19 Forest plot of standardised MD (±SDs) for dental caries measured using DMFS in CWF areas compared with fluoride-deficient areas (sensitivity analysis with one outlier study removed)

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Fluoridation status = 0.6−0.8ppm								
Ellwood and O'Mullane 1995	3.18	3.9200	196	4.18	4.5600	267	16.7%	−0.23 [−0.42; −0.05]
Kunzel and Fischer 2000	1.50	2.2100	126	4.80	3.7600	85	16.6%	−1.12 [−1.42; −0.83]
Total (95% CI)			**322**			**352**	**33.3%**	**−0.67 [−6.32; 4.98]**
Heterogeneity: $Tau^2 = 0.3793$; $Chi^2 = 24.97$, df = 1 ($P < 0.0001$); $I^2 = 96\%$								
Fluoridation status = >0.8ppm								
Murray et al. 1991	3.70	0.6900	349	6.20	0.3000	347	16.6%	−4.69 [−4.98; −4.40]
Kalsbeek et al. 1993	10.80	7.7000	285	27.70	14.6000	261	16.7%	−1.46 [−1.65; −1.28]
Treasure and Dever 1994	2.97	3.0800	134	6.19	6.4100	48	16.6%	−0.76 [−1.10; −0.42]
Gillcrist et al. 2001	0.77	6.0100	10495	1.02	4.8200	6761	16.8%	−0.04 [−0.08; −0.01]
Total (95% CI)			**11263**			**7417**	**66.7%**	**−1.74 [−5.00; 1.52]**
Heterogeneity: $Tau^2 = 4.1827$; $Chi^2 = 1195.12$, df = 3 ($P < 0.0001$); $I^2 = 99.7\%$								
Total (95% CI)			**11585**			**7769**	**100.0%**	**−1.38 [−3.17; 0.40]**
Prediction interval								**[−6.10; 3.33]**

Heterogeneity: $Tau^2 = 2.8811$; $Chi^2 = 1238.20$, df = 5 ($P < 0.0001$); $I^2 = 99.6\%$
Test for subgroup differences: $Chi^2 = 0.92$, df = 1 ($P = 0.3384$)

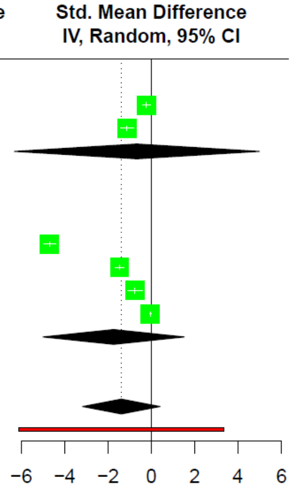


Figure 20 Forest plot of standardised MD (±SDs) for dental caries measured using DMFS in CWF areas compared with fluoride-deficient areas by CWF PPM subgroup analyses

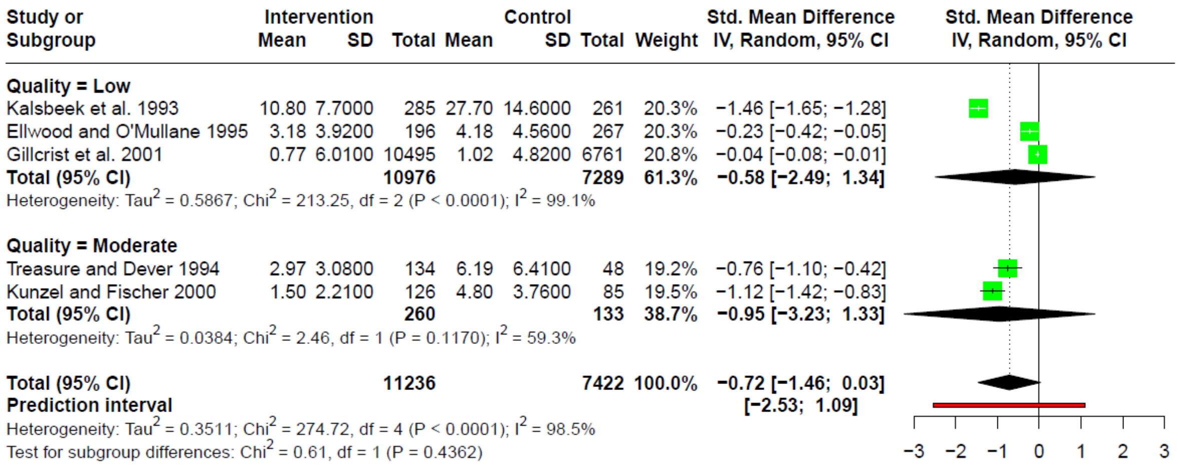


Figure 21 Forest plot of standardised MD (±SDs) for dental caries measured using DMFS in CWF areas compared with fluoride-deficient areas by study quality subgroup analyses

3.1.4.4.9 Percentage of participants without cavitated dental caries in the permanent dentition

The feasibility assessment for meta-analysis of the outcome of percentage of participants without cavitated dental caries in the permanent dentition indicated that of the three papers examined, one paper had a moderate quality rating with regard to design and conduct [83] and two papers had a low quality rating [85,118] (Appendix I of Section 6, Table 17).

The three papers were published between 1960 and 2001 and compared the effect of CWF in the intervention and control (or fluoride-deficient) areas using the outcome of percentage of participants without cavitated dental caries in the permanent dentition. The three papers were judged suitable for single-time-point meta-analysis. The participants in these papers were aged 5–17 years. The CWF level was between 1.0 and 1.2 ppm in the three papers. The results of the single-time-point pairwise random effects meta-analysis indicate an odds ratio of 6.67 (95% CI: 0.11–393.50; I^2: 96.6%; 3 papers) in favour of CWF, the results are not statistically significant and have very high heterogeneity partly due to age span and study year; two of the three papers were completed before widespread availability of fluoride toothpaste (Figure 22). The results imply there is very low certainty evidence that children aged 5–17 years have 6.67 higher odds of being cavity free in permanent teeth in the CWF area compared with the fluoride-deficient area at a single time point.

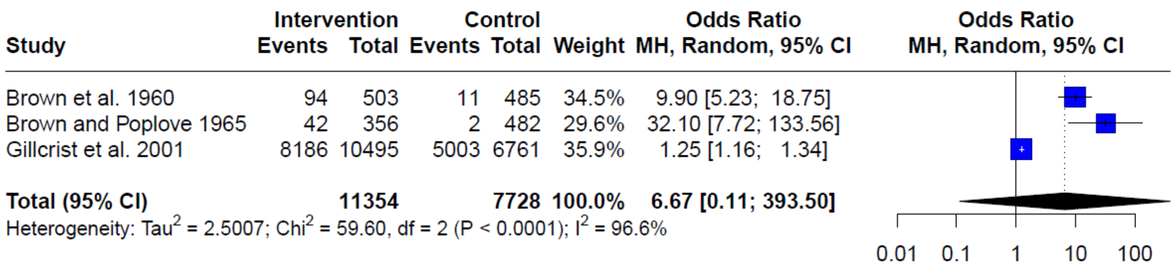


Figure 22 Forest Plot of odds ratio (MH 95% CI) of per cent without cavitated dental caries measured using DMFT in CWF areas compared with fluoride-deficient areas

One paper of moderate quality, published in 1960, compared the effect of CWF in the intervention (1.0–1.2 ppm) and control (or fluoride-deficient) areas using the outcome of percentage of participants without cavitated dental caries in the permanent dentition and reported data for two time points [83] (Table 34). The paper found that the percentage of 12–14-year-old children without cavitated dental caries in the permanent dentition after 11 years was greater in the CWF group than in the control (fluoride-deficient) group; the percentage of participants without cavitated dental caries in the CWF group had increased by 17.51 percentage points compared with the comparator group, in which that percentage had increased by only 1.65 percentage points over the 11-year study period. The percentage point difference at baseline was 0.56 (95% CI: -0.56 to -1.68). The percentage point difference at the final time point for the percentage of 12–14-year-old children without cavitated dental caries in the permanent dentition was 16.42 (95% CI: 12.77–20.07) percentage points higher in favour of CWF. The result was reported by the authors to be statistically significant. This study was undertaken before 1975 and thus without the influence of the additional effect of fluoride toothpaste. As there was only one study in this analysis, the certainty of this finding is very low. In addition, the availability of fluoride toothpaste since 1975 means that such a differential in caries between CWF and non-fluoridated areas would no longer be observed in countries where fluoride toothpaste is available and affordable. There is very low certainty evidence that the overall percentage point difference after 11 years equates to an average of 16 additional children in every 100 children aged 12–14 years having no cavitated dental caries in permanent teeth in the CWF area compared with the fluoride-deficient area.

Table 34 Percentage of participants without cavitated dental caries in the permanent dentition, baseline and follow-up study excluded from meta-analysis

Author * (year), country	Study design and census/cluster sample adjustment where reported	Study population age (in years)	CWF lifetime exposure (ppm)	Comparator lifetime exposure (ppm)	Dental caries outcome, proportion agreement where reported	Statistical measure and variance	Regression to adjust for confounding	Confounders	Study quality	Baseline total participants – CWF	Baseline % without CDC – CWF	Baseline SD – CWF	Final total participants – CWF	Final % without CDC – CWF	Final SD – CWF	Baseline total participants – no F	Baseline % without CDC – no F	Baseline SD – no F	Final total participants – no F	Final % without CDC – no F	Final SD – no F	Percentage point difference at final time point	Index
Brown et al. (1960) [83], Canada	Cross-sectional survey	12–14	1.0–1.2	No fluoride	Percentage of permanent teeth without cavitated dental caries	%, 95% CI	No	Not applicable	Moderate	593	1.18	SE 0.447 (SD 10.885)	503	18.69	SE 1.738 (SD 38.979)	486	0.62	SE 0.353 (SD 7.782)	485	2.27	SE 0.676 (SD 14.887)	16.42 (95% CI: 12.77 - 20.07)	NR

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

No F = no fluoride; SE = standard error (SD hand calculated); NR = not reported

3.1.4.4.10 Percentage of participants with cavitated dental caries in the permanent dentition

The feasibility assessment for meta-analysis of the outcome of percentage of participants with cavitated dental caries in the permanent dentition indicated that of the three papers examined, one paper had a high quality rating with regard to design and conduct [94] and two papers had a moderate quality rating [121,126] (Appendix I of Section 6, Table 18).

Two of the three papers reported on a census study [121,126] and therefore did not require a variance measure (although we provided a notional measure of 0.1 for SDs to facilitate computerised statistical analysis), and the third paper provided percentages and 95% CIs for participants with cavitated dental caries in the permanent dentition [94].

The three papers were judged suitable for single-time-point meta-analysis. The participants were aged 7–12 years. The CWF level was 0.5–0.7 ppm in one paper, and 0.6 ppm in two papers. The results of the single-time-point pairwise random effects meta-analysis indicate an odds ratio of 0.37 (95% CI: 0.07 to 1.90; I^2: 95%; 3 papers) in favour of CWF (Figure 23). However, the confidence intervals are very wide, and the results are not statistically significant. Study heterogeneity is very high but there were too few studies to identify factors that contributed to heterogeneity in the meta-analysis. Heterogeneity may be due to study location (1 study was located in Canada and 2 were in Taiwan). Therefore, there is very low certainty evidence that children aged 7–12 years have 63% lower odds of having cavitated dental caries in one or more teeth in the permanent dentition in the CWF area compared with the fluoride-deficient area at a single time point.

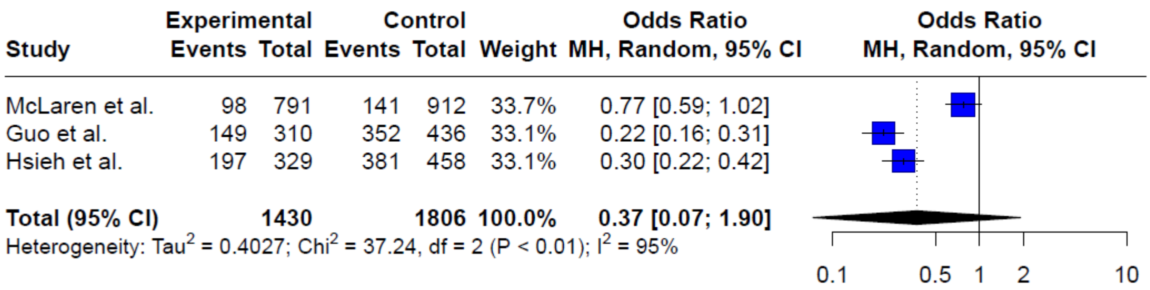


Figure 23 Forest Plot of odds ratio (MH 95% CI) of per cent with cavitated dental caries measured using DMFT in CWF areas compared with fluoride-deficient areas

Two of the three papers reporting on a census study reported data for two time points: the first paper reported data for 10-year-olds at baseline and at 9 years after the introduction of CWF, and the second paper reported data for 12-year-olds at baseline and at 12 years after the introduction of CWF [121,126]. A meta-analysis could not be undertaken for two time points due to an inadequate number of papers and the different follow-up periods. The two papers found that the percentage of participants with cavitated dental caries in the permanent dentition was lower in the CWF group at both time points: the percentage point difference between intervention and control groups at baseline was -0.50 (95% CI: -0.64 to -0.36) for the first paper, and 5.20 (95% CI: 5.06–5.34) for the second. The final percentage point difference was 32.60 (95% CI: 32.74–32.46) and 23.30 (95% CI: 23.44–23.16) respectively. The percentage of 10- and 12-year-olds with cavitated dental caries in permanent teeth in the CWF group had increased by 10.2 and 11.2 percentage points, respectively, compared with the comparator group, for which these percentages had increased by 42.3 and 39.7 percentage points, respectively, over the course of 9 and 12 years (Table 35). The certainty of the evidence is low.

Table 35 Percentage of participants with cavitated dental caries in the permanent dentition, baseline and follow-up papers excluded from meta-analysis

Author * (year), country	Study design and census/cluster sample adjustment where reported	Study population age (in years)	CWF lifetime exposure (ppm)	Comparator lifetime exposure (ppm)	Dental caries outcome, proportion agreement where reported	Statistical measure and variance	Regression to adjust for confounding	Confounders	Study quality	Baseline total participants – CWF	Baseline % with CDC – CWF	Baseline 95% CI – CWF	Final total participants – CWF	Final % with CDC – CWF	Final 95% CI – CWF	Baseline total participants – no F	Baseline % with CDC – no F	Baseline 95% CI – no F	Final % with CDC – no F	Final 95% CI – no F	Final total participants – no F	Percentage point difference at final time point	Index
Guo et al. (1984) [121], Taiwan	Cross-sectional census survey	10	0.6	0.08	Percentage of permanent teeth with cavitated dental caries	% (variance not required for prevalence, as census)	No	Not applicable	Moderate	346	37.9	0.1	310	48.1	0.1	323	38.4	0.1	80 .7	0.1	436	32.60 (95% CI: 32.74–32.46)	WHO
Hsieh et al. (1986) [126], Taiwan	Cross-sectional census survey	12	0.6	0.08	Percentage of permanent teeth with cavitated dental caries	% (variance not required for prevalence, as census)	No	Not applicable	Moderate	468	48.7	0.1	329	59.9	0.1	841	43.5	0.1	83.2	0.1	458	23.30 (95% CI: 23.44–23.16)	WHO

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

No F = no fluoride, 95% CI hand calculated

3.1.4.5 Narrative synthesis of CWF as an independent determinant of cavitated dental caries

We examined the papers on cavitated dental caries in order to determine if we could complete a meta-analysis to identify the independent influence of CWF on the cavitated dental caries outcomes of interest for the primary dentition (dmft, dmfs, percentage without cavitated dental caries, and percentage with cavitated dental caries) and the permanent dentition (DMFT, DMFS, percentage without cavitated dental caries, and percentage with cavitated dental caries). We identified all papers that completed regression analysis to control for the influence of confounding and examined the respective authors' regression analysis models in order to determine if they identified the odds (with 95% CIs) that CWF was associated with cavitated dental caries after controlling for at least one of five groups of confounders (i.e. demographic factors, socioeconomic factors, nutritional factors, other sources of dental fluoride, and access to and affordability of dental services).

Three papers completed regression analysis for the outcome of dmft in order to adjust for confounding [52,58,94]. McLaren *et al.* (2021) and James *et al.* (2021) completed regression analysis but did not quantify the independent association of CWF with change in dmft in children living in CWF areas compared with children living in fluoride-deficient areas [52,94]. Goodwin *et al.* (2022) controlled for the influence of age, sex, and deprivation and reported that the average dmft was 39% (odds ratio (OR): 0.61; 95% CI: 0.44–0.86) lower in children living in CWF areas compared with children living in fluoride-deficient areas [58].

Three papers presented regression analysis for the outcome of percentage of participants with cavitated dental caries in primary teeth in order to adjust for confounding [52,94,98]. McLaren *et al.* (2021) completed regression analysis but did not quantify the independent association of CWF with the change in the odds of cavitated dental caries in primary teeth in children living in CWF areas compared with children living in fluoride-deficient areas [94]. Silva *et al.* (2021) controlled for the influence of sex, mother's education, family income, who brushed the child's teeth, regular visits to dentist, and sugar ingestion and reported that participants living in fluoride-deficient areas had almost three times higher odds (OR: 2.86; 95% CI: 1.71–4.75) of having cavitated dental caries in their primary teeth than those living in a CWF area [98]. In addition, Goodwin *et al.* (2022) controlled for the influence of age, sex, and deprivation and reported that the percentage of children with cavitated dental caries in their primary teeth was 26% (OR: 0.74; 95% CI: 0.55–0.98) lower in children living in CWF areas compared with children living in fluoride-deficient areas [58].

McLaren *et al.* (2021) was the only paper that presented regression analysis for the outcome of DMFT, but the authors did not quantify its independent association with CWF [94].

Ellwood and O'Mullane (1995) was the only paper that presented regression analysis for the outcome of DMFS, and it identified that there were 33% fewer surfaces affected by cavitated dental caries in the CWF area compared with the control area [115].

Two papers presented regression analysis for the outcome of percentage of participants with cavitated dental caries in permanent teeth in order to adjust for confounding. McLaren *et al.* (2021) completed regression analysis, but the authors did not quantify the independent association of CWF with the change in the odds of cavitated dental caries in permanent teeth [94]. Silva *et al.* (2021) controlled for the influence of sex, mother's education, family income, and sugar ingestion and reported that participants living in fluoride-deficient areas had almost two times higher odds (OR: 1.95; 95% CI: 1.24–3.05) of having cavitated dental caries in their permanent teeth than those living in a CWF area [98].

There were no papers presenting logistic regression models for the outcomes of dmfs, percentage of participants without cavitated dental caries in primary dentition, and percentage of participants without cavitated dental caries in permanent dentition.

None of the four outcomes in primary and permanent dentition has three or more papers with a regression analysis model to determine the odds (with 95% CIs) that CWF was associated with cavitated dental caries after controlling for at least one of the five groups of confounders.

The narrative findings from one or two primary studies on the effect of CWF on different measures of caries after controlling for at least one other confounding factor is that CWF protects against caries.

3.1.5 Study characteristics: dental fluorosis

We identified 26 studies reporting on dental fluorosis in 33 papers (Table 36), of which 21 studies were reported as a unique paper [52,53,84,86–90,93–96,98–101,167–169,171,173] and 5 studies were reported across 2 or more papers; 2 studies were each reported across 3 linked papers [83,85,91,92,102,170], and 3 studies were each reported across 2 linked papers [97,165,166,172,174,175].

The 33 papers were published between 1951 and 2021 and included 13 countries: Australia (2 papers, 2 studies) [95,173], Brazil (3 papers, 3 studies) [87,98,168], Canada (11 papers, 7 studies) [83,85,86,89,90,94,102,165,166,172,175], Chile (1 paper, 1 study) [100], Cuba (1 paper, 1 study) [93], England, UK (1 paper, 1 study) [171], England and Wales, UK (1 paper, 1 study) [88], Ireland (3 papers, 3 studies) [52,53,167], Malaysia (2 papers, 1 study) [97,174], New Zealand (1 paper, 1 study) [96], Singapore (1 paper, 1 study) [101],Taiwan (1 paper, 1 study) [169], and the USA (5 papers, 3 studies) [84,91,92,99,170]. All studies and papers were based on a cross-sectional survey design (Table 36). The study populations for 27 papers (20 studies) were selected from schools only [52,53,83,85–92,94,95,97,99–102,165–167,170–175], while 2 papers (2 studies) selected participants from both daycare centres and schools [84,98] and 4 papers (4 studies) selected participants from the community [93,96,168,169].

All papers provided details on the number of participants in the studies, which varied in size; the smallest study had 219 participants [90] and the largest study had 17,851 participants [53]. Eight papers (seven studies) reported the mean age of their participants, and these ranged from 5.3 to 15.2 years [52,53,88,95,171–173,175]. Of these, two papers (two studies) reported SDs for the mean age of their participants: in one study, the mean age was 8.2 years (SD ±0.45) [172], and in the other, the mean age was 14.1 years (SD ±0.30) [88]. Only one paper (one study) reported both mean age and age range: the mean age was 8.2 years (SD ±0.45), and the age range was 6.2–9 years [172]. Twenty-two papers (17 studies) reported age ranges only; the ages ranged from 3 years to 75 years and over [83–87,89,91–93,96–102,166–170,174]. The age range for community-based studies was also from 3 years to 75 years and over [93,96,168,169]; for school-based studies it was 6–17 years [83–87,89,91,92,97–102,166,167,170,172,174]; and for daycare-based studies it was 3–5 years [84,98]. One paper (one study) provided an approximate age of 7 years [94]. One paper/study did not report mean age or age range [64].

All 26 studies (33 papers) either explicitly reported or implied that the researchers examined permanent teeth (Table 36), and 1 study (1 paper) also examined primary teeth [98]. Silva *et al.* (2021) examined the primary teeth of 5-year-olds and the permanent teeth of 12-year-olds for dental fluorosis and ascertained their predictors at the time of the survey [98]. The number of teeth examined differed across surveys. For example, 17 papers (13 studies) examined all available permanent teeth [52,53,83–85,89–92,95,99–102,168–170]; 9 papers (7 studies) examined 6 or 8 permanent teeth [87,88,96,98,165,166,172,173,175]; 6 papers (5 studies) examined between 1 and 4 teeth [94,97,167,171,173,174]; and 1 paper (1 study) examined 16 permanent teeth and 12 primary teeth [98]. In total, 28 papers (22 studies) employed only a clinical examination to diagnose dental fluorosis [52,53,83–86,88–95,98–102,165–170,172,173,175]; 4 papers (3 studies) used photographs in addition to clinical examinations [87,96,97,174]; and 1 paper (1 study) used photographs only [88].

Table 36 Summary of study characteristics for studies examining CWF and dental fluorosis

Country	Author*	Year	Study design and census/cluster sample adjustment, where reported	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Fluorosis outcome measure (and proportion agreement, where reported)	Sample in analysis	Mean age/age range	Percentage female
Australia	Medcalf [95]	1975	Cross-sectional survey	Samples of schoolchildren aged 6–8 years were examined pre- and 6 years post-fluoridation. None of the 1973 group had lifetime exposure to CWF.	During 1968–1971, the CWF level was 0.7 ppm during the summer months (October to March) and 0.9 ppm during the winter months (April to September). This seasonal variation was discontinued from 1 October 1971 in favour of a constant level of 0.9 ppm.	0.7–0.9	Pre-CWF in the Goldfields region (0.1–0.2 milligrams per litre (ppm) of fluoride)	Dean's Index of Fluorosis	Pre-CWF: 362 Post-CWF: 601	7.9 years	Not reported
Australia	Riordan and Banks [173]	1991	Cross-sectional survey	Schoolchildren born in 1978	Perth (CWF level of 0.8 ppm since 1968)	0.8	Bunbury region (<0.2 ppm of fluoride)	Thylstrup and Fejerskov Index 0.78	Total: 659 Exposure: 338 Comparator: 321	Exposure: 11 years, 7 months Comparator: 11 years, 10 months	Exposure: 48% Comparator: 47%
Brazil	Cortes *et al.* [87]	1996	Cross-sectional survey; adjusted for cluster sampling using a design effect of 1.7	Schoolchildren aged 6–12 years from three economically deprived groups who were lifetime residents of their respective areas and who used local drinking water sources.	Vitória, Espírito Santo (artificially fluoridated since 1982, at 0.7 ppm)	0.7	Maceió, Alagoas (<0.1 ppm of natural fluoride)	Thylstrup and Fejerskov Index 0.85	361	Mean age not reported/age range: 6–12 years	53%

Country	Author*	Year	Study design and census/cluster sample adjustment, where reported	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Fluorosis outcome measure (and proportion agreement, where reported)	Sample in analysis	Mean age/age range	Percentage female
Brazil	Heintze *et al.* [168]	1998	Cross-sectional survey	Participants aged 5–50 years were examined in health centres, schools, and factories.	Garça, São Paulo (CWF at 0.9 ppm (range: 0.75–1.20) since 1973) and Bauru (CWF at 0.64 ppm (range: 0.01–1.30) since 1975)	0.75–1.2	Itápolis São Paulo (0.02 ppm natural fluoridation)	Thylstrup and Fejerskov Index	Total: 985 Exposure: Garça: 430; Bauru: 207 Comparator: Itápolis: 348	Mean age not reported/age range: 5–24 years	Not reported
Brazil	Silva *et al.* [98]	2021	Cross-sectional survey	Children aged 5 years (in daycare) and 12 years (in school).	Lifetime exposure to CWF via the piped water of Teresina, Piauí (for children aged 5 years and 12 years)	0.5–0.6	Areas of Teresina Piauí, not connected to piped water supply (<0.05 ppm)	Thylstrup and Fejerskov Index 0.90	Total: 692 (5-year-olds: 330; 12-year-olds: 362)	Mean age not reported; children were aged 5 years and 12 years	Exposure: 5-year-olds: 48.4%; 12-year-olds: 48.9% Comparator: 5-year-olds: 44.4%; 12-year-olds: 55.4%
Canada	**Brown** [102]	**1951**	Cross-sectional survey	Schoolchildren aged at least 6 years but not more than 14 years, not absent from the city concerned for holidays or other reasons for more than 6 weeks at any one time.	Brantford, Ontario commenced CWF in June 1945 (1.0–1.2 ppm)–	1.0–1.2	Sarnia, Ontario (fluorine-free); Stratford, Ontario (1.3 ppm of fluorine from a natural source)	Unidentified fluorosis index	Exposure: 1948: 1,807; 1951: 1,742 Comparator: Sarnia:1948: 1,726; 1951: 1,816; Stratford: 1948: 1,308	Mean age not reported/age range: 6–14 years	Not reported

Country	Author*	Year	Study design and census/cluster sample adjustment, where reported	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Fluorosis outcome measure (and proportion agreement, where reported)	Sample in analysis	Mean age/age range	Percentage female
Canada	*Brown et al.* [83]	*1960*	Cross-sectional survey	‘’9–11-year-olds and 12–14-year-olds with ‘continuous’ residence in their respective cities, defined as including absences (since birth) of 6 weeks or less. Residence eligibility is determined from information supplied by the parents. All schools of each city were canvassed.	Brantford, Ontario commenced CWF in 1945 (1.0–1.2 ppm)–	1.0–1.2	Sarnia, Ontario (fluorine-free, negligible amount of fluoride) and Stratford, Ontario (1.3 ppm of fluorine from a natural source)	Unidentified fluorosis index	1948: 3,048; 1959: 3,018	Mean age not reported/age range: 9–14 years	Not reported
Canada	*Brown and Poplove* [85]	*1965*	Cross-sectional survey	All schoolchildren aged 16–17 years continuously resident in each city.	Brantford, Ontario commenced CWF in June 1945 (1.0–1.2 ppm)	1.0–1.2	Sarnia, Ontario (fluorine-free, negligible amount of fluoride) and Stratford, Ontario (1.3 ppm Of fluorine from a natural source)	Unidentified fluorosis index	Total: 1,065 Exposure: 356 Comparator: Sarnia: 482; Stratford: 227	Mean age not reported/age range: 16–17 years	Not reported

Country	Author*	Year	Study design and census/cluster sample adjustment, where reported	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Fluorosis outcome measure (and proportion agreement, where reported)	Sample in analysis	Mean age/age range	Percentage female
Canada	Connor [86]	1963	Cross-sectional survey (census)	Schoolchildren aged 6–8 years, 9–11 years, and 12–14 years who were continuous residents in each area.	Brandon, Manitoba: CWF commenced in March 1955 at 1.0 ppm	1.0	Fluoride deficient (survey in 1955 reported no baseline concentration, but reported that water was flouride-free)	Unidentified fluorosis index	Exposure: 1960: 1,236; 1962: 1,212 Comparator: 1955: 994	Mean age not reported/age range: 6–14 years	Not reported
Canada	Ismail *et al.* [89]	1990	Cross-sectional survey (adjusted for cluster sampling, but design effect unknown)	Representative sample of public and private school students aged 11–17 years residing in Sherbrooke and Trois Rivières, Quebec, who had been born and lived at least the first 6 years of their life in their respective city.	Trois Rivières, Quebec: three CWF levels over time (1.0–1.3 ppm in 1970–1979; 0.6–0.7 ppm in 1980–81; and 0.9–1.0 ppm in 1982–1987)	0.6–1.3	Sherbrooke, Quebec (0.1 ppm)	Tooth Surface Index of Fluorosis (TSIF) 0.85	936	Mean age not reported/age range: 11–17 years	Not reported, although it was collected
Canada	**Clark *et al.*** [165]	**1993**	Cross-sectional survey	Primary-school-aged children, stratified by socioeconomic status, who resided in the respective cities and had questionnaires completed.	Kelowna, British Columbia (CWF at 1.2 ppm)	1.2	Fluoride-deficient city of Vernon, British Columbia (<0.1 ppm)	TSIF 0.44	1,131	Mean age not reported/age range: 6–14 years	Not reported, although it was collected

Country	Author*	Year	Study design and census/cluster sample adjustment, where reported	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Fluorosis outcome measure (and proportion agreement, where reported)	Sample in analysis	Mean age/age range	Percentage female
Canada	*Clark et al.* [166]	*1994*	Cross-sectional survey	All children aged 6–14 years in selected schools were asked to participate and randomly selected for inclusion, stratified by socioeconomic status.	Kelowna, British Columbia (mean CWF level of 1.11 ppm; between 1983 and 1990 fluoride levels ranged from 0.85 to 1.24 ppm (SD ±0.46 and ±0.11 ppm, respectively).	1.11	Fluoride-deficient city of Vernon, British Columbia (<0.1 ppm)	TSIF 0.44	1,131	Mean age not reported/age range: 6–14 years	Not reported, although it was collected
Canada	Ismail *et al.* [90]	1993	Cross-sectional survey (census)	Schoolchildren in grades 5 and 6 in the two towns were included. Specific ages were not reported, but children were aged 6 years and over, and were possibly aged up to 10–12 years.	Kentville, Nova Scotia (CWF at 1.1 ppm from 1976 to 1991)	1.1	Truro, Nova Scotia (fluoride deficient; <0.1 ppm)	TSIF >0.75	219	Age was collected but not reported	Not reported, although it was collected
Canada	**Maupomé *et al.*** [175]	**2003**	Cross-sectional survey (census)	All of the schoolchildren examined who were lifelong residents in these communities.	Comox/Courtenay, British Columbia (1985–1992: 0.92 ppm (±0.21 ppm)), Campbell River, British Columbia (1985–1992: 0.88 ppm (±0.28 ppm)), and Kamloops, British Columbia (1982 to 1996–97: 0.95 ppm (±0.27 ppm)). Kamloops discontinued CWF in 2001, but the water supply was still fluoridated at the time of data collection.	0.88 – (±0.28) to 0.92 (±0.21)	Comox/Courtenay and Campbell River became fluoridation-ended (FE) communities in 1992 (FE 0.0 ppm), 14–19 months before the time of the study.	Thylstrup and Fejerskov Index >0.75	8,277	Mean age of grade 2 and 3 children: 8.3 years; mean age of grade 8 and 9 children: 14.3 years	49.8%

Country	Author*	Year	Study design and census/cluster sample adjustment, where reported	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Fluorosis outcome measure (and proportion agreement, where reported)	Sample in analysis	Mean age/age range	Percentage female
Canada	*Clark et al.* [172]	*2006*	Cross-sectional survey (census)	Schoolchildren in grades 2 and 3 in 1993–94, 1996–97, and 2002–03 who were permanent residents of their respective communities.	Comox/Courtenay, British Columbia (0.92 ppm (±0.21 ppm)) and Campbell River, British Columbia (0.88 ppm (±0.28 ppm)) in 1993–94 and 1996–97. Comox/Courtenay and Campbell River stopped CWF in 1992. All children in the 1993–94 data collection had lifetime exposure. Children aged under 9 years in the 1996–97 data collection had mixed exposure.	0.88 – (±0.28) to 0.92 (±0.21)	At the 2002–03 data collection, none of the children had exposure to CWF (0.0 ppm).	Thylstrup and Fejerskov Index 0.63	1,137	Mean age: 8.2 years (SD: ±0.45)/age range: 6.2–9.0 years	Not reported
Canada	McLaren *et al.* [94]	2021	Cross-sectional survey (adjusted for cluster sampling, but design effect unknown)	Grade 2 schoolchildren (aged approximately 7 years) enrolled in public or separate school systems in the cities of Calgary and Edmonton, Alberta.	Edmonton (CWF at 0.5–0.7 ppm in 2011–2019), Calgary (CWF 1967, 0.59–0.89 ppm 1991–2011), and from May 2011–2019 0.1-0.3 ppm)	0.5–0.7	0.1-0.3 ppm	TSIF ≥0.80	Exposure: 2,600, of whom 799 were permanent residents Comparator: 2,649, of whom 918 were permanent residents	Mean age not reported; children were aged approximatel y 7 years	Not reported

Country	Author*	Year	Study design and census/cluster sample adjustment, where reported	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Fluorosis outcome measure (and proportion agreement, where reported)	Sample in analysis	Mean age/age range	Percentage female
Chile	Villa *et al.* [100]	1998	Cross-sectional survey	Children aged 7, 12, and 15 years attending public or private schools and who were lifelong residents of one of the five areas.	San Felipe in the Fifth Region (now known as Valparaíso (CWF since 1986 at 0.93 ppm)	0.93	Rancagua (0.7 ppm), and Santiago (0.21 ppm (natural)), located in the central part of Chile at altitudes not higher than 700 m above sea level while La Serena (0.55 ppm (natural)), and Iquique northern coastal cities on the Pacific Ocean (1.10 ppm (natural))	Dean's Index of Fluorosis	2,431	Mean age not reported; children were aged 7, 12, and 15 years	51.2%
Cuba	Künzel [93]	1982	Cross-sectional survey (census)	Children resident in study area	CWF elevated fluoride to a concentration of 0.7 ppm (±0.1 ppm); CWF levels varied between 1974 and 1979, with a mean of 0.61 ppm in 1974 and 0.78 ppm in 1979.	0.7 (±0.1)	Natural fluoride content of 0.05–0.10 ppm	Dean's Index of Fluorosis	1973: 258 children; 1980: 356 children	Mean age not reported/age range: 6–13 years	Not reported
England, UK	Tabari *et al.* [171]	2000	Cross-sectional survey	8–9-year-old schoolchildren who were lifetime residents in their respective areas.	Newcastle upon Tyne (CWF at 1.0 ppm)	1.0	South Northumberland (<0.1 ppm)	Thylstrup and Fejerskov Index 0.70	Total: 812 Exposure: 409 Comparator: 403	Mean age: 9.3 years	Exposure: 55% Comparator: 51%

Country	Author*	Year	Study design and census/cluster sample adjustment, where reported	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Fluorosis outcome measure (and proportion agreement, where reported)	Sample in analysis	Mean age/age range	Percentage female
England and Wales, UK	Ellwood and O'Mullane [88]	1996	Cross-sectional survey (census for intervention group)	Schoolchildren in the third year of their secondary school education who were lifetime residents of their respective areas.	Anglesey, North Wales (0.7 ppm)	0.7	Chester (England) and Bala (North Wales) (<0.1 ppm)	Thylstrup and Fejerskov Index 0.73	Exposure: 196 Comparator: 267	Mean age: 14.1 years (±0.3 years)	Not reported
Ireland	Clarkson and' O'Mullane [167]	1992	Cross-sectional survey	8-year-old schoolchildren	CWF commenced in 1964 at 0.8–1.0 ppm	0.8–1.0	Fluoride-deficient water in Ireland has a fluoride concentration of ≤0.3 ppm.	Dean's Index of Fluorosis	Total: 831 Exposure: 459 Comparator: 372	Mean age not reported; children were aged 8 and 15 years	Not reported
Ireland	Whelton *et al.* [53]	2004	Cross-sectional survey (description indicates that authors have adjusted for cluster sampling but not stated it)	5-, 8-, 12-, and 15-year-old schoolchildren living in the Republic of Ireland.	0.8–1.0 ppm	0.8–1.0	Not reported (fluoride-deficient parts of Ireland have a fluoride concentration of ≤0.3 ppm)	Dean's Index of Fluorosis	Total: 17,851 (5-year-olds: 6,661; 8-year-olds: 3,769; 12-year-olds: 3,886; 15-year-olds: 3,535)	5-year-olds: 5.3 years; 8-year-olds: 8.4 years; 12-year-olds: 12.4 years; 15-year-olds: 15.2 years	50% (5-year-olds: 51%; 8-year-olds: 50%; 12-year-olds: 49%; 15-year-olds: 50%)

Country	Author*	Year	Study design and census/cluster sample adjustment, where reported	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Fluorosis outcome measure (and proportion agreement, where reported)	Sample in analysis	Mean age/age range	Percentage female
Ireland	James *et al.* [52]	2021	Cross-sectional survey (description indicates that authors have adjusted for cluster sampling but not stated it)	Random sample of 5-year-old schoolchildren in counties Dublin, Cork, and Kerry in 2014; follow-up at age 8 years in 2017.	Counties Dublin, Cork, and Kerry: 0.8 –1.0 ppm in 2002; reduced to 0.6–0.8 ppm in 2007	0.8–1.0, then 0.6–0.8	Fluoride-deficient areas of counties Cork and Kerry (≤0.3 ppm)	Dean's Index of Fluorosis 0.74	Exposure: Dublin: 679 (2002), 707 (2017); counties Cork and Kerry: 332 (2002), 376 (2017) Comparator (fluoride-deficient areas of counties Cork and Kerry): 233 (2002); 772 (2017)	Exposure: Dublin: 8.3 years (2002), 8.2 years (2017); counties Cork and Kerry: 8.4 years (2002), 8.3 years (2017) Comparator (fluoride-deficient areas of counties Cork and Kerry): 8.5 years (2002), 8.4 years (2017)	Exposure: Dublin: 47% (2002), 54% (2017); counties Cork and Kerry: 55% (2002), 53% (2017) Comparator (fluoride-deficient areas of counties Cork and Kerry): 56% (2002), 51% (2017)
Malaysia	**Mohd Nor *et al.*** [97]	**2018**	Cross-sectional survey (description indicates that authors have adjusted for cluster sampling but not stated it)	Schoolchildren aged 9 years (born in 2006) and 12 years (born in 2003), and lifelong residents were included in the final analysis.	Negeri Sembilan had CWF since 1972 at 0.7 ppm; this was reduced to 0.5 ppm in December 2005.	0.7 from 1972, reduced to 0.5 in 2005	Kelantan (described and confirmed as fluoride deficient (0 ppm))	Dean's Index of Fluorosis 0.72–0.90	1,155	Mean age not reported; children were aged 9 and 12 years	56.5%
Malaysia	*Mohd Nor et al.* [174]	*2021*	Cross-sectional survey (as above)	Schoolchildren aged 9 years (born in 2006) and 12 years (born in 2003), and lifelong residents were included in this study.	Negeri Sembilan had CWF since 1972 at 0.7 ppm; this was reduced to 0.5 ppm in December 2005.	0.7 from 1972, reduced to 0.5 in 2005	Kelantan (described and confirmed as fluoride deficient (0 ppm))	Dean's Index of Fluorosis 0.72–0.90	1,143	Mean age not reported; children were aged 9 and 12 years	56.5%

Country	Author*	Year	Study design and census/cluster sample adjustment, where reported	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Fluorosis outcome measure (and proportion agreement, where reported)	Sample in analysis	Mean age/age range	Percentage female
New Zealand	Ministry of Health [96]	2010	Cross-sectional survey (adjusted for cluster sampling using a design effect of ≥2)	In households, one adult aged ≥15 years and one child aged 0–14 years (if any) were randomly selected for the survey.	Average fluoride concentration around 0.8–0.9 ppm in fluoridated areas	0.8–0.9	Average fluoride concentration around 0.15 ppm in fluoride-deficient areas	Dean's Index of Fluorosis 0.78	3,196 (987 children and 2,209 adults)	Mean age not reported/age range: children: 0–14 years; adults: ≥15 years; for dental fluorosis, 8–30-year-olds	Children: 48% Adults aged 18 years or over: 61%
Singapore	Wong *et al.* [101]	1970	Cross-sectional survey	Chinese and Malay children in two age groups (aged 7–8 years and aged 8–9 years) were selected by random sampling from primary schools in various parts of the island.	After fluoridation in 1956–1958, the fluoride concentration was 0.7 ppm. The entire water supply of Singapore was fluoridated as of January 1958.	0.7	Before fluoridation, the fluoride concentration was 0.2 ppm	No index used; dental fluorosis was determined via clinical observation	2,200 up until 1965, and 1,100 thereafter	Exposure: 7–8-year-olds: 7.5–7.7 years; 8–9-year-olds: 8.4–8.6 years Comparator: 7–8-year-olds: 7.6–7.7 years; 8–9-year-olds: 8.4–8.6 years	Not reported
Taiwan	Hong *et al.* [169]	1990	Cross-sectional survey (census)	Children aged 6–15 years who were born in or continuous residents of their respective areas.	Chung-Hsing New Village: CWF at 0.6 ppm for 12 years, since 1972; prior to CWF, fluoride concentration was 0.07 ppm	0.6, then 0.7	Tsao-tun (now Caotun) (0.08 ppm)	Dean's Index of Fluorosis	Exposure: 3,066 Comparator: 4,087	Mean age not reported/age range: 6–15 years	Not reported

Country	Author*	Year	Study design and census/cluster sample adjustment, where reported	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Fluorosis outcome measure (and proportion agreement, where reported)	Sample in analysis	Mean age/age range	Percentage female
USA	Arnold *et al.* [84]	1956	Cross-sectional survey	Kindergarten and schoolchildren aged 4–16 years who had used city water supplies continuously since birth.	Grand Rapids, Michigan: CWF since 1945 (1.0 ppm (range: 0.9–1.1 ppm))	0.9–1.1	Muskegon, Michigan (<0.2 ppm until July 1951, –1.0 ppm from 1952 to 1954) and Aurora, Illinois (natural fluoride concentration of 1.2 ppm)	No index used; dental fluorosis was determined via clinical observation	1954: Exposure: 5,148 Comparator: 2,923	Mean age not reported/age range: 4–16 years	Not reported
USA	Szpunar and Burt [99]	1988	Cross-sectional survey	6–12-year-old schoolchildren	Redford, Michigan (CWF at 1.0 ppm)	1.0	Natural fluoride: Richmond, Michigan (1.2 ppm), Cadillac, Michigan (0.0 ppm), and Hudson, Michigan (0.8 ppm); fluoride mouth rinses	TSIF 0.85	380 of 556 continuous residents. Exposure: 249 Comparator: 131 (Cadillac only (0.0 ppm))	Mean age not reported/age range: 6–12 years (50 children were aged under 6 years)	Exposure: 49% Comparator: 57%
USA	**Kumar *et al.*** [91]	**1989**	Cross-sectional survey (adjusted for cluster sampling, but design effect unknown)	7–14-year-old schoolchildren. Children with orthodontic bands or only deciduous teeth, or who were not lifetime residents of their respective cities, were excluded.	Newburgh, New York: CWF at 1.0 ppm except for a 3-year period from 1978 to 1981	1.0	Kingston, New York (<0.3 ppm)	Dean's Index of Fluorosis	884 included in analysis	Mean age not reported/age range: 7–14 years	Not reported, although it was collected

Country	Author*	Year	Study design and census/cluster sample adjustment, where reported	Study population	Details of exposure	CWF exposure (ppm)	Details of comparator	Fluorosis outcome measure (and proportion agreement, where reported)	Sample in analysis	Mean age/age range	Percentage female
USA	*Kumar et al.* [92]	*1998*	Cross-sectional survey (adjusted for cluster sampling, but design effect unknown)	Schoolchildren in grades 1–8 (aged 7–14 years) who had been lifelong residents of their respective cities.	Newburgh, New York: CWF since 1945 at 1.0 ppm (±0.2 ppm) except for a 3-year interruption between 1978 and 1981	1.0 (±0.2)	Kingston, New York (<0.3 ppm)	Dean's Index of Fluorosis 0.65, 0.76, and 1.0 for three of the examiners relative to the fourth	1,493	Mean age not reported/age range: 7–14 years	Exposure: 51.0% Comparator: 49.2%
USA	*Kumar et al.* [170]	*2000*	Cross-sectional survey (adjusted for cluster sampling, but design effect unknown)	Schoolchildren who were 7–14-year-old lifelong residents of their respective cities.	The city of Newburgh, New York had CWF since 1945 at 1.0 ppm (±0.2 ppm), except for a 3-year interruption between 1978 and 1981. The town of Newburgh, New York is an entirely different municipality that started CWF at the same level in 1984.	1.0 (±0.2)	Kingston, New Windsor, and the town of Ulster, New York (<0.3 ppm)	Dean's Index of Fluorosis 0.65, 0.76, and 1.0 for three of the examiners relative to the fourth	2,193	Mean age not reported/age range: 7–14 years	51.2%

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

Thirteen papers (10 studies) [52,53,91–93,95–97,100,167,170,174,177], measured the prevalence and severity of dental fluorosis using Dean's Index of Fluorosis [9], 8 papers (7 studies) [87,88,98,168,171–173,175], used the Thylstrup and Fejerskov Index [34], 6 papers (5 studies) [89,90,94,99,165,166], used the Tooth Surface Index of Fluorosis (TSIF) [35], 4 papers (2 studies) did not name the index used [83,85,86,102], and 2 papers (2 studies) did not report the use of an index but reported undertaking a clinical examination [84,101].

All 33 papers (27 cross-sectional surveys) provide verifiable data on lifetime exposure to CWF in the intervention group: 20 papers (18 studies) reported lifetime exposure to a constant level of fluoride [53,83,85,87,88,90,92,94,96,98,99,101,167–170,172,173,175], 4 papers (3 studies) reported lifetime exposure to CWF but that there was a planned reduction in the concentration of fluoride at some point [52,89,97,174], 1 paper (part of a 3-paper study) reported lifetime exposure to CWF but that there was an unplanned reduction in the concentration of fluoride [91], and 8 papers (7 studies) reported that some age groups had lifetime exposure since birth while others missed some early years of exposure [84,86,93,95,100,102,165,166]. The fluoride dose in the 27 CWF areas ranged from 0.5 to 1.2 ppm. The CWF level in 14 papers (8 studies) was 1.0–1.2 ppm [83,85,86,90–92,99,102,165,166,170–172,175], while in 4 papers (4 studies) it varied between 0.75 ppm and 1.10 ppm [84,89,95,168]. The concentration of fluoride in the fluoridated water supply in 5 papers (5 studies) ranged from 0.80 ppm to 0.99 ppm [52,53,96,100,167,173], and in 9 papers (8 studies) it ranged from 0.50 ppm to 0.82 ppm [87,88,93,94,97,98,101,169,174]. In one study, the CWF level was set at 0.8–1.0 ppm and was then dropped to 0.6–0.8 ppm [52].

The fluoride dose in 25 fluoride-deficient areas was ≤0.3 ppm [52,53,84,87–101,165–170,172–175], and in 2 study areas (4 papers) the fluoride-deficient area was described by the authors as fluoride free [83,85,86,102]. Two of the 26 studies had both a naturally fluoride-deficient area and an area with a different level of CWF as comparators [52,97]. Six papers (four studies) had natural fluoride comparator areas with fluoride levels ranging from 0.55 to 1.30 ppm [83–85,99,100,102], and these areas with optimal natural fluoride levels (of 0.55–1.30 ppm) in their water were excluded from the analysis.

3.1.6 Study quality: dental fluorosis

The quality assessment of the 33 cross-sectional survey papers reporting on dental fluorosis indicated that 4 papers (4 studies) were of high quality [52,94,98,175], 11 papers (10 studies) were of moderate quality [53,83,89,90,96,97,100,169,172,174], and 18 papers (12 studies) were of low quality [84–88,91–93,95,99,101,102,165–168,170,173] with regard to design and implementation (Table 37; Appendix H of Section 6). For high and moderate quality studies, the weaknesses in quality assessment were an inability to complete a follow-up due to study design and an incomplete control for the five groups of confounding factors. The low quality studies had significant weaknesses in most areas including eligible population, participation rate, inclusion criteria and/or confounding.

Table 37 Quality assessment of dental fluorosis papers

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
Medcalf [95]	1975	Australia	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	1.0	Low
Riordan and Banks [173]	1991	Australia	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	2.5	Low
Cortes *et al.* [87]	1996	Brazil	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	1.0	Low
Heintze *et al.* [168]	1998	Brazil	Cross-sectional survey	No	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	1.0	Low
Silva *et al.* [98]	2021	Brazil	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Extensive	1.0	4.0	High
Brown [102]	**1951**	Canada	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	2.0	Low
Brown et al. [83]	*1960*	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	3.0	Moderate
Brown and Poplove [85]	*1965*	Canada	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	2.0	Low
Connor [86]	1963	Canada	Cross-sectional survey	Yes	1.0	No	0.0	Not applicable (census data)	1.0	Not applicable	0.0	Some	0.0	2.0	Low
Ismail *et al.* [89]	1990	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Partial	0.0	3.0	Moderate
Clark *et al.* [165]	**1993**	Canada	Cross-sectional survey	No	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	1.0	Low
Clark et al. [166]	*1994*	Canada	Cross-sectional survey	No	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	1.0	Low
Ismail *et al.* [90]	1993	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable (census data)	1.0	Not applicable	0.0	Some	0.0	3.0	Moderate

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
Maupomé *et al.* [175]	**2003**	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable (census data)	1.0	Not applicable	0.0	Some	0.0	3.0	Moderate
Clark et al. [172]	*2006*	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable (census data)	1.0	Not applicable	0.0	Some	0.0	3.0	Moderate
McLaren *et al.* [94]	2021	Canada	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	3.0	Moderate
Villa *et al.* [100]	1998	Chile	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	None	0.0	3.0	Moderate
Künzel [93]	1982	Cuba	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	1.0	Low
Ellwood and O'Mullane [88]	1996	England, Wales, UK	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	None	0.0	1.0	Low
Tabari *et al.* [171]	2000	England, UK	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	3.0	Moderate
Clarkson and' O'Mullane [167]	1992	Ireland	Cross-sectional survey	Not reported	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	1.0	Low
Whelton *et al.* [53]	2004	Ireland	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	3.0	Moderate
James *et al.* [52]	2021	Ireland	Cross-sectional survey/cohort	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Partial	0.5	3.5	High
Mohd Nor *et al.* [97]	**2018**	Malaysia	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	3.0	Moderate
Mohd Nor et al. [174]	*2021*	Malaysia	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	3.0	Moderate
Ministry of Health [96]	2010	New Zealand	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	3.0	Moderate

Author*	Year	Country	Study design	Q3: Eligible population and participation rate†	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total score	Rating
Wong *et al.* [101]	1970	Singapore	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	1.0	Low
Hong *et al.* [169]	1990	Taiwan	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable (census data)	1.0	Not applicable	0.0	Some	0.0	3.0	Moderate
Arnold *et al.* [84]	1956	USA	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	1.0	Low
Szpunar and Burt [99]	1988	USA	Cross-sectional survey	No	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	1.0	Low
Kumar *et al.* [91]	**1989**	USA	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	2.0	Low
Kumar et al. [92]	*1998*	USA	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	1.0	Low
Kumar et al. [170]	*2000*	USA	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	1.0	Low

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

† See quality assessment instrument in Appendix E of Section 6

3.1.7 Study findings: dental fluorosis

3.1.7.1 Dental fluorosis findings by country

Our first step in the analysis of exposure to CWF and development of dental fluorosis was to analyse the 33 papers (26 studies) by country, as it appears that dental fluorosis is influenced by the environment that people live in, including climate; water and soil contents; the food that people eat (including, in this case, the type of milk consumed by infants); the CWF and/or natural fluoride level; access to preventive dental products (including the increased use of fluoride toothpastes since 1975); and the availability and cost of dental services; these factors vary by geographical location so are best described by country . Within these factors, a specific factor to be considered is lifetime exposure to CWF from birth to age 4 or 6 years as this is the time that systemic fluoride strengthens the formation of the teeth and therefore, we have limited our analysis to lifetime exposure as the CWF intervention. In addition, the standardised use of the three fluorosis indices identified in the included papers is likely to be country specific; this may explain some of the variation between countries. The 26 studies (33 papers) measuring dental fluorosis were conducted in Australia, Brazil, Canada, Chile, Cuba, Ireland, Malaysia, New Zealand, Singapore, Taiwan, the UK (England and Wales), and the USA.

For each country, we report the number of studies and papers on dental fluorosis; the study design employed; quality assessment of the study design and conduct (including sample size calculation); geographical areas compared; CWF and comparator fluoride levels used in the study; method of assessment (clinical and/or use of photographs); index employed to measure dental fluorosis; agreement between examiners; dental fluorosis prevalence and severity (with 95% CIs where available) in CWF and fluoride-deficient areas; difference in the prevalence of dental fluorosis between CWF and fluoride-deficient areas; and determinants of the prevalence of dental fluorosis.

3.1.7.1.1 Australia

We identified two cross-sectional surveys (two papers) from Australia that met our inclusion criteria: one was carried out in the Goldfields region and published in 1975 [95] and one was carried out in Perth (compared with the Bunbury region) and published in1991 [173]. Both were low quality with regard to design and conduct. The two studies reported exposure to similar levels of CWF at 0.7–0.9 ppm in the Goldfields region and 0.8 ppm in Perth. One study reported lifetime exposure for the subsample of 6-year-old children (n=129 exposed to 6 years of CWF compared with 101 6-year-old children before introduction of CWF) [95] and the other study reported lifetime exposure for a sample containing mostly children who were born in 1978 (i.e. aged 11 years at the time of the survey) [173].

Following clinical examination, Medcalf [95] employed Dean’s Index of Fluorosis, while Riordan and Banks used the Thylstrup and Fejerskov Index [173] to classify the prevalence and severity of dental fluorosis. The prevalence of dental fluorosis in the Goldfields sample (in this case, white flecking of the first permanent molar cusps) was 7.8%, and no cases of severe fluorosis were identified [95]. The prevalence of dental fluorosis in the Riordan and Banks (1991) paper was 40.2% among the Perth (CWF) group compared with 33.0% for the Bunbury (fluoride-deficient) group, and there were no serious cases in either Perth or Bunbury [173]. There was a 7.2-percentage-point difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas. The level of agreement in this study between the clinical examiners was 0.78, indicating the possibility of some misdiagnoses, which could increase or decrease the prevalence estimates [173]. CIs around the prevalence of dental fluorosis were not calculated in either study, so the prevalence was not applied to the population and the authors do not mention any adjustment for homogenous effect of cluster sampling [95,173]. Riordan and Banks completed a regression analysis in order to control for confounding between exposure variables, and found that living in a fluoridated area for the first 1–4 years of life was associated with a diagnosis of dental fluorosis (living in a CWF area for 2.5–4.0 years: OR: 4.06; 95% CI: 2.55–6.44; versus living in a CWF area for 1.0–2.5 years: OR: 3.02; 95% CI: 1.42–6.42) [173]. Medcalf did not complete a regression analysis. Some of the difference in the prevalence of dental fluorosis across the two studies may be explained by the two different indices used to classify dental fluorosis, the accuracy of diagnosis, and the increased use of fluoride toothpaste after 1975.

3.1.7.1.2 Brazil

We found three cross-sectional surveys (three papers) from Brazil that met our inclusion criteria: the first was conducted in Vitória (compared with Maceió, Alagoas) [87], the second was conducted in Garça and Bauru (compared with Itápolis) [168], and the third was conducted in piped water areas of Teresina and compared these with areas of Teresina that were not connected to a piped water supply [98]. Two of the papers were rated as low quality [87,168] and one was rated as high quality with regard to design and conduct [98]. The three papers reported lifetime exposure to various levels of CWF, with 0.50–0.60 ppm in Teresina, 0.70 ppm in Vitória, 0.64 ppm (range: 0.01–1.30) in Bauru, and 0.90 ppm (range: 0.75–1.20) in Garça.

The study participants differed across the three studies. Cortes *et al.* (1996) included 6–12-year-old schoolchildren [87], Silva *et al.* (2021) included 5-year-old daycare attendees and 12-year-old schoolchildren [98], and Heintze *et al.* (1998) included participants aged 5–50 years who were examined in health centres, schools, and factories [168]. All three studies were based on samples of populations [87,98,168]. One of the three studies adjusted for the homogenous design effect of cluster sampling when calculating its sample size [98]. Two of the three studies estimated the level of agreement between the clinical examiners [87,98]. Following clinical examinations, all three study teams employed the Thylstrup and Fejerskov Index to classify the prevalence and severity of dental fluorosis [87,98,168]; the study team on the Cortes *et al.* (1996) study also took photographs. Cortes *et al.* (1996) reported on the interplay between CWF, dental fluorosis, and dental caries, but did not report on the prevalence and determinants of dental fluorosis [87]. Heintze *et al.* (1998) estimated the prevalence of dental fluorosis among 5–24-year-olds, which was 13.3% in Garça (CWF stable at 0.9 ppm), 6.8% in Bauru (CWF unstable at 0.01–1.3), and 1.7% in Itápolis (natural fluoride concentration of 0.02 ppm). There was an 11.6-percentage-point difference in the prevalence of dental fluorosis between CWF and fluoride-deficient areas. The severity of dental fluorosis was either very mild or mild for the majority of cases; however, exact proportions by category of severity were not reported [168]. CIs around the prevalence of dental fluorosis were not calculated in the Heintze *et al.* (1998) study, so the prevalence was not applied to the population and the authors did not mention any adjustment for the effect of cluster sampling. Silva *et al.* (2021) did not identify any cases of dental fluorosis among 5-year-old children in the CWF or fluoride-deficient areas of Teresina, while the prevalence of dental fluorosis among 12-year-old children was 69.6% in the fluoridated area and 18.5% in the fluoride-deficient area [98]. There was a 51.1-percentage-point difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas. The prevalence of moderate dental fluorosis among 12-year-old children was 18.0% in the CWF area and 3.3% in the fluoride-deficient area. After controlling for other confounding factors, the prevalence of very mild/mild dental fluorosis (OR: 5.45; 95% CI: 3.23–9.19) and moderate dental fluorosis (OR: 11.11; 95% CI: 4.43–27.87) was statistically significantly associated with living in an area with CWF compared with living in a fluoride-deficient area; the design effect for cluster sampling was 1.7 [98]. The prevalence and severity of dental fluorosis appears much higher in the CWF areas of Teresina than in Garça or Bauru (despite the Silva *et al.* (2021) study reporting a lower concentration of fluoride in the fluoridated water supply), and all three studies employed the same index to classify dental fluorosis. The level of agreement between the clinical examiners was estimated at 0.85 for Cortes *et al.*'s study and 0.90 for Silva *et al*.'s study, indicating the possibility of some misdiagnoses, which could increase or decrease the prevalence estimates. Some of the difference in prevalence across these two studies may be explained by the passage of time and accuracy of diagnosis.

3.1.7.1.3 Canada

We identified 7 cross-sectional surveys (reported in 11 papers) based in Canada that met our inclusion criteria [83,85,86,89,90,94,102,165,166,172,175]. Three of the seven studies included the complete population rather than a sample [86,90,175]. Two of the four studies using sample populations adjusted for the design effect of cluster sampling [89,94]. Five of the seven studies estimated the level of agreement between the clinical examiners [89,90,94,165,175].

The first study (which was the basis of three papers) was completed in Brantford, Ontario (which has had CWF at 1.0–1.2 ppm since June 1945) and Sarnia, Ontario (which is fluoride-free) [83,85,102]. The first paper examined participants after 6 years of exposure to CWF, so in the first paper, the 6-year-olds had lifetime exposure to CWF and the 7–14-year-olds had partial exposure [102]. The second and third papers examined lifetime exposure to CWF [83,85]. The study was judged as being of moderate to low quality with regard to design and conduct. The index used to determine the prevalence and severity of dental fluorosis following clinical examinations was not identified [83,85,102]. There was only one calculation of prevalence by the study authors, which determined that 15% (95% CIs were not estimated) of the sample in 1948–1951 had dental fluorosis [83,85,102]. Otherwise, the authors commented vaguely on low numbers of cases, and mentioned that there had been few moderate cases in 1948–1951 and none since then. The level of agreement between the clinical examiners was not reported. The authors of the papers reported that:

> Slight mottling of the enamel in the form of tiny snowflake-like white patches was observed in the permanent teeth of about 15% of the Stratford children. Only two cases of moderate mottling were seen. These exhibited some small degree of brownish discolouration of the enamel which would not in the opinion of most dentists call for treatment to correct the appearance. No enamel hypoplasia (underdevelopment) associated with the mottling was observed. No cases of 'severe' mottling were observed. A small number of cases of 'questionable' mottling was seen in both Brantford and Sarnia. The number was about equal for both places. *[102]* p612
>
> A few cases of very mild mottling, detectable only by an experienced examiner, were seen in Brantford and Stratford. Mottling to a significant or unsightly degree was not observed at any time during the course of this study. *[83]* p606
>
> No cases of unsightly mottling were observed among the children examined in Brantford and Stratford. *[85]* p323

The second study, which was judged to be of low quality with regard to design and conduct, was completed in Brandon, Manitoba (where CWF commenced in March 1955 at 1 ppm) in comparison with the same city at baseline (fluoride free) in 1954–55 [86]. The study included the complete population of 6–14-year-olds rather than a sample. The study examined the effects of CWF after 7 years of exposure, and so only the 6- and 7-year-olds had lifetime exposure, while the 8–14-year-olds had partial exposure [86]. The index used to determine the prevalence and severity of dental fluorosis following clinical examinations was not identified. Connor (1963) reported that "No mottling that could be ascribed to fluoride was detectable" [86] p546. The level of agreement on the diagnosis of dental fluorosis between clinical examiners was not reported.

The third study, which was judged to be of moderate quality with regard to design and conduct, was completed in Quebec and compared the lifetime exposure to CWF in Trois Rivières (where CWF levels were 1.0–1.3 ppm between 1970 and 1979, 0.6–0.7 ppm in 1980 and 1981, and 0.9–1.0 ppm from 1982 to 1987) with fluoride-deficient Sherbrooke (0.1 ppm until 1987) [89]. The TSIF was employed in order to determine the prevalence and severity of dental fluorosis using the results of the clinical examinations. The prevalence of dental fluorosis was 45.6% (95% CI: 41.1–50.1) and 58.0% (95% CI: 55.3–60.7) in Trois Rivières' public and private schools, respectively, and 31.1% (95% CI: 28.1–34.1) and 30.1% (95% CI: 27.1–33.1) in Sherbrooke's public and private schools, respectively. There was a 14.5-percentage-point difference in the prevalence of dental fluorosis between CWF and fluoride-deficient areas for public schools, and a 27.9-percentage-point difference for private schools. The level of agreement between the clinical examiners was estimated at 0.85, indicating some possibility of dental fluorosis misdiagnosis which could increase or decrease prevalence estimates. The TSIF indicated that a very small proportion of children had moderate or severe dental fluorosis. Participants attending private school (OR: 1.19; 95% CI: 1.03–1.39), living in Trois Rivières (OR: 3.43; 95% CI: 2.77–4.24), using fluoride tablets (OR: 1.70; 95% CI: 1.28– 2.27), being of male sex (OR: 1. 34; 95% CI: 1.11–1.63), and being older (OR: 1.35; 95% CI: 1.28–1.42) were statistically significantly associated with dental fluorosis. The authors adjusted for cluster sampling in the analysis [89].

The fourth study (reported in two papers) was based in British Columbia and compared 10 years of exposure to CWF in Kelowna (1.2 ppm) with fluoride-deficient Vernon (<0.1 ppm) [165,166]. The study was low quality with regard to design and conduct, and there was no adjustment for cluster sampling in the sample size calculation or analysis reported. Of note, only 6–10-year-olds had lifetime exposure, while 11–14-year-olds had partial exposure [165,166]. The two papers reported using the TSIF to determine the prevalence and severity of dental fluorosis using the results of a clinical examination [165,166]. Overall, 60% of the children had dental fluorosis on at least two tooth surfaces. A significantly higher percentage of children with dental fluorosis was observed in the fluoridated community of Kelowna compared with the fluoride-deficient community of Vernon (65% versus 55%, respectively; $p<0.001$). There was a 10-percentage-point difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas. The majority (55%) of cases of dental fluorosis in fluoridated Kelowna (CWF at 1.2 ppm) were classified with a score of 1 (very mild), whereas 48% of cases of dental fluorosis in fluoride-deficient Vernon had very mild dental fluorosis. Only 10% and 7% of the children demonstrated TSIF scores of 2 or more in the fluoridated and fluoride-deficient communities, respectively. Just 3% of participants in fluoridated Kelowna and 2% of participants in fluoride-deficient Vernon had moderate or severe dental fluorosis [165]. The level of agreement between the clinical examiners was estimated at 0.44, indicating a high possibility of dental fluorosis misdiagnoses, which could increase or decrease the prevalence estimates. The authors reported that all of the children were exposed to fluoride toothpaste and stated that "the use of fluoride dentifrices did not increase the risk of dental fluorosis" [166] p463. Logistic regression analyses demonstrated that continuous residence in a fluoridated community (OR: 0.9; $p<0.02$), the use of infant formula when children were 10–12 months old (OR: 1.8; $p<0.02$), and parental educational attainment (OR: 1.6; $p<0.06$) were statistically significantly associated with the occurrence of dental fluorosis based on combined scores from mild to severe.

The first paper for the fifth study, also based in British Columbia, compared lifetime exposure to CWF in Kamloops (which had CWF at 0.95 ppm (±0.27 ppm) from 1982 to 1997) with two areas that discontinued CWF (0.0 ppm) 14–19 months earlier in 1992: Comox/Courtenay (0.92 ppm (±0.21 ppm) from 1985 to 1992) and Campbell River (0.88 ppm (±0.28 ppm) from 1985 to 1992) [175]. The study included the complete population of schoolchildren in grades 2 and 3 (mean age: 8.3 years) and grades 8 and 9 (mean age: 14.3 years). The second paper was a comparison over time in Comox/Courtenay and Campbell River, British Columbia. Data were collected in 2002–03 (when the water fluoridation level was 0.0 ppm) and compared with data collected in 1993–94 (from children who had received lifetime exposure to CWF) and in 1996–97 (from children who had received partial exposure to CWF) [172]. Both papers were judged to be of moderate quality with regard to design and conduct. The two papers employed the Thylstrup and Fejerskov Index to determine the prevalence and severity of dental fluorosis using the results of the clinical examinations [172,175]. Comparisons between the data collected at the three time points were used in order to establish the influence of CWF and other fluoride sources on the occurrence and severity of dental fluorosis. The children participating in the 1993–94 survey had exposure to fluoride for their first 6 years of life, while the children in the 1996–97 survey had partial exposure (for 3 years) to CWF during the development of their permanent teeth. The children in the 2002–03 survey had no exposure to CWF. When fluoride was removed from the water supplies of the two communities in 1992, the prevalence of dental fluorosis (measured using the Thylstrup and Fejerskov Index) decreased significantly between the 1993–94 and 1996–97 surveys (from 58% in 1993–94 to 23% in 1996–97) and remained stable between the 1996–97 and 2002–03 surveys (at 23% in 1996–97 and 24% in 2002–03). There was a 34-percentage-point difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas. The severity of dental fluorosis, measured by the proportion of children with moderate or severe dental fluorosis, also decreased between the 1993–94 and 1996–97 surveys (from 9% in 1993–94 to 0% in both 1996–97 and 2002–03). The level of agreement between the clinical examiners was estimated to be greater than 0.75 in the Maupomé *et al.* (2003) paper and equal to 0.63 in the Clark *et al.* (2006) paper, indicating the possibility of some misdiagnoses, which could increase or decrease the prevalence estimates. The prevalence of dental fluorosis in the 1993–94 survey was not significantly different for the group that had received lifetime exposure to CWF (58%) and the group that was exposed to both fluoridated water and fluoride supplements (57%) in the first 4 years of life [172,175]. The odds of having a Thylstrup and Fejerskov Index score above the mean (Poisson regression) was greater in the 1993–94 (OR: 3.01; $p<0.0001$) and 1996–97 (OR: 1.96; $p<0.0005$) surveys compared with the 2002–03 survey, and was greater in the 1993–94 survey compared with the 1996–97 survey (OR: 1.96; $p<0.0001$) [172]. Results from regression analyses for each survey period did not identify any statistically significant associations between dental fluorosis and bottled water consumption; the frequency of use of fluoride mouth rinse; breastfeeding; and the age at which solid food, cow’s milk, and infant formula consumption began. Statistically significant associations were found for fluoride supplement use from birth to the age of 1 year in the 1996–97 survey (OR: 1.54; $p=0.040$), and for toothbrushing three or more times per day (compared with less than once per day) in the 1996–97 (OR: 2.67; $p=0.014$) and 2002–03 (OR: 3.52; $p=0.045$) surveys[172]. Of note, 95% CIs were not provided, as the population for analysis was based on a census.

The sixth study, which was judged to be of moderate quality with regard to design and conduct, was conducted in Nova Scotia and compared lifetime exposure to CWF in Kentville (1.1 ppm from 1976 to 1991) with fluoride-deficient Truro (<0.1 ppm) [90]. The study included the complete population of grades 5 and 6 schoolchildren. The TSIF was employed to determine the prevalence and severity of dental fluorosis using the results of a clinical examination [90]. The prevalence of dental fluorosis was 69.2% in Kentville (CWF at 1.1 ppm from 1976 to 1991) and 41.5% in fluoride-deficient Truro (<0.1 ppm fluoride concentration). There was a 27.7-percentage-point difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas. The level of agreement on fluoride diagnoses between the clinical examiners was estimated at 0.90, indicating the possibility of a few misdiagnoses which could increase or decrease prevalence estimates. Children in the fluoridated group had a significantly higher prevalence of dental fluorosis and a significantly higher mean number of teeth with dental fluorosis (9.64 teeth) than those in the fluoride-deficient group (4.49 teeth) ($p<0.05$). Residence in a fluoridated area during the first 6 years of life and the educational status of the mother were statistically significant risk factors that were positively associated with a higher prevalence of dental fluorosis in a stepwise logistic regression analysis [90]. However, numeric data for this analysis were not provided.

The seventh and most recent study was based in Alberta and compared lifetime exposure to CWF in Edmonton (which has had CWF since 1967, and at a level of 0.5–0.7 ppm) with non-fluoridated Calgary (which had a CWF range of 0.59–0.89 ppm from 1991–2011, and from May 2011–2019 a fluoride level of 0.1-0.3 ppm) [94]. The study was judged to be of high quality with regard to design and conduct, and it took account of design effect when calculating the sample size and completing analysis but did not report the exact adjustment factor for clustering. The TSIF was employed to determine the prevalence and severity of dental fluorosis using the results of the clinical examinations [94]. The adjusted prevalence of dental fluorosis (score >0) in Calgary (7.7%; 95% CI: 5.9–9.6; n=1,406) was significantly lower than that in Edmonton (18.3%; 95% CI: 14.9–21.6; n=1,206). There were no data reported from the regression model on the contribution of other factors to dental fluorosis. There was a 10.6-percentage-point difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas. The level of agreement between the clinical examiners was estimated to be >0.80, indicating the possibility of some dental fluorosis misdiagnoses which could increase or decrease prevalence estimates. The use of fluoride toothpaste was almost equal in both areas, at 81.8% (95% CI: 79.8–83.7; n=2,575) in Calgary and 80.3% (95% CI: 78.4–82.2; n=2,507) in Edmonton [94].

In summary, the prevalence of dental fluorosis varies across the Canadian provinces, and no real overall pattern can be observed.

3.1.7.1.4 Chile

We identified one cross-sectional survey (judged to be of moderate quality with regard to design and conduct) examining dental fluorosis in five communities in Chile [100]. Two communities were on the coast and had high levels of natural fluoride, and three were in central Chile at altitudes not higher than 700 metres above sea level. The three communities of interest were the intervention area of San Felipe (CWF at 0.93 ppm since 1986), which was compared with the fluoride-deficient areas of Rancagua (0.7 ppm) and Santiago (0.21 ppm). At the time of the survey, San Felipe had been exposed to CWF at 0.93 ppm for 11 years, which implies lifetime exposure for the 7-year-old children and 11 years of exposure for the 12-year-old and 15-year-old children. Dean's Index of Fluorosis was used to classify the prevalence of dental fluorosis using the results of the clinical examinations. The prevalence of dental fluorosis among the sample in San Felipe (CWF) was 13.5% among 7-year-old children compared with 6.0% in fluoride-deficient Rancagua, 47.7% among 12-year-old children in San Felipe compared with 3.0% in Rancagua, and 25.3% among 15-year-old children in San Felipe compared with 6.7% in Rancagua. There was a 7.5-percentage-point difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas for 7-year-old schoolchildren, and at least a 44.7 percentage-point difference for 12-year-old children. The level of agreement with regard to the diagnosis of dental fluorosis between the clinical examiners was not reported. The severity of dental fluorosis and its determinants were not examined in this paper [100].

3.1.7.1.5 Cuba

We identified one cross-sectional survey series from La Salud, Cuba that met our inclusion criteria [93]. The study was judged to be of low quality with regard to design and conduct. The introduction of CWF elevated the water fluoride concentration from 0.05 to 0.70 ppm. A cross-sectional survey was completed at baseline (in 1973) and repeated in 1980 after 7 years of CWF. All children aged 6–13 years were included at both time points. Dean's Index of Fluorosis was used to classify the prevalence of dental fluorosis using the results of the clinical examinations. No confirmed cases of dental fluorosis were identified among the children at baseline or among 6–9-year-old children at follow-up, whereas the prevalence of dental fluorosis among the 10–13-year-old children at follow-up was 1.7%. The level of agreement between the clinical examiners with regard to the diagnosis of dental fluorosis was not reported. It was too soon after the intervention to determine the prevalence of dental fluorosis among participants exposed to CWF for their entire lifetime [93]. The determinants of dental fluorosis were not examined in this study.

3.1.7.1.6 Ireland

We identified three cross-sectional surveys (three papers) from Ireland that met our inclusion criteria [52,53,167]. One study was judged to be of low quality with regard to design and conduct [167], one study was moderate quality [53], and one study was high quality [52]. Two studies were national [53,167], and one study covered three counties (Dublin, Cork, and Kerry) [52].

All three studies were based on samples of schoolchildren, and two of the studies appear to have considered design effect when calculating sample size but did not state this explicitly in the papers [52,53]. Only one study calculated the level of agreement for dental fluorosis diagnoses between the clinical examiners [52]. CWF was introduced in Ireland in 1964 at 1.0 ppm (0.8–1.0 ppm) until 2007, when the concentration was lowered to a range of 0.6–0.8 ppm, with a target of 0.7 ppm. All participants of the three studies were judged as being lifelong residents in either CWF or fluoride-deficient areas (≤0.3 ppm) [52,53,167]. The participants were exposed to CWF at a level of 0.8–1.0 ppm in the two earlier studies [53,167], while in the most recent study, the earlier cohort was exposed to CWF at a level of 0.8–1.0 ppm and the later cohort was exposed to CWF at a level of 0.6–0.8 ppm [52].

Dean’s Index of Fluorosis was used to classify the prevalence of dental fluorosis using the results of the clinical examinations for all three studies [52,53,167]. In 1992, the prevalence of dental fluorosis in a sample of 8-year-olds was 1.1% in CWF areas of Ireland and 0.0% in fluoride-deficient areas, and in a sample of 15-year-olds it was 1.3% in CWF areas of Ireland and 0.0% in fluoride-deficient areas. Of note, 95% CIs were not calculated [167]. There were no cases of moderate or severe dental fluorosis reported in 1992 [167]. There was a 1.1-percentage-point difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas in 8-year-old children and a 1.3-percentage-point difference in 15-year-old children. In 2002, the prevalence of dental fluorosis had increased considerably: among 8-year-olds, it was 12% in CWF areas of Ireland and 7% in fluoride-deficient areas, while for 15-year-olds it was 17% in CWF areas of Ireland and 7% in fluoride-deficient areas. Of note, 95% CIs were not calculated [53]. There was a 5-percentage-point difference in the prevalence of dental fluorosis between CWF and fluoride-deficient areas in 8-year-old children and a 10-percentage-point difference in 15-year-old children. The 2002 survey also examined 12-year-old children, among whom the prevalence of dental fluorosis was similar to the 15-year-olds, at 16% in CWF areas of Ireland and 6% in fluoride-deficient areas. There was a 10-percentage-point difference in the prevalence of dental fluorosis between CWF and fluoride-deficient areas. In 2002, the prevalence of moderate and severe dental fluorosis was around 2% in the older age groups [53]. In 2017, the prevalence of dental fluorosis among 8-year-olds was 18% in CWF areas of counties Dublin, Cork, and Kerry and 12% in fluoride-deficient areas of counties Cork and Kerry, indicating that the prevalence had increased marginally since 2002. Of note, 95% CIs were not calculated for prevalence estimates [52]. There was a 6-percentage-point difference in the prevalence of dental fluorosis among 8-year-olds between the CWF and fluoride-deficient areas. In 2017, the prevalence of moderate dental fluorosis was under 1%, and there were no cases of severe dental fluorosis in CWF areas. The level of agreement for dental fluorosis diagnoses between the clinical examiners was estimated to be 0.74, indicating the possibility of some misdiagnoses which could increase or decrease prevalence estimates. The only factor associated with dental fluorosis was being a female living in Dublin [52]. The two earlier studies did not do regression analysis to identify determinants of dental fluorosis in Ireland. Overall, the prevalence of dental fluorosis has increased over time in Ireland.

3.1.7.1.7 Malaysia

We identified one study (published in two papers), employing a cross-sectional survey design, that examined aspects of dental fluorosis in Malaysia [97,174]. The study was of moderate quality with regard to design and conduct. CWF was introduced in the state of Negeri Sembilan in 1972 at a concentration of 0.7 ppm, and it was reduced to 0.5 ppm in December 2005. The study was conducted in two states in Peninsular Malaysia to compare fluoridated Negeri Sembilan (at 0.7 ppm from 1972 to 2005 and 0.5 ppm from 2006 to 2015) with fluoride-deficient Kelantan (described as having a water fluoride concentration of 0.0 ppm). The study appears to have considered design effect to adjust for cluster sampling when calculating sample size but does not state this explicitly. The authors employed Dean's Index of Fluorosis to classify the prevalence and severity of dental fluorosis using the results of the clinical examinations and photographs.

The prevalence of dental fluorosis among 9- and 12-year-old children who were lifetime residents in the fluoridated area was 35.7% (95% CI: 31.9–39.6%), significantly higher than the prevalence among lifetime residents in the fluoride-deficient area (5.5%; 95% CI: 3.6–7.4%) ($p<0.001$). There was a 30.2-percentage-point difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas. Among participants in the fluoridated area, the prevalence of dental fluorosis decreased from 38.4% (95% CI: 33.1–44.3%) for 12-year-olds (exposed to 3 years of CWF at 0.7 ppm and 9 years of CWF at 0.5 ppm) to 31.9% (95% CI: 27.6–38.2%) for 9-year-olds (exposed to 9 years of CWF at 0.5 ppm), although this difference was not statistically significant ($p=0.139$). The prevalence of moderate dental fluorosis among 9- and 12-year-old children who were lifetime residents in the fluoridated area (8.7%) was higher than that among lifetime residents in the fluoride-deficient area (0.4%). There were no cases of severe dental fluorosis identified in the two geographical areas being investigated. The level of agreement between the clinical examiners was estimated to be 0.72–0.90, indicating the possibility of dental fluorosis misdiagnoses which could increase or decrease prevalence estimates. For both overall and moderate dental fluorosis outcome measures, children who were exposed to CWF at 0.7 ppm in the first 2 years of life and then to CWF at 0.5 ppm thereafter were 8–11 times more likely to develop dental fluorosis than those who did not have any exposure to CWF. Those who had been exposed to CWF at 0.5 ppm in the local water supply throughout their lives were six to eight times more likely to have dental fluorosis compared with the fluoride-deficient reference group [97]. The prevalence of CWF was the only statistically significant variable in the oral hygiene logistic regression model and it was positively associated with the prevalence of dental fluorosis (lifetime exposure to CWF at 0.5 ppm had an OR of 8.45 (95% CI: 5.45–13.10; $p=0.001$) and exposure to CWF at 0.7 ppm and 0.5 ppm had an OR of 10.88 (95% CI: 7.03–16.84; $p=0.001$)) [174]. Simple logistic regression analysis of dental fluorosis with regard to oral hygiene habits when the children were aged under 6 years found that use of fluoride toothpaste (OR: 1.09; 95% CI: 0.70–1.70; $p=0.700$), supervised toothbrushing (OR: 1.11; 95% CI: 0.37–3.36; $p=0.849$), frequency of toothbrushing (OR: 1.03; 95% CI: 0.77–1.37; $p=0.861$), the age at which children started brushing their teeth (OR: 1.12; 95% CI: 0.83–1.51; $p=0.460$), the age at which children started brushing their teeth with toothpaste (OR: 1.10; 95% CI: 0.80–1.51; $p=0.572$), swallowing toothpaste (OR: 0.87; 95% CI: 0.47–1.61; $p=0.648$), eating/licking toothpaste (OR: 0.85; 95% CI: 0.64–1.13; $p=0.267$), and the amount of toothpaste used (OR: 1.00; 95% CI: 0.75–1.33; $p=0.988$) were not statistically significantly associated with dental fluorosis (i.e. all *p*-values were greater than 0.05 and all 95% CI ranges included 1) [97].

3.1.7.1.8 New Zealand

In 2009, the Ministry of Health in New Zealand measured the national prevalence of dental fluorosis by CWF (0.8–0.9 ppm) areas and fluoride-deficient (approximately 0.15 ppm) areas using a cross-sectional survey design [96]. The study was judged to be of moderate quality with regard to design and conduct, and the authors did adjust the sample size for design effect by age group (approximately 2.4 for children with cavitated dental caries and approximately 2.0 for young adults). CWF first began in Hastings in 1954 and became more widespread throughout the 1960s. Water fluoridation has been used in many regions in New Zealand for more than 60 years, so the study authors assumed lifetime exposure for the participants aged 8–30 years examined in this survey. The authors employed Dean's Index of Fluorosis to classify the prevalence and severity of dental fluorosis using the results of the clinical examinations and photographs. The prevalence of very mild to severe dental fluorosis was 14.9% (95% CI: 6.6–31.5) in the CWF areas and 20.4% (95% CI: 10.5–38.1) in fluoride-deficient areas, while the prevalence of moderate dental fluorosis was 1.7% (95% CI: 0.3–5.5) in the CWF areas and 2.3% (95% CI: 0.5–6.8) in fluoride-deficient areas. There were very few cases of severe dental fluorosis. There was a 5.5-percentage-point difference in the overall prevalence of dental fluorosis between the CWF and fluoride-deficient areas, and the prevalence and severity of dental fluorosis were not significantly different between CWF areas and fluoride-deficient areas [96]. It is possible that people moved between the fluoridated and fluoride-deficient areas throughout their lives, which may explain the higher than expected dental fluorosis in the fluoride-deficient areas. The level of agreement between the clinical examiners on dental fluorosis diagnoses was estimated to be 0.78, indicating the possibility of some misdiagnoses which could increase or decrease prevalence estimates. The determinants of dental fluorosis were not examined in this study.

3.1.7.1.9 Singapore

We found one cross-sectional survey (one paper) reporting the prevalence of dental fluorosis in Singapore, and this survey evaluated the effect of lifetime exposure to CWF at 0.7 ppm in 1968 in 7–9-year-old Chinese and Malay schoolchildren, 10 years after its introduction in 1956–59 [101]. The study was low quality with regard to design and conduct, and the sample size calculated was not adjusted for the effect of clustering. The natural fluorine content of Singapore's water was about 0.2 ppm; however, there were no baseline dental fluorosis data. Dental fluorosis was observed during clinical examinations in Chinese and Malay schoolchildren, but no dental fluorosis index was employed to classify the prevalence or severity of the condition. Specifically, in 1968, the prevalence of dental fluorosis was 4.8% in 7–8-year-old Malay schoolchildren and 2.8% in 8–9-year-old Malay schoolchildren; similar rates were found in 7–8-year-old Chinese schoolchildren (4.7%) and in 8–9-year-old Chinese schoolchildren (3.3%). Of note, 95% CIs were not calculated. The authors concluded that the overall prevalence of dental fluorosis was less than 5% [101]. The level of agreement between the clinical examiners on dental fluorosis diagnoses was not estimated. The determinants of dental fluorosis were not investigated.

3.1.7.1.10 Taiwan

We identified one cross-sectional survey (one paper) from Taiwan evaluating the prevalence of dental fluorosis in children aged 6–15 years who were born in or continuous residents of either Chung-Hsing New Village (CWF at 0.6 ppm for 12 years, since 1972) and fluoride-deficient Tsao-Tun (now Caotun) (0.08 ppm) [169]. The 6–12-year-old children had lifetime exposure to CWF, and all children living in both villages were invited to participate. The study was judged to be of moderate quality with regard to design and conduct. The authors used Dean's Index of Fluorosis to classify the prevalence and severity of dental fluorosis using the results of the clinical examinations. The prevalence of dental fluorosis in 6-year-old children was 3.4% in Chung-Hsing New Village compared with 0.2% in Tsao-Tun (now Caotun), whereas the prevalence in 12-year-old children was 10.0% in Chung-Hsing New Village compared with 2.9% in Tsao-Tun (now Caotun). There was a 3.2-percentage-point difference for 6-year-old children and a 7.1-percentage-point difference for 12-year-old children in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas. There were no cases of moderate dental fluorosis in children aged 6–12 years from either of the two villages; however, there was one case of severe dental fluorosis in a 13-year-old child living in fluoride-deficient Tsao-Tun (now Caotun) which was not related to the CWF programme

[169]. The level of agreement between the clinical examiners on dental fluorosis diagnoses was not estimated. The determinants of dental fluorosis were not investigated.

3.1.7.1.11 UK

We identified two cross-sectional surveys (two papers) from the UK: one from Anglesey, North Wales, which had CWF at 0.7 ppm at the time of the study compared with Chester (England) and Bala (North Wales), which were not fluoridated (<0.1 ppm) [88]; and one from Newcastle upon Tyne, England, which had CWF at 1.0 ppm, compared with South Northumberland, which was not fluoridated (<0.1 ppm) [171]. All participants in the two surveys were lifetime residents in their respective geographical area of residence [88,171]. The authors of one study completed a census for the CWF area and compared it with a sample in the non-CWF area [88], and the authors of the other study calculated their estimates based on a sample of the population [171]. The authors of one study did not calculate 95% CIs around their intervention sample [171] and neither study calculated 95% CIs around prevalence estimates for the control sample [88,171]. One study was judged to be of low quality [88] and the other was judged to be of moderate quality [171] with regard to design and conduct. Tabari *et al.* (2000) completed a clinical examination for dental fluorosis and Ellwood and ’O’Mullane (1996) took photographs to be examined by experts at a later date. The authors of both studies employed the Thylstrup and Fejerskov Index to classify the prevalence and severity of dental fluorosis [88,171].

The prevalence of dental fluorosis among 12–15-year-olds was 54% in Anglesey compared with 36% in the fluoride-deficient sample from Chester and Bala [88]. There was an 18-percentage-point difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas. From the data supplied, we cannot estimate the severity of dental fluorosis. Ellwood and ’O’Mullane (1996) did not investigate the determinants of dental fluorosis [88]. The level of agreement on dental fluorosis diagnoses between the clinical examiners of the photographs was estimated to be 0.73, indicating the possibility of some misdiagnoses which could increase or decrease prevalence estimates [88]. The prevalence of dental fluorosis in children aged 8–9 years was 54.0% in Newcastle upon Tyne (CWF at 1 ppm) compared with 22.5% in South Northumberland (fluoride deficient) [171]. There was a 31.5-percentage-point difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas. In Newcastle upon Tyne, 51% of the children sampled had Thylstrup and Fejerskov Index scores of 1 or 2, and 3% had a Thylstrup and Fejerskov Index score of 3 or higher. In South Northumberland, 22.0% of the children sampled had a Thylstrup and Fejerskov Index score of 1 or 2, and 0.5% had a score of 3 or higher. The level of agreement on dental fluorosis diagnoses between the clinical examiners was estimated to be 0.70, indicating the possibility of some misdiagnoses which could increase or decrease prevalence estimates [171]. Logistic regression modelling indicated that three variables – the area of residence (proxy for CWF area) (p<0.001), Jarman score (deprivation index) (p=0.03), and type of toothpaste used (p=0.02) – were statistically significant. There were no statistically significant two-way interactions (effect modification) between the independent variables included in the model. The OR of having dental fluorosis among participants from Newcastle upon Tyne (CWF) compared with those from South Northumberland (fluoride deficient) was 4.5 (95% CI: 3.3–6.1), and participants with higher Jarman scores (more deprived) were less likely to have dental fluorosis. The odds (OR) of having dental fluorosis if a participant used an adult toothpaste compared with a children’s toothpaste was 1.6 (95% CI: 1.06–2.27). When the presence or absence of dental fluorosis was defined at the threshold Thylstrup and Fejerskov Index score of more than 2, the only significant variable in the model was area of residence. The OR of having dental fluorosis for a participant in Newcastle upon Tyne (CWF at 1.0 ppm) compared with a participant in South Northumberland (fluoride deficient at 0.1 ppm) was 7.1 (95% CI: 3.4–14.7) [171]. The two studies in the UK had very similar dental fluorosis prevalence rates in the CWF areas under investigation.

3.1.7.1.12 USA

We identified three cross-sectional surveys (published in five papers) that estimated the prevalence of dental fluorosis in the USA [84,91,92,99,170]. Two studies, which were of low quality with regard to design and conduct, were completed in Michigan. The first study examined dental fluorosis 10 years after the introduction of CWF in Grand Rapids (CWF at 0.9–1.1 ppm) compared with Muskegon (fluoride concentration of <0.2 ppm); the children were aged 4–16 years. The authors reported that they observed the presence of dental fluorosis through clinical examination but did not use an index to classify the presence or severity of the condition [84]. The authors reported that "The observations to date give evidence of only a slight increase (0.24% in 1944; 0.36% in 1954) in the number of children with the milder forms of dental fluorosis, which are not objectionable from an esthetic or cosmetic standpoint" [84] p655. The second Michigan study was completed with lifetime residents of Redford (CWF at 1.0 ppm) compared with those in Cadillac (0.0 ppm) and, following clinical examinations, employed the TSIF to classify the presence and severity of dental fluorosis [99]. It is not clear in the paper how the sample size was calculated, and no 95% CIs were calculated around the prevalence estimate. Overall, about 36.0% of the children sampled had dental fluorosis, with 12.2% in fluoride-deficient Cadillac and 49.0% in Redford (with CWF at 1.0 ppm). There was a 36.8-percentage-point difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas. All cases were classified as having very mild or mild dental fluorosis. The level of agreement on dental fluorosis diagnoses between the clinical examiners of the photographs was estimated to be 0.85, indicating the possibility of a small number of misdiagnoses which could increase or decrease prevalence estimates. The OR of experiencing dental fluorosis was 8.46 (95% CI: 4.52–15.82) for Redford (CWF set at 1 ppm) when compared with fluoride-deficient Cadillac. The ORs for experiencing very mild dental fluorosis also increased following the use of topical fluoride mouth rinses (OR: 1.57; 95% CI: 1.02–2.41) and with older age (OR: 1.25; 95% CI: 1.13–1.38).

One study (three papers), which was judged to be of low quality with regard to design and conduct, was based in New York State and compared Newburgh (CWF at 0.8–1.2 ppm) with fluorine-free Kingston (<0.3 ppm) [66]. The first paper reported "the water supply records in Newburgh indicate that the level of fluoride in the water was maintained at the recommended 1 ppm established by the US Public Health Service in 1945, except for a three-year period from 1978 to 1981. This reduction in fluoride would affect the teeth of 7- to 14-year-olds differentially, depending on the stages of development of the teeth during this time" p566 [66]. The second and third papers reported lifetime exposure to CWF for participants living in the intervention area [67,145]. The study authors used Dean's Index of Fluorosis to classify the presence and severity of dental fluorosis following clinical examinations [91,92,170]. The estimates of dental fluorosis prevalence and respective standard errors were calculated for comparison purposes using the methods appropriate for stratified cluster sampling; however, the exact adjustment was not reported, and 95% CIs were not calculated around the prevalence estimate. In 1986, the overall prevalence of dental fluorosis in 7–14-year-old children was 7.8% in Newburgh and 7.3% in Kingston [91]. There was a 0.5-percentage-point difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas. The proportion of children with moderate dental fluorosis was less than 2% in Newburgh and less than 1% in Kingston. In 1986, there were no cases of severe dental fluorosis in Newburgh or Kingston [91]. By 1995, the prevalence of dental fluorosis among 7–14-year-old children in both cities had increased considerably, with an overall prevalence of 19.6% in Newburgh and 11.7% in Kingston [92]. There was a 7.9-percentage-point difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas. The severity of dental fluorosis is not reported in the 1998 paper (reporting on the 1995 survey). The level of agreement on dental fluorosis diagnoses between the clinical examiners was estimated to range from 0.65 to 1.00, indicating the possibility of some misdiagnoses which could increase or decrease prevalence estimates. In 1995, CWF was a major factor contributing to dental fluorosis (prevalence: 17.9%; OR: 2.7; 95% CI: 1.45–4.91). Other contributing factors were CWF combined with either fluoride supplements or early toothbrushing (OR: 3.0; 95% CI: 1.64–5.49), and CWF combined with both fluoride supplements and early toothbrushing (OR: 4.1; 95% CI: 2.90–8.30) [92].

3.1.7.2 Dental fluorosis findings by fluorosis index employed

The second step in our analysis was to analyse the data by the fluoride index employed to calculate the prevalence and severity of dental fluorosis. For this analysis, we excluded the four studies (six papers) that did not use an index or identify their index [57,58,59,60,77,138].

3.1.7.2.1 Dean's Index of Fluorosis

In total, 13 papers (10 studies) measured the prevalence and/or severity of dental fluorosis using Dean's Index of Fluorosis (Table 38) [52,53,91–93,95–97,100,167,169,170,174]. The prevalence of dental fluorosis in 6–9-year-old children living in CWF areas ranged from 0.0% to 18.0%, while the prevalence of dental fluorosis in 10–15-year-old children ranged from 1.3% to 47.7%. The prevalence of dental fluorosis has increased over time. The difference in the prevalence of dental fluorosis in 10–15-year-old children between the CWF and fluoride-deficient areas ranged from 1.3 to 44.7 percentage points.

A total of nine papers (eight studies) measured the prevalence of moderate and/or severe dental fluorosis using Dean's Index of Fluorosis (Table 39) [52,53,91,95–97,167,169,174]. The prevalence of moderate dental fluorosis among children living in CWF areas was reported in six papers (five studies) and ranged from 1.0% to 8.7% [52,91,96,97,169,174]. The prevalence of both moderate and severe dental fluorosis among children living in CWF areas was reported in three papers (three studies) and the combined rate ranged from 0% to 2% (Table 39) [95,167,169]. The prevalence of severe dental fluorosis among children living in CWF areas was 0% in three papers (two studies) [91,97,174].

Table 38 Prevalence of dental fluorosis in studies employing Dean's Index of Fluorosis

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Prevalence of dental fluorosis – CWF	95% CI – CWF	Total CWF area	Prevalence of dental fluorosis – fluoride deficient	95% CI – fluoride deficient	Total fluoride deficient area	Percentage point difference	Quality rating	Cluster sampling adjustment	Identification of determinants
Australia	Medcalf [95]	1975	6	0.7–0.9	7.8%	NR	362	N/A	N/A	N/A	N/A	Low	No	No
Chile	Villa *et al.* [100]	1998	7 12 15	0.93	7-year-olds: 13.5% 12-year-olds: 47.7% 15-year-olds: 25.3%	NR	7-year-olds: 158 12-year-olds: 155 15-year-olds: 150	7-year-olds: 6.0% 12-year-olds: 3.0% 15-year-olds: 6.7%	NR	7-year-olds: 129 12-year-olds: 152 15-year-olds: 155	7-year-olds: 7.5 12-year-olds: 44.7 15-year-olds: 18.6	Moderate	No	No
Cuba	Künzel [93]	1982	6–13	0.7 (±0.1)	6–9-year-olds: 0.0% 10–13-year-olds: 1.7%	N/A (census data)	356	6–9-year-olds: 0% 10–13-year-olds: 0%	258	N/A as census	6–9-year-olds: 0.0 10–13-year-olds: 1.7	Low	N/A as census	No
Ireland	Clarkson and' O'Mullane [167]	1992	8 15	0.8–1.0	8-year-olds: 1.1% 15-year-olds: 1.3%	NR	8-year-olds: 459 15-year-olds: 229	8-year-olds: 0.0% 15-year-olds: 0.0%	NR	8-year-olds: 372 15-year-olds: 342	8-year-olds: 1.1 15-year-olds: 1.3	Low	No	No
Ireland	Whelton *et al.* [53]	2004	8 15	0.8–1.0	8-year-olds: 12.0% 15-year-olds: 17.0%	NR	9,976	8-year-olds: 7.0% 15-year-olds: 7.0%	NR	4,353	8-year-olds: 5 15-year-olds: 10	Moderate	Likely, judging by sample size	No
Ireland	James *et al.* [52]	2021	8	0.8–1.0, then 0.6–0.8	18%	NR	2002: 1,011; 2017: 1,083	12%	NR	2002: 233; 2017: 772	6	High	Likely, judging by sample size	Yes
Malaysia	**Mohd Nor *et al.*** [97]	**2018**	9, 12	0.7 from 1972, reduced to 0.5 in 2005	35.7%	31.9–39.6%	607	5.5%	3.6–7.4%	548	30.2	Moderate	Likely, judging by sample size	Yes
Malaysia	*Mohd Nor et al.* [174]	*2021*	9, 12	0.7 from 1972,	35.7%	31.9–39.6%	1,155	5.5%	3.6–7.4%	1,155	30.2	Moderate	Likely, judging by sample size	Yes

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Prevalence of dental fluorosis – CWF	95% CI – CWF	Total CWF area	Prevalence of dental fluorosis – fluoride deficient	95% CI – fluoride deficient	Total fluoride deficient area	Percentage point difference	Quality rating	Cluster sampling adjustment	Identification of determinants
				reduced to 0.5 in 2005										
New Zealand	Ministry of Health [96]	2010	8–30	0.8–0.9	14.9% Note that there is doubt about the recorded accuracy of lifetime exposure.	6.6–31.5	3,196 (987 children and 2,209 adults)	20.4% Note that there is doubt about the recorded accuracy of lifetime exposure.	10.5–38.1	3,196 (987 children and 2,209 adults)	5.5	Moderate	Yes	No
Taiwan	Hong *et al.* [169]	1990	6–15	0.6, then 0.7	12-year-olds: 10%	N/A as census	3,066	12-year-olds: 2.9%	N/A as census	4,087	7.1	Moderate	N/A as census	No
USA	**Kumar *et al.*** [91]	**1989**	7–14	0.8–1.2	7.8%	NR	459	7.3%	NR	425	0.5	Low	Yes	No
USA	*Kumar et al.* [92]	*1998*	7–14	1.0–1.2	19.6%	NR	847	11.7%	NR	646	7.9	Low	Yes	Yes
USA	*Kumar et al.* [170]	*2000*	7–14	1.0–1.2	19.6%	NR	2,193	11.7%	NR	2,193	7.9	Low	Yes	No

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

NR = not reported; N/A = not applicable

Table 39 Prevalence of moderate and/or severe dental fluorosis in studies employing Dean's Index of Fluorosis

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Moderate, severe, or moderate and severe dental fluorosis	Prevalence of moderate and/or severe dental fluorosis–CWF	95% CI – CWF	Total CWF area	Prevalence of moderate and/or severe dental fluorosis – fluoride deficient	95% CI – fluoride deficient	Total fluoride deficient area	Percentage point difference
Australia	Medcalf [95]	1975	6	0.7–0.9	Moderate and severe	0%	NR	362	N/A	N/A	N/A	N/A
Ireland	Clarkson and' O'Mullane [167]	1992	8 15	0.8–1.0	Moderate and severe	0%	NR	8-year-olds: 459 15-year-olds: 229	0%	NR	8-year-olds: 372 15-year-olds: 342	0
Ireland	Whelton *et al.* [53]	2004	8 15	0.8–1.0	Moderate and severe	8-year-olds: NR 15-year-olds: 2%	NR	9,976	NR	NR	4,353	N/A
Ireland	James *et al.* [52]	2021	8	0.8–1.0, then 0.6–0.8	Moderate	1%	NR	2002: 1,011; 2017: 1,083	NR	NR	2002: 233; 2017: 772	N/A
Malaysia	**Mohd Nor *et al.*** [97]	**2018**	9, 12	0.7 from 1972, reduced to 0.5 in 2005	Moderate Severe	Moderate: 8.7% Severe: 0.0%	NR	607	Moderate: 0.4% Severe: 0.0%	NR	548	Moderate: 8.3 Severe: 0.0
Malaysia	*Mohd Nor et al.* [174]	*2021*	9, 12	0.7 from 1972, reduced to 0.5 in 2005	Moderate Severe	Moderate: 8.7% Severe: 0.0%	NR	1,155	Moderate: 0.4% Severe: 0.0%	NR	1,155	Moderate: 8.3 Severe: 0.0
New Zealand	Ministry of Health [96]	2010	8–30	0.8–0.9	Moderate	1.7%	0.3–5.5	3,196 (987 children and 2,209 adults)	2.3%	0.5–6.8	3,196 (987 children and 2,209 adults)	0.6
Taiwan	Hong *et al.* [169]	1990	6–15	0.6, then 0.7	Moderate and severe	0.0% for 12-year-olds	N/A as census	3,066	<1.0% for 12-year-olds	N/A as census	4,087	<1.0
USA	**Kumar *et al.*** [91]	**1989**	7–14	1.0 (±0.2)	Moderate Severe	Moderate: 2.0% Severe: 0.0%	NR	459	Moderate: 1.0% Severe: 0.0%	NR	425	Moderate: 1 Severe: 0

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

NR = not reported; N/A = not applicable

3.1.7.2.2 Thylstrup and Fejerskov Index

Eight papers (seven studies) measured the prevalence and/or severity of dental fluorosis using the Thylstrup and Fejerskov Index (Table 40) [87,88,98,168,171–173,175]. One study presented prevalence by DMFT and is not comparable with the other studies [87]. For the remaining six studies, the prevalence of dental fluorosis in permanent teeth among 5–24-year-old participants living in CWF areas ranged from 13.3% to 69.6% [87,88,98,168,171,172,175].There is no temporal pattern with regard to the different study years The difference in the prevalence of dental fluorosis in permanent teeth between the CWF and fluoride-deficient areas ranged from 7.2 to 51.1 percentage points [87,88,98,168,171,172,175].

Four papers (three studies) measured the prevalence of moderate and/or severe dental fluorosis using the Thylstrup and Fejerskov Index (

Table 41); the prevalence of both moderate and severe dental fluorosis in CWF areas was 3–9% [171,172,175], and the prevalence of moderate dental fluorosis in one CWF area was 18% [98].

Table 40 Prevalence of dental fluorosis in studies employing the Thylstrup and Fejerskov Index

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Prevalence of dental fluorosis – CWF	95% CI – CWF	Total CWF area	Prevalence of dental fluorosis – fluoride deficient	95% CI – fluoride deficient	Total fluoride deficient area	Percentage point difference	Quality rating	Cluster sampling adjustment	Identification of determinants
Australia	Riordan and Banks [173]	1991	11	0.8	40.2%	NR	338	33%	NR	321	7.2	Low	No	Yes
Brazil	Cortes *et al.* [87]	1996	6–12	0.7	NR	NR	N/A	NR	NR	N/A	N/A	Low	No	No
Brazil	Heintze *et al.* [168]	1998	5–24	0.9	Garça: 13.3% Bauru: 6.8%	NR	Bauru: 207 Garça: 430	1.7%	NR	348	11.6	Low	No	No
Brazil	Silva *et al.* [98]	2021	5 12	0.5–0.6	5-year-olds: 0.0% 12-year-olds: 69.6%	NR	5-year-olds: 161 12-year-olds:169	5-year-olds: 0.0% 12-year-olds: 18.5%	NR	5-year-olds: 178 12-year-olds:184	5-year-olds: 0.0 12-year-olds: 51.1	High	Yes (1.7)	Yes
Canada	**Maupomé *et al.*** [175]	**2003**	8.3 14.3	0.95 (±0.27)	1993–94: 58%	N/A (census data)	4,153	1996–97: 23%	N/A as census	4,131	35.0	Moderate	N/A as census	No
Canada	*Clark et al.* [172]	*2006*	NR	0.92 (±0.21)	1993–94: 58%	N/A (census data)	1993–94: 698	1996–97: 23% 2002–03: 24%	N/A as census	1996–97: 293 2002–03: 146	34.0	Moderate	N/A as census	Yes
England and Wales, UK	Ellwood and' O'Mullane [88]	1996	14.1	0.7	54%	N/A (census data)	196	36%	NR	267	18	Low	No	No
England, UK	Tabari *et al.* [171]	2000	8–9	1.0	54%	NR	409	22.5%	NR	403	31.5	Moderate	No	Yes

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

NR = not reported; N/A = not applicable

Table 41 Prevalence of moderate and/or severe dental fluorosis in studies employing the Thylstrup and Fejerskov Index

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Moderate, severe, or moderate and severe dental fluorosis	Prevalence of moderate and/or severe dental fluorosis– CWF	95% CI – CWF	Total CWF area	Prevalence of moderate and/or severe dental fluorosis – fluoride deficient	95% CI – fluoride deficient	Total fluoride deficient area	Percentage point difference
Brazil	Silva *et al.* [98]	2021	5 12	0.5–0.6	Moderate	18.0%	NR	5-year-olds: 161 12-year-olds: 169	3.3%	NR	5-year-olds: 178 12-year-olds: 184	14.7
Canada	**Maupomé *et al.*** [175]	**2003**	8.3 14.3	0.95 (±0.27)	Moderate and severe	1993–94: 9%	NR	4,153	1996–97: 0%	NR	4,131	9
Canada	*Clark et al.* [172]	*2006*	NR	0.92 (±0.21)	Moderate and severe	1993–94: 9%	NR	1993–94: 698	1996–97: 0% 2002–03: 0%	NR	1996–97–293 2002–03 146	9
England, UK	Tabari *et al.* [171]	2000	8–9	1.0	Moderate and severe	3.0%	NR	409	0.5%	NR	403	2.5

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

NR = not reported

3.1.7.2.3 Tooth Surface Index of Fluorosis

Six papers (five studies) measured the prevalence and/or severity of dental fluorosis using the TSIF (Table 42) [89,90,94,99,165,166]. The prevalence of dental fluorosis in schoolchildren living in CWF areas ranged from 18.3% to 69.2%. There is no temporal pattern with regard to the year when the study was conducted. The difference in the prevalence of dental fluorosis between the CWF and fluoride-deficient areas ranged from 10.0 to 36.8 percentage points.

Two papers (one study) measured the prevalence of moderate and severe dental fluorosis using the TSIF (Table 43) [165,166]. The prevalence of both moderate and severe dental fluorosis in schoolchildren living in CWF areas was 3% in the one study (two papers) in Canada [165,166]. There was a 1-percentage-point difference in the prevalence of both moderate and severe dental fluorosis between the CWF and fluoride-deficient areas.

Table 42 Prevalence of dental fluorosis in studies employing the TSIF

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Prevalence of dental fluorosis – CWF	95% CI – CWF	Total CWF area	Prevalence of dental fluorosis – fluoride deficient	95% CI – fluoride deficient	Total fluoride deficient area	Percentage point difference	Quality rating	Cluster sampling adjustment	Identification of determinants
Canada	Ismail *et al.* [89]	1990	17	0.6–1.3	Public school: 45.6% Private school: 58.0%	Public school: 41.1–50.1 Private school: 55.3–60.7	Public school:222 Private school: 215	Public school: 31.1% Private school: 30.1%	Public school: 28.1–34.1 Private school: 27.1–33.1	Public school:251 Private school: 248	Public school:14.5 Private school: 27.9	Low	Yes	Yes
Canada	**Clark *et al.*** [165]	**1993**	6–14	1.2	65%	NR	510	55%	NR	621	10	Low	No	No
Canada	*Clark et al.* [166]	*1994*	6–14	1.11	65%	NR	510	55%	NR	621	10	Low	No	Yes
Canada	Ismail *et al.* [90]	1993	NR	1.1	69.2%	N/A (census data)	103	41.5%	N/A as census	116	27.7	Moderate	N/A as census	Yes
Canada	McLaren *et al.* [94]	2021	NR	0.5–0.7	18.3%	14.9–21.6	1,620	7.7%	5.9–9.6	1,402	10.6	Moderate	Yes	No
USA	Szpunar and Burt [99]	1998	6–12	1.0	49%	NR	249	12.2%	NR	131	36.8	Low	No	Yes

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

NR = not reported; N/A = not applicable

Table 43 Prevalence of moderate and/or severe dental fluorosis in studies employing the TSIF

Country	Author*	Year	Age (in years)	CWF level (in ppm)	Moderate, severe, or moderate and severe dental fluorosis	Prevalence of moderate and/or severe dental fluorosis– CWF	95% CI – CWF	Total CWF area	Prevalence of moderate and/or severe dental fluorosis – fluoride deficient	95% CI – fluoride deficient	Total fluoride deficient area	Percentage point difference
Canada	**Clark *et al.*** [165]	**1993**	6–14	1.2	Moderate and severe	3%	NR	510	2%	NR	621	1
Canada	*Clark et al.* [166]	*1994*	6–14	1.11	Moderate and severe	3%	NR	510	2%	NR	621	1

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

NR = not reported

3.1.7.3 Feasibility assessment for meta-analysis

The feasibility assessment for meta-analysis indicated that the dental fluorosis prevalence rates could not be summarised into a single overall prevalence for 17 papers (14 studies) out of the 27 included papers, as they did not use a census approach for the complete sample and/or did not report 95% CIs for their prevalence estimates [52,53,87,88,91,92,95,98–100,165–168,170,171,173]; therefore, these papers were excluded from further analysis. As these studies employed a cluster sampling approach to select their sample but did not report the design effect adjustment, the Health Research Board (HRB) authors were unable to calculate accurate CIs. Only five papers (four studies) used a census approach [90,93,169,172,175] and five papers (four studies) provided CIs [89,94,96,97,174]; however, we are not sure whether the authors of one of the studies (two papers) adjusted for design effect in the calculation of their CIs [97,174]. When studies with undetermined variance in their prevalence calculations are excluded, we have seven studies (eight papers) that we can consider for summarisation or synthesis [89,90,93,94,96,169,172,175]. One of the seven remaining studies was rated as low quality with regard to design and conduct [93]. When the low-quality study is excluded, we have six studies (seven papers) that we can consider for summarisation [89,90,94,96,169,172,175]. For one of the six remaining studies, we have doubts about the accuracy of lifetime exposure [94]. The five remaining studies are from Taiwan (one study, one paper) [169] and Canada (four studies, five papers) [89,90,94,172,175]. One of the four Canadian studies did not report the ages of the schoolchildren who participated [90]. An international prevalence estimate comprising rates from two countries collected over 20 years would not be very accurate, so we will refrain from calculating such a summary standardised prevalence estimate.

See Appendix I of Section 6, Table 19 for a feasibility assessment of the dental fluorosis outcome data for meta-analysis.

3.1.7.4 Narrative synthesis by country and index

We included 26 studies (reported in 33 papers) estimating the prevalence of dental fluorosis in a CWF area compared with a fluoride-deficient area or with baseline in 13 countries, specifically: Australia, Brazil, Canada, Chile, Cuba, Ireland, Malaysia, New Zealand, Singapore, Taiwan, the UK (England and Wales), and the USA. For analysis by the dental fluorosis index used by the primary study authors, we excluded the four studies (six papers) [57,58,59,60,77,138] that either did not use an index or did not identify the index employed.

The prevalence of dental fluorosis increased over time in Brazil [98,168], Ireland [52,53,167], and the USA[91,92,170], and this increase was observed both in areas with and without CWF. We used three indices in this review in order to measure the prevalence of dental fluorosis, specifically Dean’s Index of Fluorosis, the Tooth Surface Index of Fluorosis, and the Thylstrup and Fejerskov Index. The prevalence of dental fluorosis by index was marginally lower using Dean’s Index of Fluorosis(see Table 38 compared with Table 40 and Table 42). For example, the synthesised evidence in this review found that:

- The prevalence of dental fluorosis in permanent teeth of 10–15-year-old children living in CWF areas, using Dean’s Index of Fluorosis, ranged from 1.3% to 47.7%.
- The prevalence of dental fluorosis in in permanent teeth of schoolchildren and young people living in CWF areas, using the Tooth Surface Index of Fluorosis, ranged from 18.3% to 69.2%.
- The prevalence of dental fluorosis in permanent teeth of among 6–14-year-old children living in CWF areas, using the Thylstrup and Fejerskov Index, ranged from 13.3% to 69.6%.

The lower dental fluorosis prevalence using the Dean’s index of fluorosis is likely explained by the exclusion of questionable dental fluorosis cases when using this index to measure prevalence. The synthesised evidence in this review indicated that the prevalence of both moderate and severe dental fluorosis ranged from 0.0% to 18.0%, while the reported prevalence of severe dental fluorosis was 0.0% (Tables 39, 41, and 43). Moderate and severe dental fluorosis are the classifications of dental fluorosis that cause concern among dentists, parents, and children. Moderate dental fluorosis is associated with aesthetic concerns among affected children and their parents and may require topical treatment, while severe dental fluorosis requires restorative interventions by dentists in order to address the damage. The evidence synthesised in this systematic review found few cases of severe dental fluorosis in areas with CWF.

The between-country difference in the prevalence of both moderate and severe dental fluorosis was most apparent when using the Thylstrup and Fejerskov Index. For example, in Brazil, the prevalence of both moderate and severe dental fluorosis in children living in CWF areas was 18.0% (no severe cases) [98], compared with 9% in Canada [172,175] and 3% in England [171]. The prevalence of both moderate and severe dental fluorosis was higher in CWF areas compared with fluoride-deficient areas in all three countries. The difference in the prevalence of moderate and severe dental fluorosis combined among children living in CWF and fluoride-deficient areas was 14.7 percentage points in Brazil, 9.0 percentage points in Canada, and 2.5 percentage points in England [98,171,172,175].

All 26 studies (33 papers) were cross-sectional in nature, and 15 of the 26 studies (18 of the 33 papers) were low quality with regard to conduct and design [84–88,91–93,95,99,101,102,165–168,170,173]. Only one of the 33 papers controlled for all five groups of confounding variables [98]. The dental fluorosis prevalence estimates by fluoride concentration in the drinking water did not demonstrate a clear pattern across countries, although a pattern could be observed within CWF areas in some countries (specifically England (54% in the two included studies [88,171]), Ireland (with increasing levels over time, for example in 8 year olds, the levels were 1.1% in 1992, 12% in 2002 and 18% in 2017 [52,53,167]), and the USA (with increasing levels over time, for example, 7.8% in 1989 and 19.6% in 1998 and 2000 among 7–14 year odls [91,92,170]). Only four studies (five papers) provided population prevalence estimates [90,93,169,172,175] or sample estimates with 95% CIs (four papers) [89,94,96,97] for dental fluorosis. Of note, one of the sample estimates did not state that the authors took account of the cluster sampling design effect when calculating the 95% CIs [97]. Therefore, the certainty of evidence is very low.

3.1.7.5 CWF as a determinant of dental fluorosis

3.1.7.5.1 Feasibility assessment for meta-analysis

Five studies (six papers) provided logistic regression models measuring the association between CWF and very mild to severe dental fluorosis and reported their full logistic regression model (including the number and proportion of participants affected and the corresponding total number of participants exposed to both CWF and fluoride-deficient areas, as well as the odds ratio and its 95% CI). All five studies made some attempt to control for confounding resulting from five key groups of determinant factors (demographic factors, socioeconomic factors, nutritional factors, dental fluoride sources, and access to and availability of dental services). No study controlled for all five groups of variables; one study controlled for three or four key determinants [173], and four studies (five papers) controlled for only two determinants [89,92,97,170,171,174]. Three studies (four papers) were judged to be of moderate quality with regard to design and conduct [89,97,171,174], and two studies (three papers) were judged to be of low quality [92,170,173] (see Appendix I of Section 6 for a feasibility assessment of the outcome data for meta-analysis).

3.1.7.5.2 Narrative and meta synthesis by determinant factors

We completed a pairwise meta-analysis using the results of three moderate-quality cross-sectional surveys in order to determine the standardised odds of having dental fluorosis when exposed to CWF, which indicated that children living in CWF areas had statistically significant (two to seven times higher) adjusted odds of developing dental fluorosis than children living in fluoride-deficient areas (adjusted odds ratio (AOR): 3.66; 95% CI: 1.92–6.98; I^2: 0%) [89,97,171,174] (**Error! Reference source not found.** and Table 44). The vast majority of cases had very mild or mild dental fluorosis. The three studies controlled for two to four of the five possible confounding factors. Ismail *et al.* (1990) controlled for demographic, socioeconomic, and dental fluoride sources; Mohd Nor *et al.* (2018, 2021) controlled for demographic factors, socioeconomic factors, nutritional factors, and dental fluoride sources; and Tabari *et al.* (2000) controlled for socioeconomic factors and dental fluoride sources [89,97,171,174]. The between-study heterogeneity variance was estimated at τ^2 = 0.00 (95% CI: 0.00–5.62), with an I^2 value of 0% (95% CI: 0.0–89.6%). The prediction interval ranged from g = 0.06 to 241.44, negative intervention effects are not expected for future studies, although the prediction intervals are extremely wide. There were insufficient studies to examine the effects of subgroup analyses on heterogeneity. The certainty of evidence is very low.

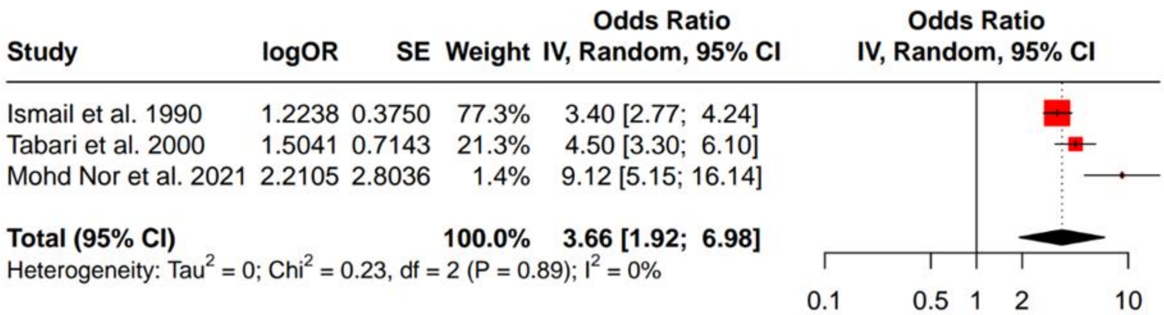


Figure 24 Forest plot of standardised adjusted odds of dental fluorosis when exposed to CWF

Table 44 CWF as an independent determinant of dental fluorosis

Author*	Year	Total sample size	Sample size	Number with dental fluorosis	Proportion with dental fluorosis	CWF influence	AOR	95% CI (lower)	95% CI (upper)	Study quality	Confounding
Ismail *et al.* [89]	1990	936	499	153	31%	No CWF†	1			Moderate	Partial
		936	437	226	52%	CWF at 1 ppm for the first 6 years of life	3.4	2.77	4.24		
Mohd Nor et al. [174]	*2021*	1,143	607	30	5%	No CWF	1			Moderate	Partial
		1,143	548	213	39%	CWF at 0.7 ppm for the first 2 years of life, and then at 0.5 ppm thereafter	9.12	5.15	16.14		
Tabari *et al.* [171]	2000	812	403	91	22.5%	No CWF	1			Moderate	Some
		812	409	221	54%	Lifetime exposure to CWF at 1 ppm	4.5	3.3	6.1		

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

†Fluoride-free or fluoride-deficient water

3.2 Question 2A: What is the effect of fluoride toothpaste in areas with CWF on dental health in children who are aged under 6 years when they receive the intervention?

3.2.1 Search and screening results

The database search retrieved 2,564 records, which we exported to EndNote. There were 461 duplicate records removed in EndNote, leaving 2,103 records. These 2,103 records were imported into EPPI-Reviewer for dual screening on title and abstract by one of two sets of two reviewers (JL and SS, and OC and AF), and 1,860 were excluded, leaving 243 records. Those 243 papers were sought for full-text screening, and 229 were retrieved. The 229 retrieved papers were screened on full text, resulting in the inclusion of 16 full-text papers. Supplemental searching and reference and citation chasing identified 1,394 records; of these, 1,105 were duplicates and were removed, leaving 289 records. Those 289 records were screened on title and abstract and 246 were excluded, leaving 43 records. The 43 full-text papers were retrieved and screened; 40 were excluded and 3 were included. In total, 19 papers were included in order to answer Question 2A.

See Appendix F of Section 7 for the PRISMA flow diagram for Question 2A.

3.2.2 Study characteristics

The HRB identified 19 papers (18 studies), published between 1988 and 2021, which examined the effects of non-prescribed fluoride toothpaste on permanent and/or primary teeth in children who used fluoride toothpaste when they were aged under 6 years and lived in communities with CWF (Table 45).

Table 45 Summary of study characteristics for studies examining CWF and fluoride toothpastes

Country	Author*	Year	Study design	Study population	Details of exposure	CWF exposure (ppm)	Study objectives	Details of comparator	Outcome measure	Sample in analysis	Mean age/age range	Percentage female
Australia	Riordan [178]	1993	Cross-sectional survey	Children born in 1983 (aged 7 years)	Perth metropolitan region, Western Australia (0.8 ppm)	0.8	To record the prevalence and severity of dental caries and dental fluorosis and to correlate these against the reported use of dentifrice and the age of weaning.	No comparator	Dental caries and dental fluorosis	350	Mean age: 7 years, 5.6 months (SD: 3.3 months)	47%
Australia	Riordan [179]	2002	Cross-sectional survey	10-year-old schoolchildren	Perth, Western Australia (CWF at 0.85 ppm); children born in 1990; residence in the period from birth to 5 years of age was categorised as 'fluoridated' if more than half that period had been spent in a fluoridated area and as 'non-fluoridated' if not	0.8	To evaluate the effect of years of residence in an area with CWF on the prevalence of dental fluorosis and dental caries.	Bunbury, Western Australia (0.2–0.3 ppm)	Dental caries and dental fluorosis	582	Mean age not reported; children were aged 10 years	48.6%

Country	Author*	Year	Study design	Study population	Details of exposure	CWF exposure (ppm)	Study objectives	Details of comparator	Outcome measure	Sample in analysis	Mean age/age range	Percentage female
Australia	Bal *et al.* [180]	2015	Cross-sectional survey	Schoolchildren aged 7–11 years	City of Blue Mountains, New South Wales (CWF since 1992, at 1.0 ppm)	1.0	To evaluate the prevalence and risk of dental fluorosis from a range of fluoride sources.	No comparator with respect to fluoride therapies Comparator city of Hawkesbury with respect to CWF 1 ppm since either 1967 or 1969	Dental fluorosis	1,138	Mean age not reported/ age range: 7–11 years	Not reported
Brazil	Tiano *et al.* [157]	2009 a	Cross-sectional survey	Children aged 36 months and under in public daycare centres	Gabriel Monteiro, São Paulo (year not reported; 0.60–0.75 ppm)	0.60–0.75	To determine the prevalence of dental caries and the contribution of some variables in children with different fluoride levels in the water supply.	Clementina (0.40 ppm) and Gabriel Monteiro, São Paulo (year not reported; 0.60–0.75 ppm)	Dental caries and oral hygiene quality	68	Exposure: age range: 8–36 months (mean age: 23.63 months (±9.28 months)) Comparator: age range: 8–36 months (mean age: 23.70 months (±8.30 months))	Not reported

Country	Author*	Year	Study design	Study population	Details of exposure	CWF exposure (ppm)	Study objectives	Details of comparator	Outcome measure	Sample in analysis	Mean age/age range	Percentage female
Brazil	de Moura *et al.* [181]	2013	Cross-sectional survey	8–12-year-old children who were lifelong residents of Teresina, Piauí	The city of Teresina, Piauí, Brazil (CWF since 1997 at 0.6–0.8 ppm)	0.6–0.8	To investigate the prevalence and severity of dental fluorosis in children following a dental programme for maternal and infant health undertaken by the parents when the children were aged 0–3 years.	No comparator	Dental fluorosis	Exposure: 128 Comparator: 128	Mean age not reported/ age range: 8–12 years	Exposure: 49% Comparator: 60%
Brazil	Celeste and Luz [182]	2016	Matched case-control study	12-year-old schoolchildren	Cachoeira do Sul and Rio Grande do Sul, Rio Grande do Sul (CWF at 0.6–0.8 ppm)	0.6–0.8	To investigate the independent and joint contributions of different sources of fluoride exposure to dental fluorosis.	No comparator	Dental caries and dental fluorosis	271	Mean age not reported; children were aged 12 years	51%
Brazil	Marques *et al.* [183]	2021	Cross-sectional survey	High school students aged 17–20 years, enrolled in public schools	Teresina, Piauí (CWF since 1997 at 0.6–0.8 ppm)	0.6–0.8	To determine the association of water fluoridation with the prevalence and severity of dental caries and dental fluorosis in individuals exposed to fluoride toothpaste.	Fluoride-deficient areas of Teresina	Dental caries and dental fluorosis	660	17.8 years (±1.19 years	Total: 58.3% Exposure: 56.5% Comparator: 60.2%

Country	Author*	Year	Study design	Study population	Details of exposure	CWF exposure (ppm)	Study objectives	Details of comparator	Outcome measure	Sample in analysis	Mean age/age range	Percentage female
Brazil	Silva *et al.* [98]	2021	Cross-sectional survey	Children aged 5 and 12 years	CWF areas of Teresina, Piauí, with lifelong exposure	0.5–0.6	To evaluate the experience and severity of dental caries and dental fluorosis in participants when using fluoride toothpaste, and with or without exposure to CWF.	Non-fluoridated areas of Teresina, Piauí (<0.05 ppm)	Dental caries and dental fluorosis	692	Mean age not reported; children were aged 5 years (12-year-olds excluded as data were not historic)	Exposure: 5-year-olds: 48.4%; Comparator: 5-year-olds: 44.4%;
Canada	Osujp *et al.* [184]	1988	Case-control study	8-, 9-, and 10-year-old schoolchildren	A nearly optimally fluoridated community in Toronto, Ontario (CWF introduced between 1963 and 1984, at an average level of 0.95 ppm or about 79% of the optimal level of 1.2 ppm for a location at that latitude)	0.95	To determine the prevalence of dental fluorosis, the sources of excess fluorides, and the degree of risk associated with each source.	No comparator	Dental fluorosis	633	Mean age not reported; children were aged 8, 9, and 10 years	55%

Country	Author*	Year	Study design	Study population	Details of exposure	CWF exposure (ppm)	Study objectives	Details of comparator	Outcome measure	Sample in analysis	Mean age/age range	Percentage female
Canada	**Clark *et al.*** [166]	**1994**	Cross-sectional survey	All children aged 6–14 years in selected schools were asked to participate and randomly selected, stratified by socioeconomic status.	Kelowna, British Columbia (mean CWF level of 1.11 ppm; between 1983 and 1990 fluoride levels ranged from 0.85 to 1.24 ppm (SD ±0.46 and ±0.11 ppm, respectively).	0.85–1.24	To assess the influence of exposure to various fluoride technologies and of infant feeding habits as variables related to the occurrence of dental fluorosis.	Vernon, British Columbia (<0.1 ppm)	Dental fluorosis	1,131	Mean age not reported/ age range: 6–14 years	Not reported, although it was collected
Canada	*Clark et al.* [112]	*1995*	Cross-sectional survey	Schoolchildren aged 6–14 years	Fluoridated city of Kelowna, British Columbia (1.2 ppm)	1.2	To assess the influence of exposure to various fluoride technologies and of other demographic characteristics on dental caries prevalence.	Fluoride-deficient city of Vernon, British Columbia (<0.1 ppm)	Dental caries	483	Mean age not reported/ age range: 6–14 years	Not reported, although it was collected

Country	Author*	Year	Study design	Study population	Details of exposure	CWF exposure (ppm)	Study objectives	Details of comparator	Outcome measure	Sample in analysis	Mean age/age range	Percentage female
Canada	Clark *et al.* [172]	2006	Cross-sectional survey	Schoolchildren in grades 2 and 3 in 1993–94, 1996–97, and 2002–03 who were permanent residents of their respective communities.	Comox/Courtenay, British Columbia (0.92 ppm (±0.21 ppm)) and Campbell River, British Columbia (0.88 ppm (±0.28 ppm)) in 1993–94 and 1996–97. CWF ceased in 1992 in both areas. All children in the 1993–94 data collection had lifetime exposure. Children aged under 9 years in the 1996–97 data collection had mixed exposure.	0.88 (±0.28) to 0.92 (±0.21	To determine changes in the prevalence of dental fluorosis, and perceptions of aesthetic concerns due to dental fluorosis after cessation of CWF.	At the 2002–03 data collection, none of the children had exposure to CWF (0.0 ppm).	Dental fluorosis	1,137	Mean age: 8.2 years (SD: ±0.45)/age range: 6.2–9.0 years	Not reported
Canada	McLaren *et al.* [94]	2021	Cross-sectional survey	Grade 2 schoolchildren (aged approximately 7 years) enrolled in public or separate school systems in the cities of Calgary and Edmonton, Alberta.	Edmonton (CWF at 0.5–0.7 ppm in 2011–2019), Calgary (CWF 1967, 0.59–0.89 ppm 1991–2011), and from May 2011–2019 0.1-0.3 ppm	0.5–0.7	To examine the longer-term effect of fluoridation cessation on dental caries experience.	Calgary (CWF 1967, 0.59–0.89 ppm 1991–2011), and from May 2011–2019 0.1-0.3 ppm	Dental caries and dental fluorosis	Exposure: 2,600, of whom 799 were permanent residents Comparator: 2,649, of whom 918 were permanent residents	Mean age not reported; children were aged approximately 7 years	Not reported

Country	Author*	Year	Study design	Study population	Details of exposure	CWF exposure (ppm)	Study objectives	Details of comparator	Outcome measure	Sample in analysis	Mean age/age range	Percentage female
England, UK	Rock and Sabieha [185]	1997	Cross-sectional survey	Schoolchildren aged 8–9 years	Five primary schools in the city of Birmingham (CWF at 1.0 ppm)	1.0	To examine the relationship between reported toothbrushing habits in infancy and dental fluorosis.	No comparator	Dental caries and dental fluorosis	325	Mean age not reported/ age range: 8–9 years	44%
England, UK	Tabari *et al.* [171]	2000	Cross-sectional survey	8–9-year-old schoolchildren who were lifetime residents in their respective areas.	Newcastle upon Tyne (CWF at 1.0 ppm)	1.0	To determine the prevalence and severity of dental fluorosis in a fluoridated and a fluoride-deficient community and to establish what relationship, if any, there was between the occurrence of dental fluorosis and the reported use of fluoride toothpaste in childhood.	South Northumberland (<0.1 ppm)	Dental fluorosis	Total: 867 had clinical examination and 812 had photographs taken Exposure: 439 had clinical examination and 409 had photographs taken Comparator: 428 had clinical examination and 403 had photographs taken	Mean age: 9.3 years	Exposure: 55% Comparator: 51%

Country	Author*	Year	Study design	Study population	Details of exposure	CWF exposure (ppm)	Study objectives	Details of comparator	Outcome measure	Sample in analysis	Mean age/age range	Percentage female
Ireland	James *et al.* [52]	2021	Cross-sectional survey	Random sample of 5-year-old schoolchildren in counties Dublin, Cork, and Kerry in 2014; follow-up at age 8 years in 2017.	Counties Dublin, Cork, and Kerry in 2002: CWF at 0.8–1.0 ppm	0.8–1.0, then 0.6–0.8	To evaluate the impact of downward adjustment of water fluoride concentration and introduction of toothbrushing guidance on dental caries and dental fluorosis.	Fluoride-deficient areas in counties Cork and Kerry (≤0.3 ppm)	Dental caries and dental fluorosis	Exposure: Dublin: 679 (2002), 707 (2017); counties Cork and Kerry: 332 (2002), 376 (2017) Comparator: 233 (2002); 772 (2017)	Exposure: Dublin: 8.3 years (2002), 8.2 years (2017); counties Cork and Kerry: 8.4 years (2002), 8.3 years (2017) Comparator: 8.5 years (2002), 8.4 years (2017)	Exposure: Dublin: 47% (2002), 54% (2017); counties Cork and Kerry: 55% (2002), 53% (2017) Comparator: 56% (2002), 51% (2017)
Malaysia	Mohd Nor *et al.* [174]	2021	Cross-sectional survey	Schoolchildren aged 9 years (born in 2006) and 12 years (born in 2003), who were lifelong residents were included	Negeri Sembilan had CWF since 1972 at 0.7 ppm; this was reduced to 0.5 ppm in December 2005.	0.7 from 1972, reduced to 0.5 in 2005	To determine the factors associated with dental fluorosis occurrence in two cohorts exposed to different fluoride concentrations.	Kelantan (described and confirmed as fluoride deficient (0 ppm))	Dental fluorosis	1,143	Mean age not reported; children were aged 7 and 12 years	56.5%

Country	Author*	Year	Study design	Study population	Details of exposure	CWF exposure (ppm)	Study objectives	Details of comparator	Outcome measure	Sample in analysis	Mean age/age range	Percentage female
USA	Williams and Zwemer [186]	1990	Cross-sectional survey	12–14-year-old schoolchildren	Residents of the city of Augusta, Georgia with lifelong exposure to CWF (at 0.9–1.2 ppm)	0.9–1.2	To determine dental fluorosis levels by residence, and to assess the association with sex, race, preschool dietary patterns, and dentifrice ingestion.	Residents of Richmond County, Georgia, where lifelong exposure to CWF fluctuated between 0.2 and 0.9 ppm	Dental fluorosis	374 (157 in Augusta and 217 in Richmond County)	Mean age not reported/ age range: 12–14 years	57% (61% in Augusta and 54% in Richmond County)

Country	Author*	Year	Study design	Study population	Details of exposure	CWF exposure (ppm)	Study objectives	Details of comparator	Outcome measure	Sample in analysis	Mean age/age range	Percentage female
USA	Kumar and Swango [187]	1999	Cross-sectional survey	Schoolchildren aged 7–10 years and 11–14-years with lifelong residency	The city of Newburgh, New York (CWF since 1945 at 1.0 ppm (±0.2 ppm), except for a 3-year period from 1978 to 1981) and the town of Newburgh, New York (CWF commenced in 1984).	1.0 (±0.2)	To determine the effect of water fluoridation and other known sources of fluoride on dental fluorosis and whether the risk imposed by fluoride exposure has changed over time.	New Windsor, Kingston, and the town of Ulster, New York (all fluoride deficient)	Dental caries and dental fluorosis	3,500	Mean age not reported/ age range: 7–14 years	Exposure: city of Newburgh: 52.1% and 51.0% in 1986 and 1995, respectively; town of Newburgh: 41.2% and 50.9% in 1986 and 1995, respectively Comparators: New Windsor: 47.8% and 58.2% in 1986 and 1995, respectively; Kingston: 49.7% and 49.2%; Ulster: 50.0% in 1986 and 1995, respectively

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

The study designs were cross-sectional surveys in 17 of the papers [52,91,94,98,112,157,166,171,172,174,178–181,183,185,186] and were case-control studies in 2 of the papers [182,184]. Both cross-sectional survey and case-control study designs are susceptible to recall bias because participants are required to recall their history of exposures.

Ten of the 17 papers describing cross-sectional surveys provide verifiable data that there was lifetime exposure to CWF in the intervention group [52,98,171,174,178,179,181,185–187], 3 papers controlled for lifetime exposure [66,112,165] , and another 3 papers measured the time children were exposed to CWF over their life course [172,180,183]. The remaining cross-sectional survey implied lifetime exposure [157]. The fluoride dose in the CWF areas examined in the 19 papers was between 0.5 and 1.2 ppm (Table 45). Ten papers reported a CWF level greater than 0.8 ppm [52,112,166,171,172,180,184–187], 8 papers reported a level of between 0.6 and 0.8 ppm [94,157,174,178,179,181–183], and 1 paper reported a level of 0.5–0.6 ppm [98].

There were nine papers with a naturally fluoride-deficient comparator [94,98,112,166,171,172,179,183,187] and two papers with a comparator that had a different level of CWF than the intervention [157,186]. Two papers had both naturally fluoride-deficient and CWF comparators [52,174]. There was no separate comparator group for six papers [178,180–182,184,185].

All of the studies investigated fluoride toothpaste use and various questions on its methods of use (Table 45). In nine of the papers on cross-sectional surveys, the participants were compared with children who used fluoride toothpaste when they were aged under 6 years and who lived in communities with fluoride-deficient water [94,98,112,166,171,172,179,183,187] and two studies with a comparison that had a different level of CWF [157,186]. Two studies examined fluoridated toothpaste use in both naturally fluoride-deficient and CWF comparators where CWF levels were reduced [52,174]. One cross-sectional survey compared participants who received an intensive prevention approach and lived in an area with CWF with those who did not attend the intensive intervention but who also lived in an area with CWF [181].

The studies were completed in Australia (three papers/studies) [178–180], Brazil (five papers/studies) [98,157,181–183], Canada (five papers/four studies) [94,112,166,172,184], England (two papers/studies) [171,185], Ireland (one paper/study) [52], Malaysia (one paper/study) [174], and the USA (two papers/studies) [186,187], and were published between 1988 and 2021 (Table 45).

Sixteen papers included children aged 5–14 years [52,98,112,166,171,172,174,178–182,184–187]. One study included young children aged 8–36 months [157] and one study included adolescents aged 17–20 years [183]. The exact age of the children was not reported in one study [94].

Thirteen studies (reported in 14 papers) were completed in schools [52,94,112,166,171,172,174,180,182–187], 1 study was conducted in daycare facilities [157], 1 study was completed in a combination of daycare centres and schools [98], and 3 studies were completed through dental treatment centres [178,179,181].

The proportion of female participants (where reported) varied from 41.2% to 61.0% across the studies as well as between the intervention and comparator groups within the same study [52,98,171,174,178,179,181–187] .

Two main outcomes were measured and reported: dental caries (11 papers/studies) [52,94,98,112,157,178,179,182,183,185,187] and dental fluorosis (17 papers/studies) [52,94,98,166,171,172,174,178–187]. Both exposure (CWF status and fluoride toothpaste status) and outcome (dental caries and/or dental fluorosis) data were collected at the same time in all papers/studies, so recall bias is an issue [52,94,98,112,157,166,171,172,174,178–187].

The indices employed to classify dental caries following clinical examination were: the World Health Organization's (WHO's) *Oral Health Surveys: Basic Methods, 5th Edition*, 2013 index (five papers) [52,157,178,179,183], the National Dental Epidemiology Project (one paper) [112], the National Institute of Dental Research, USA (one paper) [187], and the UK classification (one paper) [185]. Two of the papers that used the WHO index also used the American Dental Association (ADA) Caries Classification System (CCS) index [157,182], and one paper did not report the specific index used [98]. The main dental disease outcomes reported for each study were: decayed, missing, or filled permanent teeth (DMFT) (six papers/studies) [94,98,178,182,183,185], decayed, missing, or filled permanent tooth surfaces including level of cavitation to enamel ($D_{1–2}$MFS) (one paper/study) [112], $D_{1–6}$MFT decayed, missing, or filled permanent teeth (one paper/study) [174], decayed, missing, or filled permanent surfaces (DMFS) (two papers/studies) [94,187], decayed, missing, or filled primary teeth (dmft) (two papers/studies) [98,157], decayed, missing, or filled primary surfaces (dmfs) (one paper/study) [94], decayed, extracted/missing, or filled primary surfaces (defs) (one paper/study) [94], and percentage of teeth with or without cavitated dental caries (% with/without CDC) (three papers/studies) [52,98,179].

The indices employed to measure and classify the severity of dental fluorosis were: the Thylstrup and Fejerskov Index (10 papers/studies) [52,98,171,172,178,179,181,183–185], Dean's Index of Fluorosis (4 papers/studies) [174,180,182,187], and the Tooth Surface Index of Fluorosis (TSIF) (3 papers/studies) [94,166,186]. Thirteen of those 17 papers examined permanent teeth [52,94,171,172,174,178,179,181,183–187], one paper examined both primary and permanent teeth [98], and three papers did not report the type of dentition examined, but the data on age and/or dental caries indicate that the dentition type examined was permanent [166,180,182]. The type of permanent teeth examined differed across the studies: two studies examined all permanent teeth [52,172]; seven studies examined the incisors only [94,171,174,178,179,181,185]; one study examined the incisors and canines [166]; two studies examined the upper and lower incisors, canines, and first permanent molars [186,187]; and four studies examined the maxillary incisors, maxillary canines, and maxillary premolars [98,180,183,184]. The remaining study did not report the type of permanent teeth examined [182]. The study assessing primary teeth examined the maxillary incisors and maxillary canines [98].

3.2.3 Study quality

The quality assessment of the 17 papers reporting on cross-sectional surveys indicated that 9 were low quality with regard to design and implementation [112,166,178–181,185–187], 3 were moderate quality [157,171,174], and 5 were high quality [52,94,98,172,183] (Table 46 and Appendix H of Section 7, Table 34). The quality assessment of the two case-control studies indicated that one study was high quality with regard to design and implementation [184], while the other was low quality [182] (Table 47 and Appendix H of Section 7, Table 35). For high and moderate quality observational studies, the main weaknesses in quality assessment were an inability to complete a follow-up due to study design and an incomplete control for the five groups of confounding factors. The low quality studies had significant weaknesses in most areas including eligible population, participation rate, and/or inclusion criteria.

Table 46 Summary of quality assessment for cross-sectional surveys examining the additive effects of CWF and fluoride toothpaste

Country	Author*	Year	Study design	Q3: Eligible population and participation rate	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total	Quality rating
Australia	Riordan [178]	1993	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	2.5	Low
Australia	Riordan [179]	2002	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	2.5	Low
Australia	Bal *et al.* [180]	2015	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	2.0	Low
Brazil	Tiano *et al.* [157]	2009a	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Extensive	1.0	3.0	Moderate
Brazil	de Moura *et al.* [181]	2013	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	1.5	Low
Brazil	Marques *et al.* [183]	2021	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Partial	0.5	3.5	High
Brazil	Silva *et al.* [98]	2021	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Extensive	1.0	4.0	High
Canada	**Clark *et al.* [166]**	**1994**	Cross-sectional survey	No	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	1.5	Low
Canada	*Clark et al. [112]*	*1995*	Cross-sectional survey	Cannot determine	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	1.5	Low
Canada	Clark *et al.* [172]	2006	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable (census data)	1.0	Not applicable	0.0	Extensive	0.0	3.0	Moderate
Canada	McLaren *et al.* [94]	2021	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Extensive	1.0	4.0	High
England, UK	Rock and Sabieha [185]	1997	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	2.0	Low
England, UK	Tabari *et al.* [171]	2000	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	3.0	Moderate
Ireland	James *et al.* [52]	2021	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Yes	1.0	Partial	0.5	4.5	High
Malaysia	Mohd Nor *et al.* [174]	2021	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Some	0.0	3.0	Moderate
USA	Williams and Zwemer [186]	1990	Cross-sectional survey	No	0.0	Yes	1.0	Not applicable (census data)	1.0	Not applicable	0.0	Partial	0.5	2.5	Low
USA	Kumar and Swango [187]	1999	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	2.5	Low

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

Table 47 Summary of quality assessment for case-control studies examining the additive effects of CWF and fluoride toothpaste

Country	Author	Year	Study design	Q3: Representation	Q3 score	Q4: Sample size	Q4 score	Q6: Inclusion and exclusion	Q6 score	Q12: Blinding	Q12 score	Q13: Adjusted for confounding	Q13 score	Total	Quality classification
Brazil	Celeste and Luz [182]	2016	Matched case-control study	Yes	1.0	No	0.0	Yes	1.0	No	0.0	Some	0.0	2.0	Low
Canada	Osujp *et al.* [184]	1988	Case-control study	Yes	1.0	Yes	1.0	Yes	1.0	Yes	1.0	Partial	0.5	4.5	High

3.2.4 Study findings

3.2.4.1 Dental caries

3.2.4.1.1 Paper/study summaries

Eleven papers/studies presented data on dental caries and fluoride toothpaste in CWF areas [52,94,98,112,157,178,179,182,183,185,187]. We present a summary of each paper that measured dental caries in Table 48, followed by a narrative summary of the papers measuring dental caries in CWF areas by toothpaste use and toothbrushing practices. Only five papers/studies examined the actual relationship between dental caries and the use of CWF in addition to fluoridated toothpaste [52,94,98,112,157].

Table 48 Papers/studies presented data on dental caries and fluoride toothpaste in CWF areas

Author, date, country	Objective and characteristics	Findings: dental caries in CWF areas by toothpaste use and toothbrushing practices
Riordan 1993 [178] Australia	Riordan (1993) estimated the prevalence and severity of dental caries (DMFT, using the WHO index, no radiographs) among 350 schoolchildren aged 7 years (born in 1983) in the Perth metropolitan region (CWF at 0.8 ppm) and analysed the findings, taking account of exposure to CWF in number of months, reported use of fluoridated toothpaste and/or fluoride supplements, and the age of weaning. Fluoride exposure data from birth to the age of 4 years were documented [178]. Most children (89%) had lived at least 2.5 years in a fluoridated area. Fluoride supplement use was minimal and unrelated to dental caries. The mean age of weaning of those who had been breastfed was 7.7 months; by 9.0 months, 74% of the children had been weaned. Eighty-five percent liked toothpaste, 60.7% had swallowed it, and the mean age of starting to use it was 1.5 years (SD: ±0.96 years).	The prevalence of cavitated dental caries in the permanent dentition was 0.1 (10%), and the mean DMFT was 0.13 (SD: ±0.43). Of the 35 children who had cavitated dental caries, 25 children (71.4%) had a DMFT score of 1, 9 children (25.7%) had a DMFT score of 2, and 1 child (2.8%) had a DMFT score of 3. No teeth were recorded as missing due to dental caries. There was no statistically significant relationship between the presence of dental caries and residence in a CWF area. Although data on fluoride toothpaste use were collected, the relationship between the presence of dental caries and use of fluoride toothpaste was not reported. The mean age of those who had dental caries experience was about 1 month older than those who had no dental caries experience (p=0.043). The 16 participants who had used fluoride supplements all had a DMFT score of 0, but this finding was not statistically significant (p=0.17). Dental caries prevalence among girls was 0.15 (15%), and among boys it was 0.05 (5%) (p=0.002) [178].
Riordan 2002 [179] Australia	In 1990, the mean DMFT score for 12-year-olds was 0.84. The School Dental Service in Perth, Western Australia took steps to discourage the consumption of fluoride supplements and fluoride toothpaste ingestion, and to promote the use of low-fluoride toothpaste for children aged under 6 years [179]. Ten years later, 582 10-year-olds were examined for dental fluorosis (using the Thylstrup and Fejerskov Index) and dental caries (using DMFT) in school dental clinics between May and July 2000 using a cross-sectional survey design and a risk factor questionnaire in order to evaluate the effect of the School Dental Service's campaign regarding dental fluorosis and dental caries.	The overall prevalence of cavitated dental caries in permanent teeth was 17.5%. Mean cavitated dental caries experience was 0.3 (range: 0.0–4.0). Mean DMFT values in Perth and Bunbury were not statistically significantly different, at 0.3 and 0.3 (p=0.04) [179].
Clark *et al.* 1995 [112] Canada	This cross-sectional survey was completed by Clark *et al.* (1995) in order to determine the prevalence of both non-cavitated and cavitated dental caries in children aged 6–14 years who	The 110 children with lifelong exposure to only fluoridated water had 35%, or 0.88 (SD: ±2.91), fewer decayed or filled tooth surfaces per child (p<0.07) than children with no reported exposure to

Author, date, country	Objective and characteristics	Findings: dental caries in CWF areas by toothpaste use and toothbrushing practices
	were living in either fluoridated (1.2 ppm) or fluoride-deficient (<0.1 ppm) areas in British Columbia, Canada, and the effects of engaging in certain caries-preventive practices during childhood. Children from two communities were surveyed using a modified DMFS index ($D_{1–2}$MFS) [112]. Completed questionnaires were returned and dental examinations were performed on 1,131 children. Crude dental caries prevalence scores for the different fluoride exposure groups were tested for differences in dental age and the level of educational attainment of parents and/or guardians. No significant group differences were found. Ninety-three percent of all children reported using a fluoride dentifrice by the age of 2 years. Within subgroups, there were no statistically significant differences among the exposure groups relative to the dental age of the children and use of fluoride dentifrices.	systemic fluorides. For the 122 children who had taken fluoride supplements for 4 years or more, 0.67 fewer decayed and filled tooth surfaces (or a 26% reduction) were observed per child when compared with children with no exposure to fluoridated water or supplements. For children who used fluoride supplements for less than 4 years, no significant benefits were observed. Approximately 75% of the dental caries prevalence for the control and fluoride-exposed groups was on pit-and-fissure surfaces. Reductions in caries by surface type showed better outcomes for both smooth and pit-and-fissure surfaces [112].
Rock and Sabieha 1997 [185] UK	Rock and Sabieha (1997) examined the teeth of 325 children aged 8–9 years in a cross-sectional survey that took place in five primary schools in the city of Birmingham, where the water was fluoridated to a concentration of 1.0 ppm [185].	The average DMFT was 0.3 (range: 0.0–4.1) [185]. The mean DMFT for the dental fluorosis group was 0.2 (range: 0.0–3.0), while for the fluorosis-free group, it was 0.4 (range: 0.0–4.0) (p<0.01). The proportion of children without cavitated dental caries in the more socially affluent group was 81.8%, and in the more socially deprived group it was 81.4%. There was no separate comparator group [185]. Although data were collected, the relationship between fluoride toothpaste and dental caries was not reported.
Kumar and Swango 1999 [187] USA	Kumar and Swango (1999) described the relationship between dental caries (measured using the DMFS index) and dental fluorosis in children attending school in the Newburgh and Kingston school districts in New York State [187]. The authors analysed two cross-sectional surveys completed in the 1986 and 1995 school years and limited their analysis to 3,500 lifelong residents aged 7–14 years in the two communities, one fluoridated (CWF at 1.0 ppm (±0.2 ppm)) and one fluoride deficient (<0.1 ppm).	There was an inconsistent relationship between dental caries and dental fluorosis. The adjusted mean DMFS did not demonstrate a linear relationship between dental fluorosis and DMFS. For example, children without dental fluorosis had an adjusted DMFS of 1.06 (±0.08); for those with questionable dental fluorosis this was 0.65 (±0.15, p=0.001); for those with very mild dental fluorosis this was 1.39 (±0.17, not significant); and for those with mild to severe dental fluorosis this was 0.77 (±0.24, not significant) [187]. Although data were collected, the relationship between fluoride toothpaste use and dental caries was not reported.
Tiano *et al.* 2009a [157] Brazil	Tiano *et al.* (2009a) [157] determined the prevalence of cavitated caries with enamel involvement in primary teeth (d_2) and early childhood or non-cavitated caries in primary teeth (d_1) in a cross-sectional survey, and the contribution of independent variables in 68 children aged 36 months or under attending daycare centres in municipalities with different	The dmft Indices calculated for the adequate fluoride content and low fluoride content municipalities were 0.68 and 0.57, respectively. Out of all the children examined, 17.6% had cavitated dental caries lesions and 33.8% had early childhood or non-cavitated dental caries. The use of fluoridated toothpaste was not associated with

Author, date, country	Objective and characteristics	Findings: dental caries in CWF areas by toothpaste use and toothbrushing practices
	fluoride levels in the water supply: one was described as having adequate fluoride content (Gabriel Monteiro, São Paulo: 0.60–0.75 ppm; n=38), and the comparator was described as having low fluoride content (Clementina, São Paulo: 0.40 ppm; n=30) [157]. The parents were interviewed, and the children had a dental examination. The dental examinations employed codes and criteria established by the WHO and the ADA.	cavitated dental caries lesions or early childhood dental caries in bivariate analysis. The child's economic classification, mother's level of education, and duration of breastfeeding were considered statistically significant with regard to the prevalence of cavitated dental caries lesions. The age group, duration of the habit of drinking milk before bedtime, and the age at which oral hygiene started were considered statistically significant with regard to the prevalence of early childhood dental caries [157].
Celeste and Luz 2016 [182] Brazil	Celeste and Luz (2016) investigated the relationship between different sources of fluoride and dental caries in a community with water fluoridation (at 0.6–0.8 ppm) [182]. This population-based, matched case-control study used a representative sample of 271 schoolchildren in Brazil to identify 67 one-to-one pairs matched by sex and school grade level. Dental caries were measured using the DMFT index. Children's caregivers were interviewed about nine contributory factors.	Data were analysed using conditional logistic regression [182]. The dental caries findings were not presented in the paper despite being mentioned in the objective and methods.
Marques *et al.* 2021 [183] Brazil	Marques *et al.* (2021) evaluated the impact of water fluoridation (CWF at 0.6–0.8 ppm) on the prevalence and severity of dental caries in individuals aged 17–20 years who were also exposed to fluoride toothpaste in Teresina, Piauí, Brazil [183]. Students from both CWF and fluoride deficient groups had access to fluoride toothpaste throughout their life, and this study examined the additional effect of CWF. No results by toothpaste type were reported. The study population consisted of 660 students from public schools who were residents of areas supplied with fluoridated water (exposed group: CWF at 0.6–0.8 ppm) or fluoride-deficient areas (control group: fluoride content <0.05 ppm). A questionnaire about socioeconomic and demographic details, conditions related to access and exposure to CWF, and habits related to dental health was administered. Dental caries were measured using the DMFT index. In total, 660 of 738 selected students aged 17–20 years participated in the study, with a mean age of 17.8 years (±1.19 years).	Students who were not exposed to CWF had a higher experience of dental caries (p<0.001) and higher DMFT mean values, as well as more decayed and missing teeth (p<0.05). Dental caries experience was significantly higher in students from areas that did not have CWF, after adjusting for clinical conditions, demographic and socioeconomic profile, and hygiene habits. Students who were not exposed to CWF had higher odds (OR: 2.01; 95% CI: 1.35–2.99) of having tooth decay. Associations were observed between dental caries experience and female sex (OR: 1.55; 95% CI: 1.05–2.29), tooth/mouth discomfort (OR: 1.82; 95% CI: 1.22–2.70), having no toothaches in the last 6 months (OR: 0.47; 95% CI: 0.31–0.71), and not having visited a dentist (OR: 0.32; 95% CI: 0.17–0.58). The mean DMFT (±SD) was significantly higher in students from areas that did not have CWF than those from areas with CWF, at 3.83 (±3.28) compared with 2.48 (±2.71), respectively [183].
Silva *et al.* 2021 [98] Brazil	Silva *et al.* (2021) completed a cross-sectional survey in order to evaluate the prevalence and severity of dental caries and dental fluorosis in children and adolescents using fluoride toothpaste who were from areas with and without CWF (0.5–0.6 ppm compared with < 0.05 ppm, respectively) [98]. Of the 692	The mean dmft in the 5-year-olds from the exposed (CWF) and not exposed (non-fluoridated water) groups was 1.53 (±2.47) and 3.54 (±4.10), respectively. Children who did not consume fluoridated water had greater dental caries experience (OR: 2.86; 95% CI: 1.71–4.75). There were no significant differences between the CWF

Author, date, country	Objective and characteristics	Findings: dental caries in CWF areas by toothpaste use and toothbrushing practices
	participants, 330 (47.7%) were 5-year-olds and 362 (52.3%) were 12-year-olds. The data on 5-year-olds were suitable for use in this systematic review, as exposure to CWF occurred within the first 6 years of life.	and fluoride-deficient areas' groups with regard to dmft for the variables of toothbrushing frequency and type of toothpaste used in bivariate analysis, and therefore no adjusted ORs and associated 95% CIs were calculated for these covariates. Children who brushed their teeth on their own were marginally more likely to have dental caries in their primary teeth than children who had their teeth brushed by their parents (OR: 1.92; 95% CI: 1.00–3.70) [98].
McLaren *et al*. 2021 [94] Canada	McLaren *et al*. (2021) [94] examined the effect of CWF cessation on 'children's dental caries experience in the Canadian cities of Calgary, Alberta (which ceased CWF in 2011 and now has a water fluoride concentration of 0.1-0.3 ppm) and Edmonton, Alberta (which still had CWF at 0.5–0.7 ppm in 2011–2019) [94]. They used a before and after cross-sectional survey design with a comparison group. They studied grade 2 schoolchildren (aged approximately 7 years) 7–8 years after CWF cessation in Calgary, thus capturing children born after CWF ended in 2011. Data collection included a dental examination conducted in school by calibrated dental hygienists, a questionnaire completed by parents, and fingernail clippings for a small subsample. McLaren *et al*.'s (2021) overall analytic approach was twofold: the authors first examined differences in dental caries experience (decayed, extracted/missing, or filled primary teeth (deft) and DMFT, and smooth surface dental caries based on defs and DMFS) between Calgary and Edmonton and then over time (comparing 2018–19 data with 2013–14, 2009–10, and 2004–05 data); second, they evaluated whether the observed differences were likely to reflect CWF cessation in Calgary or other factors.	The prevalence of dental caries in the primary dentition was significantly higher ($p<0.05$) in Calgary (fluoridation-ended (FE)) than in Edmonton (still fluoridated). For example, adjusted deft prevalence in 2018–19 was 66.1% (95% CI: 63.6–68.6) in Calgary and 54.3% (95% CI: 51.4–57.2) in Edmonton. The adjusted prevalence of dental caries on smooth teeth surfaces was 61.5% (95% CI: 58.8–64.1) in Calgary and 49.9% (95% CI: 47.1–52.7) in Edmonton. For the permanent dentition, the mean DMFT and the prevalence of DMFT in 2018–19 were higher in Calgary (FE) than in Edmonton (still fluoridated) in the crude and adjusted analyses. For example, the covariate-adjusted prevalence of DMFT was 16.8% (95% CI: 14.5–19.1) in Calgary and 12.5% (95% CI: 10.4–14.6) in Edmonton. For smooth surface dental caries in the permanent dentition, there were no statistically significant differences between the Calgary (2.0%; 95% CI: 1.3–2.7) and Edmonton (2.3%; 95% CI: 1.5–3.0) samples. The observed differences were consistent and robust: the differences persisted with adjustment for potential confounders and in the subset of respondents who were lifelong residents and reported usually drinking tap water; the differences widened following CWF cessation in Calgary; and the differences were corroborated by assessments of dental fluorosis and estimates of total fluoride intake from fingernail clippings. The use of fluoride toothpaste – which was 81.8% (95% CI: 79.8–83.7) in Calgary (FE) and 80.3% (95% CI: 78.4–82.2) in Edmonton (still fluoridated) – was almost equal and did not influence the prevalence of dental caries. Findings for permanent teeth were less consistent, which likely reflects that 7-year-olds have not had the time to accumulate enough permanent dentition dental caries experience for differences to have become apparent [94].
James *et al.* 2021 [52] Ireland	Guidance intended to reduce fluoride toothpaste ingestion in early childhood was introduced in Ireland in 2002. In 2007, water fluoride concentration was reduced from 0.8–	In Dublin (full CWF), cavitated dental caries prevalence was 55% in 2017 compared with 54% in 2002. Among children with cavitated dental caries experience, mean $d_3$vcmft(cde) (±SD) was 3.4 (±2.3)

Author, date, country	Objective and characteristics	Findings: dental caries in CWF areas by toothpaste use and toothbrushing practices
	1.0 ppm to 0.6–0.8 ppm. James *et al.* (2021) measured the difference in dental caries levels following the introduction of these two policy measures [52]. A before-and-after study (comparing data from 2002 with data from 2017) with different participants compared the prevalence of dental caries in random samples of 8-year-olds in the counties of Dublin (n=707) and of Cork and Kerry (n=1,148) in 2017 with random samples of 8-year-olds in the counties of Dublin (n=679) and of Cork and Kerry (n=565) in 2002. Dentinal caries experience in primary teeth ($d_3$vcmft(cde)) [188] was clinically measured. Lifetime exposure to CWF was classified as 'full CWF' and compared with 'no CWF'. The effect of examination year on dental caries prevalence and severity was assessed using multivariate regression analysis adjusting for other explanatory variables. There was little change in the commencement of fluoride toothpaste use in children aged under 2 years following the introduction of toothbrushing guidance.	in 2017 compared with 3.3 (±2.1) in 2002. Multivariate regression analysis revealed no statistically significant difference in either the prevalence or severity of dental caries in children in Dublin (full CWF) in 2017 relative to 2002. Results were similar among children receiving full CWF in counties Cork and Kerry. Dental caries prevalence and mean $d_3$vcmft(cde) among children who received fluoride-free or fluoride-deficient water in counties Cork and Kerry were higher at both time points compared with their counterparts receiving full CWF. The difference in dental caries prevalence among children with fluoride-free or fluoride-deficient water in counties Cork and Kerry in 2017 (65%) relative to 2002 (73%) was not statistically significant. However, among children with dental caries, the reduction in mean $d_3$vcmft(cde) (±SD) from 4.9 (±2.6) in 2002 to 4.2 (±2.5) in 2017 was statistically significant (reduction in mean: 13%; 95% CI: 1–24). The difference in dental caries prevalence between children with full CWF and fluoride-free or fluoride-deficient water in counties Cork and Kerry was similar in 2002 and 2017 (interaction: *p*=0.098). However, among children with dental caries experience, the difference in dental caries severity between children with full CWF and fluoride-free or fluoride-deficient water was lower in 2017 than in 2002 (interaction: *p*=0.013). Other explanatory variables associated with increased prevalence and/or severity of dental caries in 2002 and 2017 were medical card ownership (as a proxy for deprivation), brushing with (fluoridated) toothpaste once per day or less (compared with twice per day or more), having sweet foods/drinks more than once per day between meals, and visiting the dentist at least once (compared with never). In Dublin (full CWF), first using toothpaste at the age of 2 years or under was associated with reduced prevalence of dental caries. [52].

3.2.4.1.2 Feasibility assessment results

We identified five papers/studies examining the relationship between fluoride toothpaste and dental caries [52,94,98,112,157]. Three of these papers/studies completed a regression analysis to identify the independent association between fluoride toothpaste and associated variables and the prevention of dental caries [52,98,157]; however, only one paper/study provided a numeric measure of the independent contribution of fluoride-toothpaste-related variables to dental caries [98]. Therefore, we could not complete a meta-analysis. See Appendix I of Section 7, Table 36, for our feasibility assessment of outcome data for meta-analysis.

3.2.4.1.3 Dental caries studies narrative synthesis

Eleven papers/studies reported data on dental caries, CWF, and fluoride toothpaste [52,94,98,112,157,178,179,182,183,185,187]. Although data were collected, the relationship between fluoride toothpaste use and dental caries was not reported for five of these papers/studies [178,179,182,185,187]. Five papers/studies examined the relationship between dental caries and CWF together with fluoride toothpaste use [52,94,98,112,157], and one of these studies reported that using fluoride toothpaste before the age of 24 months was associated with reduced prevalence of dental caries in Dublin, an area with CWF at a concentration of 0.6–0.8 ppm [52]. In addition, this paper/study reported that toothbrushing (with fluoride toothpaste) once per day or less (compared with twice per day or more) was associated with an increased prevalence of dental caries. Another of the five papers/studies reported that 5-year-old children who brushed their teeth on their own since eruption were marginally more likely to have dental caries in their primary teeth than 5-year-old children whose parents brushed their teeth for them [98]. The remaining three papers/studies found no relationship between the use of fluoride toothpaste together with CWF and dental caries [94,112,157]. The 11th paper/study examined the added effect of CWF (at a concentration of 0.6–0.8 ppm) in an area where there was universal use of fluoride toothpaste and reported a beneficial effect for the addition of CWF alongside fluoride toothpaste use on dental caries prevalence and severity [183]. For example, students who were not exposed to CWF had increased odds (OR: 2.01; 95% CI: 1.35–2.99) of having tooth decay. In addition, the mean DMFT (±SD) was significantly higher in students from areas that did not have CWF (3.83 (±3.28)) compared with those from areas that had CWF (2.48 (±2.71)) [183]. None of the papers/studies calculated the exact additive effect of fluoride toothpaste use toothpaste during the first 6 years of life in addition to CWF on dental caries. The results of the papers/studies indicate that the relationship between fluoride toothpaste use in a CWF area and dental caries is mixed, with two papers/studies reporting a protective effect [52,98] and three papers/studies reporting no relationship [94,112,157].

3.2.4.1.4 Certainty or level of evidence

The certainty of evidence for the outcome of dental caries following exposure to fluoride toothpaste use in a CWF area is very low due to the inclusion of observation study designs only, the likelihood of recall bias, the low quality of many of the primary studies with regard to design and conduct, the different measures (including proxy measures) used to assess exposure to fluoride toothpaste, and issues with controlling for confounding. In addition, none of the studies calculated the exact additive effect of fluoride toothpaste use in addition to CWF on dental caries, and only one study measured the independent association between fluoride toothpaste and dental caries in a CWF area.

3.2.4.2 Dental fluorosis

3.2.4.2.1 Paper/study summaries

Seventeen papers/studies measured the outcome of dental fluorosis [52,94,98,166,171,172,174,178–187]. Each of the 17 individual papers are summarised in Table 49, and these summaries are followed by a narrative synthesis.

Table 49 Papers/studies presented data on dental fluorosis and fluoride toothpaste in CWF areas

Author, date, country	Objective and characteristics	Findings: dental fluorosis in CWF areas by toothpaste use and toothbrushing practices
Williams and Zwemer 1990 [186] USA	Williams and Zwemer (1990) examined 374 selected children, aged 12–14 years, with lifelong exposure to community water supplies fluoridated at different levels in the two adjacent communities of the city of Augusta (CWF at 0.9–1.2 ppm) and Richmond County (CWF at 0.2–0.9 ppm), Georgia, in order to determine TSIF values by residence and to assess the association between the children's index values and their place of residence considering the covariates of sex, race, preschool dietary patterns, fluoride supplement use, and toothpaste ingestion [186]. The participants included boys and girls of both Black and White races who reported lifelong residence in either the city of Augusta or adjoining Richmond County. TSIF scores were recorded on each included tooth, and the highest tooth score was noted for each participant. The frequency of TSIF scores in all participants was analysed for dental arch symmetry and for association with city/county of residence.	The frequency of TSIF scores was then analysed separately for children living in the city of Augusta (80.9% had dental fluorosis) and children living in Richmond County (53.9% had dental fluorosis) in order to determine if there was an association with race, sex, preschool dietary habits, and toothpaste ingestion. Chi-square analysis revealed that higher TSIF scores were associated with children living in Augusta significantly more than with children living in Richmond County (*p*<0.0001). For example, the higher dental fluorosis scores (4–5) were observed in 14.1% of children living in Augusta, and in 1.4% of children living in Richmond County. None of the children in either area had dental fluorosis scores of 6 and 7. There was no association of TSIF scores in either the children living in Augusta or the children living in Richmond County with regard to sex, race, preschool dietary patterns, or toothpaste ingestion. CWF of 0.9–1.2 ppm was the main factor associated with dental fluorosis [186].
Riordan 1993 [178] Australia	Riordan (1993) estimated the prevalence and severity of dental fluorosis (using the Thylstrup– Fejerskov Index to examine dry permanent incisors) among 350 schoolchildren aged 7 years (born in 1983) and residing in the Perth metropolitan region (CWF at 0.8 ppm) and analysed the findings, taking account of exposure to CWF in number of months, reported use of fluoridated toothpaste and/or fluoride supplements, and the age of weaning [178]. Fluoride exposure data from birth to the age of 4 years were documented. Most children (89%) had lived at least 2.5 years in a fluoridated area. Fluoride supplement use was minimal and unrelated to dental fluorosis. The mean age of weaning of those who had been breastfed was 7.7 months; by 9.0 months, 74% of the children had been weaned. Eighty-five percent liked toothpaste, 60.7% had swallowed it, and the mean age of starting to use it was 1.5 years (SD: ±0.96 years).	The prevalence of dental fluorosis was 48.6%. Of the 169 children who had dental fluorosis, 108 (63.9%) were assessed as having a Thylstrup and Fejerskov Index score of 1, 44 (26.00%) were assessed as having a Thylstrup and Fejerskov Index score of 2, and 17 (10.1%) were assessed as having a Thylstrup and Fejerskov Index score of 3. The results of logistic regression analysis to identify factors associated with dental fluorosis indicated that residence in a CWF area for 2.5 years or more of the first 4 years of life had an OR of 4.88 (95% CI: 1.74–13.69) for dental fluorosis. Weaning (as a proxy for infant formula use) before the age of 9 months (OR: 1.81; 95% CI: 1.09–3.01), swallowing toothpaste (OR: 1.73; 95% CI: 1.10–2.72), and liking toothpaste (OR: 2.61; 95% CI: 1.36–5.01) were also statistically significant risk factors for the presence of dental fluorosis in the model. Risk factors for more severe dental fluorosis (indicated by a Thylstrup and Fejerskov Index score of 2 or higher) were early weaning (OR: 2.77; 95% CI:

Author, date, country	Objective and characteristics	Findings: dental fluorosis in CWF areas by toothpaste use and toothbrushing practices
		1.25–6.17) and swallowing toothpaste (OR: 2.64; 95% CI: 1.37–5.06) [178].
Riordan 2002 [179] Australia	In 1989–90, the prevalence of dental fluorosis in 659 12-year-old children in the Perth (CWF at 0.8 ppm) and Bunbury (fluoride deficient; approximately 0.25 ppm) regions of Western Australia were 40.2% and 33.0%, respectively [179]. Extended residence in a CWF area (OR: 4.06) and consuming fluoride supplements (OR: 4.63) were factors that were statistically significantly associated with dental fluorosis in 1990. Toothpaste ingestion variables were also statistically significantly associated with dental fluorosis. The School Dental Service in this part of Australia took steps to discourage the consumption of fluoride supplements and fluoride toothpaste ingestion, and to promote the use of low-fluoride toothpaste for children aged under 6 years. Ten years later, 582 10-year-olds were examined for dental fluorosis (using the Thylstrup and Fejerskov Index) and dental caries (using DMFT) in school dental clinics between May and July 2000 using a cross-sectional survey design and a risk factor questionnaire in order to evaluate the effect of the School Dental Service's campaign regarding dental fluorosis and dental caries.	The distribution of Thylstrup and Fejerskov Index scores for boys and girls was almost identical. Overall, 18.2% of participants had some degree of dental fluorosis; among these participants, 80.2% had a Thylstrup and Fejerskov Index score of 1, 17.9% had a score of 2, and just 1.9% had a score of 3. The prevalence of dental fluorosis among persons currently resident in the fluoridated area was 20.7% compared with 15.1% among those in fluoride-deficient areas (statistical difference not tested). People who were resident in the Perth region as children (from birth to the age of 4 years) were more likely to have some dental fluorosis than people who were resident in fluoride-deficient areas at the same age, and this difference was statistically significant (21.9% compared with 11.6%; $p<0.05$). In 1989–90, 79 participating children had used fluoride supplements before the age of 4 years, while in 2000, only 40 had done so ($p<0.001$). Almost all fluoride supplement users were residents of the fluoride-deficient areas. Low-fluoride toothpaste, unavailable in 1989–90, had been used by 24.5% of the 2002 survey participants. In a bivariate analysis, no relationships were found between the presence of dental fluorosis and the age of commencement of toothpaste use, reported swallowing of toothpaste, reported liking of toothpaste, the duration of breastfeeding, and the duration of formula use ($p>0.2$). Fluoride supplement use was not associated with the presence of dental fluorosis in a bivariate analysis ($p=0.7$), but residence in a fluoridated area from birth to the age of 4 years showed a strong bivariate association ($p=0.0025$). The only statistically significant risk factor identified using multiple logistic regression analysis was residence in a fluoridated area from birth to the age of 4 years (OR: 2.06; 95% CI: 1.21–3.50) [179].
Osujp *et al.* 1988 [184] Canada	Osujp *et al.* (1988) completed a case-control study in order to determine the sources of fluoride which are risk factors for dental fluorosis [184]. Cases of dental fluorosis (n=67) and controls (n=74) were identified by screening 633 out of the 1,380 eligible schoolchildren aged 8, 9, and 10 years in the CWF area of East York, Ontario. Parents were interviewed about 'their child's first 5 years of residence and about diet and dental caries preventive practices. The authors reported that the background characteristics of the parents of children in the dental fluorosis (known as cases) and control	The association between dental fluorosis and potential risk factors in the cases and control groups were assessed using Chi-square analysis and $p=0.05$ as the cut-off level of significance. Almost all children (99%) had been exposed to fluoride toothpastes. About one-half of the children started to brush their teeth with a fluoride toothpaste before they were aged 25 months. Children in the dental fluorosis group started to use the fluoride dentifrice when they were aged 22 months on average, compared with at the age of 36 months on average for children in the control group. Dental fluorosis was statistically significantly associated with brushing with a fluoride toothpaste before the age of 24 months as a single

Author, date, country	Objective and characteristics	Findings: dental fluorosis in CWF areas by toothpaste use and toothbrushing practices
	groups differed only in one aspect: 33 (51%) mothers of children in the dental fluorosis group had an education beyond high school, compared with 26 (33%) mothers of children in the control group (*p*=0.04). The authors found that nearly all children (96%) were born in an area with CWF, and that 88% had resided continuously in an area with CWF. Eighty percent of participants reported receiving professionally applied topical fluoride between one and four times per year.	factor (OR: 13.8; 95% CI: 5.12–37.38), use of infant feeding formula before the age of 12 months as a single factor (OR: 7.1; 95% CI: 1.14–44.45), and both factors combined with a much higher odds ratio (OR: 37.9; 95% CI: 10.60–134.52) [184].
Clark *et al.* 1994 [166] Canada	Clark *et al.* (1994) investigated fluoride exposure (via fluoride technologies including dentifrice and infant formula) and diagnosis with dental fluorosis among children living in one of two communities in British Columbia, Canada: fluoride-deficient Vernon (<0.1 ppm) and fluoridated Kelowna (CWF at 1.2 ppm) [166]. Parents or guardians completed a questionnaire which detailed exposure to different types of fluorides as well as infant feeding practices during the first 6 years of their child's life. Completed questionnaires were returned and dental examinations were performed on 1,131 children. The TSIF was used to diagnose and measure dental fluorosis.	The authors reported that 60% of all children had dental fluorosis; the proportion was 55% in fluoride-deficient Vernon and 65% in fluoridated Kelowna. Among those with dental fluorosis, 48% in Vernon and 55% in Kelowna had a TSIF score of 1, while 7% in Vernon and 10% in Kelowna had a TSIF score of 2 or higher. The authors reported that all of the children were exposed to fluoride toothpaste and stated that "the use of fluoride dentifrices did not increase the risk of dental fluorosis" [166] p463. Logistic regression analyses showed that the use of infant formula and parental educational attainment were significantly associated with the occurrence of dental fluorosis classified as having TSIF scores of 2–6. The authors reported that despite these statistically significant findings, these variables provided little additional predictive value beyond a chance occurrence in determining which children would have dental fluorosis [166].
Rock and Sabieha 1997 [185] UK	Rock and Sabieha (1997) examined the relationship between reported toothbrushing habits in infancy and dental fluorosis in the permanent maxillary incisors of 325 children aged 8–9 years in a cross-sectional survey that took place in five primary schools in the city of Birmingham, where the water was fluoridated to 1.0 ppm [185]. The sample comprised 56% boys and 44% girls. The children's maxillary central incisors were examined for dental fluorosis clinically and photographically employing a modified version of the Thylstrup and Fejerskov Index; the index modifications were not explained in the paper. Results of clinical dental examinations were linked with historical data collected via parental questionnaires and toothpaste weights to estimate the amount of fluoride that each child may have ingested from toothpaste each day. The weight of fluoride swallowed per day was calculated from the weight of toothpaste used, the reported daily frequency of toothbrushing, the age at which	Dental fluorosis was recorded on the maxillary central incisors of 34.5% of participants examined. There were 112 children in the dental fluorosis group and 213 in the dental-fluorosis-free group. Tooth cleaning was reported to have started for the dental fluorosis group at a mean age of 9.5 months, which was 7.0 months earlier than for the fluorosis-free group (for whom tooth cleaning was reported to have started at a mean age of 16.8 months), and was reportedly done twice per day by the fluorosis group as opposed to once per day by the fluorosis free group. The average weight of toothpaste used by the parents of children with dental fluorosis (0.7 grams (g); range: 0.1–2.7 g) was almost twice that of the fluorosis-free group (0.4 g; range: 0.1–1.7 g). In addition, a higher proportion of parents of children in the dental fluorosis group (38.0%) reported using high-fluoride toothpaste when compared with the fluorosis-free group (19.8%) (*p*<0.001). Due to the interaction of toothpaste weight and type and brushing frequency, the mean weight of toothpaste estimated to have been swallowed each day by the children with dental fluorosis was more than three

Author, date, country	Objective and characteristics	Findings: dental fluorosis in CWF areas by toothpaste use and toothbrushing practices
	toothbrushing began, and the brand of toothpaste used, with toothpaste being graded as low (500 ppm), medium (1000 ppm), and high (1500 ppm) fluoride. It was assumed that one-half of the toothpaste on the brush was swallowed by the included children, aged 8–9 years at the time of data collection.	times greater than for the children without fluorosis. According to the analysis of variance, the difference between the amount of fluoride calculated to have been swallowed by the two groups was highly significant (*p*<0.001). Almost one-third of the children with dental fluorosis (34/112) were less socioeconomically deprived, while only 15% (32/213) of the children in the unaffected group were less socioeconomically deprived (*p*<0.001) [185].
Kumar and Swango 1999 [187] USA	Kumar and Swango (1999) determined changes in the effect of exposure to CWF and other sources of fluoride on dental fluorosis in children attending school in the Newburgh and Kingston school districts in New York State [187]. The authors analysed two cross-sectional surveys completed in the 1986 and 1995 school years and limited their analysis to 3,500 lifelong residents aged 7–14 years in the two communities, one fluoridated (CWF at 1.0 ppm (±0.2 ppm)) and one fluoride deficient (<0.1 ppm). Dean's Index of Fluorosis were used. A questionnaire was used to collect fluoride exposure data. Regression analyses were used to estimate the individual effect of fluoridation, fluoride supplements, and toothbrushing before the age of 2 years on dental fluorosis. In both 1986 and 1995, there were proportionately more African-American children in the city of Newburgh compared with other areas. In the city of Newburgh (which was fluoridated), the percentage of children exposed to daily fluoride tablets, to early toothbrushing, or to a combination of both did not change between the two surveys (50.3% in 1986 compared with 49.2% in 1995). The daily use of fluoride tablets declined from 31.1% to 21.8% after the introduction of CWF in the town of Newburgh. In other areas, the reported use of fluoride tablets in the first 8 years of life varied from a low of 24.6% in New Windsor (non-fluoridated) in 1986 to a high of 32.9% in New Windsor in 1995. In 1995, more than one-half of the children reportedly started toothbrushing before the age of 2 years.	The highest prevalence of the very mild to severe categories of dental fluorosis (at 18.6%) was observed in the fluoridated city of Newburgh in 1995, which was an increase from 7.0% in 1986. Between-survey comparisons show that neither the prevalence nor the severity of dental fluorosis increased significantly after the town of Newburgh was fluoridated (in 1984); for example, the prevalence of the very mild to severe categories of dental fluorosis was 13.9% in 1986 and 14.8% in 1995. However, changes were evident in the fluoridated city of Newburgh, where analysis over time showed that the odds were 4:3 (calculated from 0.58/0.42) that a child examined in 1995 would have at least questionable dental fluorosis, compared with a similar child examined in 1986. Children who reported the combined use of fluoride tablets and early toothbrushing had the highest OR (5.0; 95% CI: 2.5–10.2) for very mild to severe dental fluorosis in both survey years. Elevated ORs for very mild to severe dental fluorosis were observed for most fluoride exposure variables in both years; however, exposure to CWF alone compared with exposure to CWF plus early toothbrushing or fluoride tablet use in 1986 was not statistically significant. African-American children studied in 1995 were at higher risk for dental fluorosis than children of other racial groups (OR: 1.6; 95% CI: 1.2–2.1). The results of the logistic regression procedures performed on the combined dataset show a different pattern of the effect of year on race among those who used fluoride from sources other than water. The computation of the difference in logit shows that among African-American children who received fluoride from sources other than water, the risk for very mild to severe dental fluorosis increased from a baseline OR of 1.0 in 1986 to 10.5 in 1995, whereas for children of other racial groups there was a suggestion of a slightly decreased risk (OR: 0.9). Among those living in CWF areas, the risk for very mild to severe dental fluorosis increased for of all races and was slightly higher for African-American

Author, date, country	Objective and characteristics	Findings: dental fluorosis in CWF areas by toothpaste use and toothbrushing practices
		children (OR: 3.9 for African-American children and 2.5 for children of other racial groups) [187].
Tabari *et al.* 2000 [171] UK	Tabari *et al.* (2000) estimated the prevalence and severity of dental fluorosis in the permanent incisor teeth of 867 schoolchildren aged 8–9 years in fluoridated Newcastle upon Tyne (CWF at 1 ppm) and fluoride-deficient South Northumberland (<0.1 ppm) in 1998 in order to establish what relationship, if any, there was between the occurrence of dental fluorosis and the reported use of fluoride toothpaste in childhood, (812 were clinically examined and had photographs taken while 55 had a clinical examination only) [171]. Dental fluorosis was assessed by clinical examination using the Thylstrup and Fejerskov Index. A closed-response questionnaire enquired into the children's early experiences of toothbrushing and use of fluoride toothpastes. Social deprivation was measured by the Jarman score. The proportion of eligible children (i.e. lifetime residents with complete data) was 409 (78%) of 524 in Newcastle upon Tyne (CWF) and 403 (79%) of 510 in South Northumberland (fluoride deficient). The mean age of the children was 9.3 years (±0.47 years) and was not different between the two areas. In Newcastle upon Tyne (CWF) and South Northumberland (fluoride deficient), 45% and 49% of the participants were male, respectively. The mean Jarman score was 16.3 (±19.1) for participants in Newcastle upon Tyne and 7.3 (±15.0) for South Northumberland. This difference was statistically significant (p<0.001) and suggested that the participants from Newcastle upon Tyne (CWF) tended to reside in more underprivileged areas than those in South Northumberland (fluoride deficient).	In Newcastle upon Tyne (CWF at 1 ppm), 222 children (50.6%) had Thylstrup and Fejerskov Index scores of 1 or 2, and 15 (3.4%) had a Thylstrup and Fejerskov Index score of 3 or higher. In South Northumberland (fluoride deficient), 96 children (22.4%) had a Thylstrup and Fejerskov Index score of 1 or 2, and 2 (0.5%) had a score of 3 or higher. The age at which toothbrushing started, toothbrushing frequency, the weight of toothpaste used, the type of toothpaste used, the area of residence, and the Jarman score were entered into a logistic regression model with the presence or absence of dental fluorosis (Thylstrup–Fejerskov Index score of ≥1 or 0, respectively) as the outcome measure. Three variables – the area of residence (p<0.001), the Jarman score (p=0.03), and the type of toothpaste used (p=0.02) – were statistically significant. There were no statistically significant two-way interactions (effect modification) between the independent variables included in the model. The OR of having dental fluorosis among participants from Newcastle upon Tyne (CWF) compared with those from South Northumberland (fluoride deficient) was 4.5 (95% CI: 3.3–6.1), and participants with lower Jarman scores (more affluent) were more likely to have dental fluorosis. The odds of a participant using an adult toothpaste having dental fluorosis compared with a participant using a children's toothpaste was 1.6 (95% CI: 1.06–2.27). When the presence or absence of dental fluorosis was defined at the threshold Thylstrup and Fejerskov Index score of >2, the only significant variable in the model was area of residence. The OR of a participant living in Newcastle upon Tyne (CWF at 1.0 ppm) having dental fluorosis compared with a participant living in South Northumberland (fluoride deficient: <0.1 ppm) was 7.1 (95% CI: 3.4–14.7) [171].
Clark *et al.* 2006 [172] Canada	Clark *et al.* (2006) determined changes in the prevalence of dental fluorosis after CWF in Comox/Courtenay, British Columbia ceased in 1992 among schoolchildren aged 6–9 years in 1993–94, 1996–97, and 2002–03 [172]. The Thylstrup and Fejerskov Index was used to quantify the severity of dental fluorosis. Residence and dental histories were documented for all children in order to determine the extent of exposure to all sources of fluoride (consumption of fluoridated water; use of fluoridated dentifrices, fluoride mouth rinses, and fluoride supplements; and infant feeding practices before the age of 6	When CWF ceased in 1992, the prevalence of dental fluorosis (measured using the Thylstrup and Fejerskov Index) decreased significantly between the 1993–94 and 1996–97 surveys (from 58% in 1993–94 to 23% in 1996–97) and remained stable between the 1996–97 and 2002–03 survey cycles (at 23% in 1996–97 and 24% in 2002–03). The severity of dental fluorosis, measured by the proportion of children with moderate or severe dental fluorosis, also decreased between the 1993–94 and 1996–97 surveys (from 9% in 1993–94 to 0% in both 1996–97 and 2002–03). The prevalence of dental fluorosis in 1993–94 was not significantly different for the CWF-only group (58%) and the group that was exposed to

Author, date, country	Objective and characteristics	Findings: dental fluorosis in CWF areas by toothpaste use and toothbrushing practices
	years). Comparisons between the three surveys were used in order to establish the influence of CWF and other fluoride sources on the occurrence and severity of dental fluorosis. The children participating in the 1993–94 survey had exposure to CWF for their first 6 years of life, while the children in the 1996–97 survey represent a partial exposure (3 years) to CWF during the development of their permanent teeth. The children in the 2002–03 survey had no exposure to CWF.	both CWF and fluoride supplements (57%) in the first 4 years of life. Results from regression analyses for each survey period failed to identify any statistically significant associations between dental fluorosis and bottled water consumption; fluoride mouth rinse frequency; breastfeeding; and the age at which solid food, cow's milk, and infant formula consumption began. Statistically significant associations were found for fluoride supplement use from birth to the age of 1 year in the 1996–97 survey (OR: 1.54; p=0.040) and for toothbrushing frequency three or more times per day (compared with once per day or less) in the 1996–97 (OR: 2.67; p=0.014) and 2002–03 (OR: 3.52; p=0.045) surveys [172]. Use of fluoride toothpaste was implied in the toothbrushing frequency variable.
de Moura *et al.* 2013 [181] Brazil	de Moura *et al.* (2013) assessed the prevalence of dental fluorosis in children whose parents had participated in an dental health programme when the children were aged 0–3 years and who resided in a city with CWF (Teresina, Piauí, Brazil: CWF at 0.6–0.8 ppm) [181]. Group 1 consisted of 128 children aged 8–12 years whose parents had visited the programme on at least five occasions and received education about toothbrushing and the proper use of fluoride toothpaste when the children were aged 0–3 years. The prevalence of dental fluorosis in the permanent maxillary incisors of the children in Group 1 (using the Thylstrup and Fejerskov Index) was compared with that of an age-matched group of children (n=128) whose parents had not participated in the programme (Group 2). The children examined in both groups had similar demographic characteristics. Group 1 mothers, however, reported higher education levels than Group 2 mothers (74% compared with 55%, $p<0.05$). Most of the study families received federal aid, which indicated a low socioeconomic status in the sample as a whole.	There was a significant difference in the prevalence of dental fluorosis between Groups 1 and 2; Group 1 children had a significantly lower prevalence of dental fluorosis (42%) than Group 2 children (61%). The OR values were adjusted for education and sex, as these were considered confounding factors for the study. Additionally, there was a significant difference between Groups 1 and 2 in terms of the severity of dental fluorosis, with Group 1 demonstrating less severe dental fluorosis ($p<0.05$). In Group 1 children, mostly milder degrees of dental fluorosis were observed. The higher degrees of severity, indicated by a Thylstrup and Fejerskov Index score of 3 or 4, were observed only in Group 2 children. Children whose parents participated in a dental health programme that included counselling on the proper amount of fluoride toothpaste to use when their children were aged 0–3 years presented with dental fluorosis less frequently (OR: 0.51; 95% CI: 0.31–0.86) than children in the control group when examined at the age of 8–12 years; these findings were adjusted for age and sex [181].
Bal *et al.* 2015 [180] Australia	Bal *et al.* (2015) determined whether the adjustment of the fluoride concentration to 1 ppm in the drinking water supplied to the City of Blue Mountains, New South Wales, Australia since 1992 was associated with dental fluorosis prevalence [180]. In 2003, children attending schools in the City of Blue Mountains and in a control region (Hawkesbury fluoridated at 1 ppm since 1967–1969), who had been randomly selected at baseline in 1992 and again in 2003, were examined for dental fluorosis (maxillary central incisors only) using	The prevalence of very mild to severe dental fluorosis was 39.2% in the City of Blue Mountains, 39.0% in Hawkesbury, and 39.0% in the two regions combined, which included 16 cases of moderate or severe dental fluorosis (1.4%). Community Index of Dental Fluorosis values were above the 0.6 level nominated by Dean as indicative of a public health concern. Sixty-four percent of participants had been exposed to CWF from birth. In addition, children were exposed to other sources of fluoride, including the use of fluoridated water for infant formula reconstitution, toothbrushing with fluoride

Author, date, country	Objective and characteristics	Findings: dental fluorosis in CWF areas by toothpaste use and toothbrushing practices
	Dean's Index of Fluorosis. A fluoride history for each child was obtained via a questionnaire. Associations between dental fluorosis and 58 potential explanatory variables were explored. A total of 1,138 children aged 7–11 years with erupted permanent central incisors were examined for dental fluorosis in 2003.	toothpaste before the age of 2 years, early use of fluoride rinses, and the use of fluoride supplements. Some of these factors, including related toothbrushing habits (rinsing practices and toothpaste swallowing), were associated with higher-than-expected proportions of very mild or more severe dental fluorosis. Of the 58 potential explanatory variables that Bal *et al.* assessed in bivariate associations with dental fluorosis, 5 were statistically significant. These included frequency of toothbrushing, rinsing habits after brushing, eating or licking toothpaste (these behaviours relate to when toothbrushing commenced as a habit), exposure to fluoridated water, and the type of water used for the reconstitution of infant formula. Exposure to fluoridated water and the type of water used to reconstitute infant formula were highly correlated variables, so each of these two variables was entered into separate logistic regression models with the three oral hygiene habit variables (frequency of toothbrushing when this habit first started, rinsing habits after toothbrushing, and licking or eating toothpaste). The four variables in each model were significant independent explanations of very mild or more severe dental fluorosis. Compared with reference groups in the first model, swallowing toothpaste with or without rinsing following brushing (OR: 2.30; 95% CI: 1.30–4.08) or licking or eating toothpaste often (OR: 1.81; 95% CI: 1.29–2.56) were associated with elevated odds of dental fluorosis. Compared with those who brushed daily with a fluoride toothpaste, those brushing less frequently (OR: 0.58; 95% CI: 0.36–0.94) had reduced odds of dental fluorosis. Compared with children who did not consume infant formula, those who had infant formula reconstituted with fluoridated water (OR: 1.69; 95% CI: 1.21–2.37) were more likely to develop very mild or more severe dental fluorosis. The second model revealed that children exposed to fluoridated mains supply water had elevated odds (OR: 1.55; 95% CI: 1.21–2.13) of very mild or more severe dental fluorosis compared with those whose drinking water was from spring or rainwater sources. The adjusted ORs that were associated with oral hygiene habits were almost identical in the second model. In a separate analysis, it was shown that exposure to an increasing number of risk factors significantly increased the risk of very mild or more severe dental fluorosis (OR: 1.33; 95% CI: 1.17–1.52) [180].
Celeste and Luz 2016 [182] Brazil	Celeste and Luz (2016) investigated the relationship between different sources of fluoride and dental fluorosis in a community	The prevalence of questionable cases of dental fluorosis was 18.8%, and the prevalence of very mild, mild, or moderate cases was 11.5%, with no severe

Author, date, country	Objective and characteristics	Findings: dental fluorosis in CWF areas by toothpaste use and toothbrushing practices
	with water fluoridation (at 0.6–0.8 ppm) [182]. This population-based, matched case-control study (67 one-to-one pairs matched by sex and school grade level) used a representative sample of 271 schoolchildren in Brazil. Dental fluorosis was measured using Dean's Index of Fluorosis. Children's caregivers were interviewed about nine risk factors. Data were analysed using conditional logistic regression.	cases. The age at which children commenced toothbrushing, whether or not children drank water from wells, the frequency of toothbrushing, the type of toothpaste used, children's mouth rinse usage, and the use of fluoride supplements were not significant contributing factors ($p>0.15$). Drinking water from wells and using fluoride supplements were underpowered (they applied to fewer than six children). Children who frequently ate toothpaste had five times greater odds (OR: 5.56; 95% CI: 1.75–17.73) of having dental fluorosis; those applying enough toothpaste to cover the bristles of their toothbrush had five times greater odds (OR: 5.55; 95% CI: 1.44–21.42) of having dental fluorosis; and those using an adult-sized toothbrush had three times greater odds (OR: 3.17; 95% CI: 1.15–8.71) of having dental fluorosis. There was a significant interaction between the toothpaste variables ($p<0.01$). In a community with water fluoridation (at 0.6–0.8 ppm), the factors most associated with dental fluorosis were toothpaste ingestion and toothpaste applied to the whole toothbrush [182].
Marques *et al.* 2021 [183] Brazil	Marques *et al.* (2021) evaluated the impact of water fluoridation (CWF at 0.6–0.8 ppm) on the prevalence and severity of dental fluorosis in individuals aged 17–20 years who were also exposed to fluoride toothpaste [183]. The study population consisted of 660 students from public schools who were residents of areas supplied with fluoridated water (exposed group: CWF at 0.6–0.8 ppm) or fluoride-deficient areas (control group: fluoride-free or fluoride-deficient water). Students from both groups had access to fluoride toothpaste throughout their lives. No results by toothpaste type were reported. A questionnaire was administered that asked participants about socioeconomic and demographic factors, conditions related to access and exposure to fluoridated water, and habits related to dental health. Dental fluorosis was measured using the Thylstrup and Fejerskov Index. The Chi-square test, *t*-test, and subsequent logistic regression were applied for data analysis. In total, 660 out of 738 selected students participated in the study; they were aged 17–20 years, with a mean age of 17.8 years (±1.19 years).	The prevalence of very mild/mild and moderate dental fluorosis was 41.1% and 21.0% for students who were exposed to fluoridated water and were not exposed to fluoridated water, respectively. The independent associations between dental fluorosis and exposure to fluoridated water, demographic profile, socioeconomic situation, clinical conditions, and oral hygiene habits were measured using logistic regression. There was a difference in the severity of dental fluorosis in relation to exposure to fluoridated water ($p<0.001$). In the exposed group, 29.0% of students had very mild/mild dental fluorosis, and 12.1% had moderate dental fluorosis. In the control group, 16.7% had very mild/mild dental fluorosis and 4.3% had moderate dental fluorosis. In the final multivariate model, students exposed to fluoridated water were more likely to have very mild/mild dental fluorosis (OR: 2.26; 95% CI: 1.54–3.32) and moderate dental fluorosis (OR: 3.66; 95% CI: 1.93–6.95) than those who were not exposed to fluoridated water. In addition, the odds of moderate dental fluorosis were 2.01 times higher in males than in females [183].
Silva *et al.* 2021 [98] Brazil	Silva *et al.* (2021) completed a cross-sectional survey in order to evaluate the prevalence and severity of dental fluorosis in children and adolescents using fluoride toothpaste who resided in areas with and without CWF (0.5–	No dental fluorosis was observed in the primary teeth of 5-year-old children in either area [98].

Author, date, country	Objective and characteristics	Findings: dental fluorosis in CWF areas by toothpaste use and toothbrushing practices
	0.6 ppm compared with < 0.05 ppm, respectively) [98]. Of the 692 participants, 330 (47.7%) were 5-year-olds and 362 (52.3%) were 12-year-olds. The data on 5-year-olds were suitable for use in this systematic review, as exposure to CWF occurred within the first 6 years of life.	
McLaren *et al.* 2021 [94] Canada	McLaren *et al.* (2021) examined the effect of CWF cessation on children's dental fluorosis experience in the Canadian cities of Calgary, Alberta (which ceased CWF in 2011 and now has a water fluoride concentration of 0.1–0.3 ppm) and Edmonton, Alberta (which still had CWF at 0.5–0.7 ppm in 2011–2019) [94]. They used a before and after cross-sectional survey design with a comparison group. They studied grade 2 schoolchildren (aged approximately 7 years) 7–8 years after CWF cessation in Calgary, thus capturing children born after CWF ended in 2011. Data collection included a dental fluorosis examination using the TSIF conducted in school by calibrated dental hygienists, a questionnaire completed by parents, and fingernail clippings for a small subsample. McLaren *et al.*'s (2021) overall analytic approach was twofold: the authors first examined differences in dental fluorosis experience between Calgary and Edmonton and then over time (comparing 2018–19 data with 2013–14, 2009–10, and 2004–05 data); second, they evaluated whether the observed differences were likely to reflect CWF cessation in Calgary or other factors.	The adjusted prevalence of dental fluorosis (>0) in Calgary (7.7%; 95% CI: 5.9–9.6; n=1,406) was significantly lower than in Edmonton (18.3%; 95% CI: 14.9–21.6; n=1,206). The use of fluoride toothpaste was almost equal in both areas, at 81.8% (95% CI: 79.8–83.7; n=2,575) in Calgary and 80.3% (95% CI: 78.4–82.2; n=2,507) in Edmonton. The association between the use of fluoride toothpaste together with CWF and dental fluorosis was not examined further in this paper [94].
James *et al.* 2021 [52] Ireland	Guidance intended to reduce fluoride toothpaste ingestion in early childhood was introduced in Ireland in 2002. In 2007, water fluoride concentration was reduced from 0.8–1.0 ppm to 0.6–0.8 ppm. James *et al.* (2021) determined the difference in dental fluorosis levels following the introduction of these two policy measures [52]. A before-and-after study (comparing data from 2002 with data from 2017) with different participants compared the prevalence of dental fluorosis in random samples of 8-year-olds in the counties of Dublin (n=707) and of Cork and Kerry (n=1,148) in 2017 with random samples of 8-year-olds in the counties of Dublin (n=679) and of Cork and Kerry (n=565) in 2002. Fluorosis prevalence in permanent teeth, using Dean's Index of Fluorosis, was measured using clinical examinations. Lifetime exposure to CWF was classified as 'full CWF' and compared with	Among children living in areas of Dublin with full CWF, dental fluorosis prevalence was 18% in 2017 and 15% in 2002, and among children living in areas of counties Cork and Kerry with full CWF, it was 12% in 2017 and 13% in 2002. Dental fluorosis prevalence among children living in areas of counties Cork and Kerry with fluoride-free or fluoride-deficient water was 5% in 2017 and 3% in 2002. The dental fluorosis prevalence estimates between the two time periods and by geographical area were not statistically significantly different. In Dublin (full CWF), being female (compared with being male) was associated with increased prevalence of dental fluorosis. Associations between the age at which children first used fluoride toothpaste and the amount of toothpaste used and dental fluorosis were not presented in the paper [52].

Author, date, country	Objective and characteristics	Findings: dental fluorosis in CWF areas by toothpaste use and toothbrushing practices
	'fluoride-free or fluoride-deficient water'. The effect of examination year on dental fluorosis prevalence was assessed using multivariate regression analysis adjusting for other explanatory variables. There was little change in the commencement of fluoride toothpaste use in children aged under 2 years following the introduction of toothbrushing guidance. Of 4,215 children invited to participate in phase 1 (2002) of the Fluoride and Caring for Children's Teeth (FACCT) project, 2,308 (55%) were examined for dental caries and 2,304 (55%) for dental fluorosis in phase 2 (2017). The characteristics of the children whose parents consented to participate in 2014 and of the children who were followed up and examined in 2017 were similar. Of the children examined in Dublin, 94% had full CWF in 2002 and 89% had full CWF in 2017. Of those examined in counties Cork and Kerry, 51% had full CWF in 2002 and 25% had full CWF in 2017, whereas 36% had fluoride-free or fluoride-deficient water in 2002 and 51% had fluoride-free or fluoride-deficient water in 2017. Approximately one-third of the study population was eligible for a medical card (Primary Care Reimbursement Service). The proportion of the samples in James *et al.*'s (2021) 2002 survey and the FACCT survey who were dependants of medical card holders was 21% and 26%, respectively. A higher proportion of children in the 2017 survey brushed at least twice per day and used a pea-sized amount of toothpaste or less compared with the children in the 2002 survey. However, despite advice to delay commencing fluoride toothpaste use until after the age of 24 months, 80% of parents in 2017 (both in areas with full CWF and with fluoride-free or fluoride-deficient water) indicated that they first used toothpaste with their child when their child was aged ≤24 months compared with 76–86% of parents in 2002.	
Mohd Nor *et al.* 2021 [174] Malaysia	Mohd Nor *et al.* (2021) estimated the prevalence of dental fluorosis and identified factors associated with its occurrence in two cohorts of children exposed to different fluoride concentrations in the Malaysian water supply [174]. The authors employed a cross-sectional survey which was conducted among lifelong residents (n=1,143 of 1,155) of fluoridated and fluoride-deficient areas who were aged 9 and 12 years. The Malaysian	Dental fluorosis prevalence was lower (31.9%) among the younger children born after the reduction of the fluoride concentration in the water, compared with a prevalence of 38.4% in the older cohort. The presence of CWF was the only statistically significant variable in the oral hygiene logistic regression model, and it was positively associated with the presence of dental fluorosis (0.5 ppm lifetime CWF: OR: 8.45 (95% CI: 5.45–13.10), *p*=0.001; 0.7 ppm followed by 0.5 ppm CWF: OR: 10.88 (95% CI: 7.03–

Author, date, country	Objective and characteristics	Findings: dental fluorosis in CWF areas by toothpaste use and toothbrushing practices
	children living in the fluoridated area who were aged 12 years were born when the level of fluoride in the public water supply was 0.7 ppm, while those aged 9 years were born after the level was reduced to 0.5 ppm. There was no fluoride in the water within the fluoride-deficient area (0 ppm). Dental fluorosis was blind scored using standardised photographs of maxillary central incisors using Dean's Index of Fluorosis. Fluoride exposure and other factors were assessed via a parental questionnaire. Data were analysed using descriptive statistics, Chi-square analyses, and logistic regression.	16.84), *p*=0.001). Simple logistic regression analysis of dental fluorosis with regard to oral hygiene habits when the children were aged under 6 years found that the use of fluoride toothpaste (OR: 1.09; 95% CI: 0.70–1.70; *p*=0.700); supervised toothbrushing (OR: 1.11; 95% CI: 0.37–3.36; *p*=0.849); frequency of toothbrushing (OR: 1.03; 95% CI: 0.77–1.37; *p*=0.861); the age at which children started toothbrushing (OR: 1.12; 95% CI: 0.83–1.51; *p*=0.460); the age at which children started toothbrushing with toothpaste (OR: 1.10; 95% CI: 0.80–1.51; *p*=0.572); swallowing toothpaste (OR: 0.87; 95% CI: 0.47–1.61; *p*=0.648); eating/licking toothpaste (OR: 0.85; 95% CI: 0.64–1.13; *p*=0.267); and the amount of toothpaste used (OR: 1.00; 95% CI: 0.75–1.33; *p*=0.988) were not statistically significant (i.e. all *p*-values were greater than 0.05 and all CI ranges included 1). The prevalence of dental fluorosis in the final overall model was significantly associated with parents' education level, parents' income, consumption of fluoridated water, type of infant feeding method, the age at which breastfeeding ceased, use of formula milk, duration of formula milk intake, and type of water used to reconstitute formula milk via simple logistic regression. Fluoridated water remained a significant risk factor for dental fluorosis in multiple logistic regression. Dental fluorosis was lower among children born after the adjustment of fluoride concentration in the water; however, fluoridated water remained a strong risk factor for dental fluorosis after the fluoride concentration was reduced [174].

3.2.4.2.2 Feasibility assessment results

We completed a feasibility assessment in order to determine whether we should complete a meta-analysis on the effect of exposure to CWF plus fluoride toothpaste or its proxies during the first 6 years of life on the prevalence of mild to severe dental fluorosis (Appendix I of Section 7, Table 36). Our parameters for the feasibility assessment were study design, population, concentration of fluoride in the fluoridated water supply, fluoride toothpaste use, toothbrushing practices, the use of and type of comparator dental fluorosis and its assessment measure, dentition type, statistical measure including variance, and adjustment for named confounders. The included study designs were 12 cross-sectional surveys and 2 case-control studies. Nine of the 14 studies identified oral hygiene practices related to the use of fluoride toothpaste and dental fluorosis, indicating that there may be a true relationship between exposure to fluoride toothpaste and how it is used and the outcome of dental fluorosis in permanent teeth. However, this relationship cannot be quantified accurately, as three of the four studies reporting no association did not report adequate numeric data to be included in the synthesised findings, and summarising positive findings only would introduce a bias.

3.2.4.2.3 Fluorosis studies narrative synthesis

The additive effect of using fluoride toothpaste in CWF areas on the prevalence of dental fluorosis was not studied in any of the papers identified; however, factors associated with dental fluorosis were studied. Seventeen of the studies measured dental fluorosis in the context of CWF (at concentrations of 0.5–1.2 ppm) and the use of fluoride toothpaste using observational study designs (cross-sectional surveys or case-control studies) [52,94,98,166,171,172,174,178–187]. The prevalence of mild to severe dental fluorosis in permanent teeth in areas with CWF varied across the 17 included studies, ranging from 11.5% to 80.9%. Eleven studies reported a lower prevalence of dental fluorosis in fluoride-deficient or fluoride-free areas, ranging from 3% to 55% [52,94,157,166,171,172,174,179,183,186,187]. One study reported no cases of dental fluorosis in primary teeth [98].

Eight studies reported an association between fluoride toothpaste use and oral hygiene practices during the first 6 years of life and any dental fluorosis in erupted permanent teeth [171,172,178,180,182,184,185,187]. Specifically, one study reported a statistically significant positive interaction between the use of fluoride toothpaste, the amount of toothpaste used, and toothbrushing frequency, and an increased likelihood of diagnosis with dental fluorosis [185]. Another study reported a significant interaction between the amount of toothpaste used, toothpaste ingestion, and use of an adult-sized toothbrush and an increased likelihood of diagnosis with dental fluorosis [182]. Five of the other six studies supported aspects of these findings; for example, early toothbrushing [184,187] and higher toothbrushing frequency [52,172,180] were also positively associated with a diagnosis of dental fluorosis. One study reported that young children's use of fluoride toothpaste intended for adults was positively associated with a diagnosis of dental fluorosis [171]. Two studies reported that licking, eating, and/or swallowing toothpaste was associated with a diagnosis of dental fluorosis [178,180]. On the other hand, four studies found no association between oral hygiene practices (including toothbrushing frequency and toothpaste ingestion) and the use of fluoride toothpaste and dental fluorosis [166,174,179,186]. However, three of those four studies did not report standardised numeric data, limiting the opportunity to complete a meta-analysis [166,174,186]. One study reported a protective effect of oral hygiene education on increasing the correct use of fluoride toothpaste and reducing the likelihood of a diagnosis of dental fluorosis [181].

In summary, 8 of the 17 studies identified a relationship between oral hygiene practices related to the use or misuse of fluoride toothpaste and dental fluorosis, indicating that there may be a true relationship between exposure to fluoride toothpaste and how it is used, and the outcome of dental fluorosis in permanent teeth. Two of the 17 studies reported incomplete or different types of analyses [94,183]. One study reported no cases of dental fluorosis in primary teeth [98].

3.2.4.2.4 Certainty or level of evidence

The certainty of evidence for the outcome of dental fluorosis associated with exposure to CWF plus fluoride toothpaste or its proxies during the first 6 years of life is very low due to the inclusion of observation study designs, the likelihood of recall bias, the low quality of many of the primary studies with regard to design and conduct, and the presence of clinical heterogeneity. The exact additive effect of fluoride toothpaste in addition to the effect of CWF on dental fluorosis cannot not be ascertained from the existing research.

3.3 Question 2B: What is the additive effect of topical fluoride therapies in areas with CWF (and with widespread use of fluoride toothpaste) on dental health in children who are aged under 6 years when they receive the intervention?

3.3.1 Search and screening results

The database search retrieved 2,564 records, which we exported to EndNote. There were 461 duplicate records removed in EndNote, leaving 2,103 records. These 2,103 records were imported into EPPI-Reviewer for dual screening on title and abstract by one of two sets of two reviewers (JL and SS, and OC and AF), and 1,910 were excluded, leaving 193 records. Those 193 papers were sought for full-text screening, and 180 were retrieved. The 180 retrieved papers were screened on full text, resulting in the inclusion of 4 full-text papers. Supplemental searching and reference and citation chasing identified an additional 333 records; of these, 59 were duplicates and were removed, leaving 274records. These 274 records were screened on title and abstract and 195 were excluded, leaving 79 records, of which the full text could not be obtained for 14 records. The remaining 65 full-text papers were retrieved and screened; 62 were excluded and 3 were included. In total, seven papers were included in order to answer Question 2B.

See Appendix F of Section 8 for the PRISMA flow diagram for Question 2B.

3.3.2 Study characteristics

The Health Research Board (HRB) identified seven studies that examined the effect of topical fluoride therapies in communities with CWF to some extent: one from Australia [180], three from Canada [94,163,172] two from Hong Kong [189,190], and one from the USA [99] (Table 50). The studies were published in 1988 [99], 2001 [163], 2006 [172], 2014 [189], 2015 [180], and 2021 [94,190]. The study designs comprised four cross-sectional surveys [94,99,172,180], one longitudinal prospective cohort study with a 3-year follow-up [163], and two randomised controlled trials [189,190]. One randomised controlled trial was a block randomised trial with a follow-up at 24 months [189], and the other was a parallel group trial with 6- and 12-month follow-ups [190]. Five studies included children aged between 6 and 12 years (and examined their primary and/or permanent teeth for dental caries and their permanent teeth for dental fluorosis) [94,99,163,172,180], and two studies included children aged under 5 years and investigated dental caries in their primary teeth [189,190]. The vast majority of children in the intervention groups had lifetime exposure to CWF, and so we included studies of children aged over 6 years who were exposed to fluoride interventions over their early life course and reported these. The fluoride level in the drinking water was approximately 1.0 ppm for three of the studies from North America [99,163,172] and for the one study from Australia [180], between 0.6 and 0.8 ppm for one study from North America [94], and 0.5 ppm for the two studies from Hong Kong [189,190]. The additional fluoride interventions also differed across the seven studies: two studies examined the effect of fluoride mouth rinses plus CWF [99,172], three examined the effect of exposure to diverse fluoride technologies (such as fluoride toothpaste, fluoride mouth rinses, and fluoride supplements) plus CWF [94,163,180], and two examined the effect of sodium fluoride varnish plus CWF [189,190]. The comparator for three of the five cross-sectional surveys was areas or years where CWF was discontinued [94,163,172], while for one study the comparator was a never-fluoridated area [99]. The comparator for the remaining cross-sectional survey was another area with CWF since 1967. The comparators for the two randomised controlled trials differed, with one comparing the intervention with a placebo and no intervention in a CWF area [189] and the other comparing the efficacy of the intervention with that of glass ionomer sealants in a CWF area [190]. Five studies measured dental caries [94,99,163,189,190]. However, different systems of measurement were used: one study used the National Institute of Dental Research dental caries classification system [99]; one used the Canadian Dental Association's (CDA's) classification system, which included a modified decayed, missing, or filled permanent teeth surfaces including level of cavitation to enamel (D_{1-2}MFS) index [163]; two studies used the WHO classification system [94,163]; and two studies used the International Caries Detection and Assessment System (ICDAS) to measure occlusal dental caries, specifically those assigned codes 4, 5, and 6 [189,190]. Four cross-sectional surveys measured dental fluorosis [94,99,172,180]. Two studies used the TSIF to diagnose dental fluorosis [94,99], one study used the Thylstrup and Fejerskov Index [172] and the remaining study used Dean's Index of Fluorosis [180]. Two studies used Russell's criteria to control for other dental enamel defects [99,180].

3.3.3 Study quality

The quality assessment of the five observational studies indicated that three were low quality [99,172,180] and two were high quality [94,163] with regard to design and implementation (Table 51; Appendix H of Section 8, Table 44). For high and moderate quality studies, the weaknesses in quality assessment were an inability to complete a follow-up due to study design and an incomplete control for the five groups of confounding factors. The low quality studies had significant weaknesses in most areas including eligible population, participation rate, and/or inclusion criteria. The two randomised controlled trials included in this analysis were judged to have some concerns with regard to bias [189,190] (

Table 52; Appendix H of Section 8, Table 45).

Table 50 Summary of study characteristics for studies examining the additive effects of CWF and topical fluoride therapies

Country	Author	Year	Study design	Study population	Details of exposure	CWF exposure (ppm)	Study objectives	Details of comparator	Outcome measure	Sample in analysis	Mean age/age range	Percentage female
Australia	Bal *et al.* [180]	2015	Cross-sectional survey	Schoolchildren aged 7–11 years	City of Blue Mountains, New South Wales (CWF since 1992, at 1.0 ppm)	1.0	To evaluate the prevalence and risk of dental fluorosis from a range of fluoride sources (use of toothpastes, fluoride supplements, fluoride mouth rinses, and professionally applied fluoride gel)	No comparator with respect to fluoride therapies Comparator city of Hawkesbury with respect to CWF 1 ppm since either 1967 or 1969	Dental fluorosis	1,138	Mean age not reported/age range: 7–11 years	Not reported
Canada	Maupomé *et al.* [163]	2001	Prospective cohort study	Schoolchildren in grades 2, 3, 8, and 9 in 1993–94, and in grades 5, 6, 11, and 12 in 1996–97.	Still-fluoridated communities in British Columbia	1.2	To outline the prevalence of dental caries among participants living in fluoridated and fluoridation-ended areas after 3 years and to measure exposure to diverse fluoride technologies (e.g. fluoride supplements, mouth rinses, toothpaste), snacking, oral hygiene, and socioeconomic status.	Former CWF areas of British Columbia, which had ceased CWF 14 months prior to initiation of the baseline examinations.	Dental caries	5,927	Exposure: mean age of grade 2 and 3 children: 8.3 years; mean age of grade 8 and 9 children: 14.3 years Comparator: mean age of grade 2 and 3 children: 8.3 years; mean age of grade 8 and 9 children: 14.4 years	51%

Country	Author	Year	Study design	Study population	Details of exposure	CWF exposure (ppm)	Study objectives	Details of comparator	Outcome measure	Sample in analysis	Mean age/age range	Percentage female
Canada	Clark *et al.* [172]	2006	Cross-sectional survey	Schoolchildren in grades 2 and 3 in 1993–94, 1996–97, and 2002–03 who were permanent residents of their respective communities.	Comox/Courtenay, British Columbia (0.92 ppm (±0.21 ppm)) and Campbell River, British Columbia (0.88 ppm (±0.28 ppm)) in 1993–94 and 1996–97. CWF ceased in 1992 in both areas. All children in the 1993–94 data collection had lifetime exposure. Children aged under 9 years in the 1996–97 data collection had mixed exposure.	1.2	To determine changes in the prevalence of dental fluorosis, and perceptions of aesthetic concerns due to dental fluorosis after cessation of CWF by the age at which participants commenced toothpaste use and by survey year.	At the 2002–03 data collection, none of the children had exposure to CWF (0.0 ppm).	Dental fluorosis	1,137	Mean age: 8.2 years (SD: ±0.45)/age range: 6.2–9.0 years	0.88 (±0.28) to 0.92 (±0.21)
Canada	McLaren *et al.* [94]	2021	Cross-sectional survey	Grade 2 schoolchildren (aged approximately 7 years) enrolled in public or separate school systems in the cities of Calgary and Edmonton, Alberta.	Edmonton (CWF at 0.5–0.7 ppm in 2011–2019), Calgary (CWF 1967, 0.59–0.89 ppm 1991–2011), and from May 2011–2019 0.1-0.3 ppm	0.5–0.7	To examine the longer-term effect of fluoridation cessation on dental caries experience by brushing routine; by the use of fluoride supplements, fluoride toothpaste, fluoride mouth wash, and fluoride treatments at the dentist office or school; and by the presence of sealants.	Calgary (CWF 1967, 0.59–0.89 ppm 1991–2011), and from May 2011–2019 0.1-0.3 ppm	Dental caries and dental fluorosis	Exposure: 2,600, of whom 799 were permanent residents Comparator: 2,649, of whom 918 were permanent residents	Mean age not reported; children were aged approximately 7 years	Not reported

Country	Author	Year	Study design	Study population	Details of exposure	CWF exposure (ppm)	Study objectives	Details of comparator	Outcome measure	Sample in analysis	Mean age/age range	Percentage female
Hong Kong, China	Jiang *et al.* [189]	2014	Randomised controlled trial	Children (aged 8–23 months) and their parents who were attending either parenting education centres or child daycare centres.	Hong Kong (fluoridated at 0.5 ppm)	0.5	To investigate the effectiveness of hands-on training in parental toothbrushing, with or without semi-annual applications of 5% sodium fluoride varnish, in preventing dental caries.	A once-off dental health education talk to parents.	Dental caries	Total: 415 Exposure: Group 2 (oral hygiene education, training on brushing their child's teeth, and placebo varnish): 144; Group 3 (oral hygiene education, received training on brushing, and fluoride varnish): 137 Comparator: Group 1 (oral hygiene information and education only): 134	Exposure: Group 2 mean age: 15.6 months (±3.8 months); Group 3 mean age: 15.3 months (±3.8 months) Comparator: Group 1 mean age: 15.5 months (±3.9 months)	Total: 56% Exposure: Group 2: 57%; Group 3: 55% Comparator: Group 1: 57%
Hong Kong, China	Lam *et al.* [190]	2021	Parallel group randomised controlled trial	Children attending kindergarten and grade 1	Hong Kong (fluoridated at 0.5 ppm) and topical application of 5% sodium fluoride varnish	0.5	To compare the efficacy of glass ionomer sealants versus topical application of 5% sodium fluoride varnish in the prevention of occlusal dental caries in a community with CWF.	Hong Kong (fluoridated at 0.5 ppm) and use of glass ionomer sealants	Dental caries	Total: 280 Exposure: 154 Comparator: 169	Exposure: mean age: 46.5 months (±3.7 months) Comparator: mean age: 46.3 months (±3.7 months)	Exposure: 50.6% Comparator: 43.2%

Country	Author	Year	Study design	Study population	Details of exposure	CWF exposure (ppm)	Study objectives	Details of comparator	Outcome measure	Sample in analysis	Mean age/age range	Percentage female
USA	Szpunar and Burt [99]	1988	Cross-sectional survey	6–12-year-old schoolchildren	Redford, Michigan (CWF at 1.0 ppm)	1.0	To assess the prevalence of dental caries and dental fluorosis in areas with various concentrations of fluoride in the communities' water supplies, together with the use of fluoride mouth rinses, dental services, and infant nutrition.	Richmond (natural fluoride: 1.2 ppm), Cadillac (natural fluoride: 0.0 ppm), and Hudson (natural fluoride: 0.8 ppm), Michigan	Dental caries and dental fluorosis	Total: 380 Exposure: 249 Comparator: 131 (Cadillac only (0.0 ppm))	Mean age not reported/age range: 6–12 years	Exposure: 49% Comparator: 57%

*Authors of linked papers are presented in **bold** for the earliest paper and in *italics* for subsequent papers. Authors of unique papers are presented in normal font.

Table 51 Summary of quality assessment for observational studies examining the additive effects of CWF and topical fluoride therapy

Country	Author	Year	Study design	Q3: Eligible population and participation rate	Q3 score	Q4: Inclusion and exclusion	Q4 score	Q5: Sample size and variance	Q5 score	Q13: Loss to follow-up	Q13 score	Q14: Adjusted for confounding	Q14 score	Total	Quality rating
Australia	Bal *et al.* [180]	2015	Cross-sectional survey	Yes	1.0	Yes	1.0	No	0.0	Not applicable	0.0	Partial	0.5	2.5	Low
Canada	Clark *et al.* [172]	2006	Cross-sectional survey	Yes	1.0	Yes	1.0	Not applicable (census data)	1.0	Not applicable	0.0	Partial	0.0	3.0	Moderate
Canada	Maupomé *et al.* [163]	2001	Retrospective/prospective cohort study	Yes	1.0	Yes	1.0	Not applicable (census data)	1.0	No	0.0	Partial	0.5	3.5	High
Canada	McLaren *et al.* [94]	2021	Cross-sectional survey	Yes	1.0	Yes	1.0	Yes	1.0	Not applicable	0.0	Extensive	1.0	4.0	High
USA	Szpunar and Burt [99]	1988	Cross-sectional survey	No	0.0	Yes	1.0	No	0.0	Not applicable	0.0	Some	0.0	1.0	Low

Table 52 Risk of bias assessment for randomised controlled trials examining the additive effects of CWF and topical fluoride therapy

Country	Author	Year	Study design	Randomisation	Effect of assignment	Effect of adherence	Missing outcome data	Measurement of outcomes	Reported results	Overall risk of bias
Hong Kong	Jiang *et al.* [189]	2014	Randomised controlled trial	Low	Some concerns	Low	Low	Low	Some concerns	Some concerns
Hong Kong	Lam *et al.* [190]	2021	Randomised controlled trial	Low	Low	Low	Low	Some concerns	Low	Some concerns

3.3.4 Study findings

The additional fluoride interventions differed across the seven included studies: two studies examined the effect of fluoride mouth rinses plus CWF [99,172], three examined the effect of exposure to diverse fluoride technologies (such as fluoride toothpaste, fluoride mouth rinses, and fluoride supplements) plus CWF [94,163,180], and two examined the effect of sodium fluoride varnish plus CWF [189,190]. The provision of quantitative data detailing associations was limited. Given the differences in study designs, populations, interventions, outcome measures, and follow-up periods described in Section 3.3.2, we completed a narrative synthesis rather than a meta-analysis. Five studies measured dental caries [94,99,163,189,190]. Four cross-sectional surveys measured dental fluorosis [94,99,172,180].

3.3.4.1 Dental caries

3.3.4.1.1 Exposure to fluoride technologies

3.3.4.1.1.1 Maupomé *et al.* (2001)

Maupomé *et al.* (2001) analysed a prospective longitudinal cohort of schoolchildren aged 6–12 years at baseline [163]. Variables on snacking, oral hygiene, exposure to fluoride technologies, and socioeconomic status were used together as predictors of dental caries (measured using the D_{1-2}MFS index) in multiple regression models. Dental caries incidence (assessed in 2,994 lifelong residents in grades 5, 6, 11, and 12 (aged 11, 12, 17, and 18 years)), expressed in terms of D_{1-2}MFS, was not different between the fluoridation-ended communities and still-fluoridated communities. The prevalence of dental caries (assessed in 5,927 children in grades 2, 3, 8, and 9) decreased over time in the fluoridation-ended communities while remaining unchanged in the still-fluoridated communities. Regression models did not identify which specific topical fluorides (in this case mouth rinses) markedly affected changes in the prevalence of dental decay. While the number of filled surfaces did not vary between surveys, the number of sealed surfaces increased at both study sites between the survey time points. There were, however, differences in dental caries experienced when D_{1-2}MFS components and surfaces at risk were investigated in detail. For example, in the still-fluoridated site, higher scores were found for non-cavitated caries in permanent teeth (D_1) and the complete D_{1-2}MFS indices. In contrast, in the fluoridation-ended site, higher scores were present for cavitated caries with enamel involvement in permanent teeth (D_2). Maupomé *et al.* (2001) concluded that “The results suggest a complicated pattern of disease following cessation of fluoridation. Multiple sources of fluoride besides water fluoridation have made it more difficult to detect changes in the epidemiological profile of a population with generally low dental caries experience and living in an affluent setting with widely accessible dental services” p37 [163].

3.3.4.1.2 Exposure to fluoride mouth rinses

3.3.4.1.2.1 Szpunar and Burt (1988)

Szpunar and Burt’s (1988) cross-sectional survey found that the prevalence of dental caries was significantly associated with the fluoride concentration in the community water supply [99]. Approximately 65% of all schoolchildren were without cavitated dental caries, ranging from 55.1% in fluoride-deficient Cadillac, Michigan to 73.7% in Redford, Michigan (CWF at 1.0 ppm). The logistic regression findings indicated that a lower prevalence of dental caries was significantly associated with younger age, regular dentist attendance, and the use of a water supply fluoridated at 1.0 ppm or above. The use of fluoride mouth rinses was not associated with the prevalence of dental caries [99].

3.3.4.1.2.2 McLaren *et al.* (2021)

McLaren *et al.* (2021) examined the effect of CWF cessation on grade 2 schoolchildren’s dental caries and dental fluorosis experience in the Canadian cities of Calgary, Alberta (which ceased CWF in 2011) and Edmonton, Alberta (which is still fluoridated) using a cross-sectional survey design 7–8 years after CWF cessation in Calgary [94]. The authors completed the survey in 2018–19 and compared their survey findings to earlier surveys (2004–05, 2009–10, and 2013–14). Data collection included a dental examination (to determine decayed, extracted/missing, or filled primary teeth (deft) and decayed, missing, or filled permanent teeth (DMFT), and smooth surface dental caries based on decayed, extracted/missing, or filled primary surfaces (defs) and decayed, missing, or filled permanent surfaces (DMFS)) conducted in school by dental hygienists (with standardised training), a questionnaire (including information on the general health of the child's mouth, daily toothbrushing frequency, consumption of sugary drinks, whether they took fluoride supplements at home, the provision of fluoride treatments at the dentist's office, the provision of fluoride treatments in a school programme, the use of fluoride toothpaste, and the use of fluoride mouth wash) completed by parents, and fingernail clippings for a small subsample. The crude and adjusted prevalence of dental caries in primary dentition was significantly higher (p<0.05) in Calgary (no CWF) than in Edmonton (still fluoridated). Adjusted deft prevalence in 2018–19 was 66.1% (95% CI: 63.6–68.6; n=2,317) in Calgary and 54.3% (95% CI: 51.4–57.2; n=2,217) in Edmonton, while adjusted decayed, missing, or filled primary surfaces – smooth surfaces (dmfs-ss) prevalence was 61.5% (95% CI: 58.8–64.1) in Calgary and 49.9% (95% CI: 47.1–52.7) in Edmonton. The crude and adjusted prevalence of dental caries in permanent dentition measured by DMFT was significantly higher (p<0.05) in Calgary (no CWF) (adjusted odds ratio (AOR): 16.8; 95% CI: 14.5–19.1) than in Edmonton (still fluoridated) (AOR: 12.5; 95% CI: 10.4–14.6). However, there was no difference in the crude and adjusted prevalence of dental caries in the permanent dentition measured by decayed, missing, or filled permanent surfaces – smooth surfaces (DMFS-SS). The authors stated that their findings for permanent teeth may reflect the fact that 7-year-olds have not had the time to accumulate enough permanent dentition dental caries experience for differences to have become apparent. The use of fluoride mouth rinse was significantly higher among children living in the fluoride cessation area (OR: 25.1 95% CI: 23.3–27.0) compared with the still-fluoridated area (OR: 20.9; 95% CI: 19.1–22.8). The use of fluoride toothpaste and fluoride supplements was not different between the fluoride cessation area and the still-fluoridated area [94]. The additive effect of mouth rinses plus CWF with regard to dental caries was not calculated.

3.3.4.1.3 Exposure to fluoride varnish

3.3.4.1.3.1 Jiang *et al*. (2014)

Jiang *et al.* (2014) evaluated, in a block randomised controlled trial, the effectiveness of applications of 5% sodium fluoride varnish two times per year plus toothbrushing training for parents of 415 (out of 450) young children living in Hong Kong (CWF at 0.5 ppm) compared with a placebo varnish plus toothbrushing training, and with toothbrushing training alone, in preventing both non-cavitated and cavitated early childhood dental caries [189]. The outcomes of early childhood dental caries lesions and change in the incidence of dmft were measured at baseline and at 24 months. The authors reported that 2% of the children had non-cavitated enamel caries lesions at baseline, and the mean dmft score was 0.03 (±0.24). In addition, no dentine caries lesions were identified. Most of the children neither had daily parental toothbrushing (65–73%) nor completed self-toothbrushing (86–90%). At 24 months follow-up, the incidences of early childhood dental caries lesions (including both non-cavitated and cavitated caries lesions) in the intervention group (Group 3), the placebo group (Group 2), and the education-only group (Group 1) were 17.5%, 11.8%, and 11.9%, respectively (p>0.05), and the mean new dmft scores in Groups 1, 2, and 3 were 0.3, 0.2, and 0.3, respectively (p>0.05). The proportion of parents who practised parental toothbrushing twice daily at 24 months follow-up was 62.7%, 60.4%, and 65.7% in Groups 1, 2, and 3, respectively (p>0.05). The authors identified the study population as being at low risk for dental caries and concluded that twice-annual applications of fluoride varnish may not have any additional dental caries prevention effect in the primary teeth of young children with a low risk of dental caries living in an area with CWF [189].

3.3.4.1.3.2 Lam *et al.* (2021)

The findings of the Lam *et al.* (2021) randomised controlled trial suggest no difference between sodium fluoride varnish and glass ionomer sealants among kindergarten children with moderate to high risk of dental caries regarding their effectiveness in preventing occlusal surface dental caries in primary second molars in an area with CWF set at 0.5 ppm [190]. At 6 months after the start of the trial, only 1.6% of all included molars (17/1,081) had dental caries progressed into dentine (ICDAS code 4 or higher). The proportion of included molars with dental caries progression into dentine in the sodium fluoride varnish and glass ionomer sealant groups were 1.3% (7/524 molars) and 1.8% (10/557 molars), respectively (p=0.549). At 12 months after the start of the trial, the overall prevalence of primary second molars with occlusal dental caries progression into dentine was 7.9%. No significant difference was found between the two study groups (sodium fluoride varnish group: 7.8% (37/475 molars); glass ionomer sealant group: 8.0% (41/514 molars); p=0.913). Lam *et al.* (2021) concluded that “Quarterly [sodium fluoride varnish] application and single [glass ionomer sealant] placement showed similar effectiveness in the prevention of dental caries” in primary teeth among children with moderate to high risk of dental caries in an area with CWF p322–3 [190].

3.3.4.1.4 Feasibility assessment results

We completed a feasibility assessment in order to determine whether we should complete a meta-analysis on the effect of exposure to CWF plus topical fluorides during the first 6 years of life on the prevalence of dental caries. Our parameters for the feasibility assessment were study design, population, concentration of fluoride in the fluoridated water supply, topical fluoride (mouth rinse and fluoride varnish), the use of a comparator dental caries and its assessment measure, statistical measure including variance, and adjustment for named confounders. The numeric data provided on exposure to fluoride mouth rinse in the three relevant studies was limited to statistical significance (p-value) and did not permit meta-analysis. The population, comparator, and results of the risk of bias assessment for the two available randomised controlled trials covering the intervention of fluoride varnish did not permit meta-analysis, as they had different population groups (a low-risk population compared with a moderate- and high-risk population) and comparators (another effective intervention compared with a placebo intervention).

3.3.4.1.5 Narrative synthesis: dental caries

Five studies reported on children who were aged under 6 years when they commenced using topical fluoride. Three of these studies examined the influence of mouth rinses, and two studies examined the influence of fluoride varnish.

Three studies reported data on children who were aged under 6 years when they commenced using mouth rinses. One study reported that regression models did not identify topical fluoride therapies (including mouth rinses) as being associated with the prevalence of dental caries [163]. Another study found that the use of fluoride mouth rinses in CWF areas had no effect on dental caries prevention [99], while the third study measured the use of fluoride mouth rinses in CWF areas, but not their effect on dental caries prevention [94].

Two randomised controlled trials reported data on fluoride varnish use. One trial demonstrated that twice-annual applications of fluoride varnish did not have any additional dental caries prevention effect in the primary teeth of young children with a low risk of dental caries who were living in an area with CWF [189], while the other trial demonstrated that fluoride varnish and glass ionomer sealants had the same positive effect on primary second molar teeth in children who had a moderate to high risk of dental caries and who lived in areas with CWF [190].

The findings of these five studies indicate that it was difficult to calculate an exact additive effect on dental caries of fluoride-based topical therapies commenced when children living in areas with CWF were aged under 6 years. The certainty of evidence for the exposure to topical fluoride therapies (including mouth rinses) during the first 6 years of life and the outcome of dental caries is very low. Apart from mouth rinses and fluoride varnish, other topical fluoride therapies were not studied.

3.3.4.1.6 Certainty or level of evidence

The certainty of evidence for the exposure of mouth rinses and the outcome of dental caries is very low due to the inclusion of observation study designs, the likelihood of recall bias, the low quality of one of the three observational studies with regard to design and conduct, and the lack of consistency when measuring the effects of the interventions. The certainty of evidence for the exposure of fluoride varnish and the outcome of dental caries is also very low, as both randomised controlled trials measure the intervention in populations with different risk levels and employ different comparators. In addition, both trials were judged to have some concerns with regard to risk of bias.

3.3.4.2 Dental fluorosis

3.3.4.2.1 Exposure to fluoride technologies including fluoride mouth rinses

3.3.4.2.1.1 Clark *et al.* (2006)

Clark *et al.* (2006) determined changes in the prevalence of dental fluorosis after CWF in Comox/Courtenay, British Columbia ceased in 1992 among schoolchildren aged 6–9 years in 1993–94, 1996–97, and 2002–03 [172]. The Thylstrup and Fejerskov Index was used to quantify the severity of dental fluorosis. Residence and dental histories were documented for all children in order to determine the extent of exposure to all types of fluorides (consumption of fluoridated water; use of fluoridated dentifrices, fluoride mouth rinses, and fluoride supplements; and infant feeding practices before the age of 6 years). Comparisons between the three surveys were used in order to establish the influence of CWF and other fluoride sources on the occurrence and severity of dental fluorosis. The children participating in the 1993–94 survey had exposure to CWF for their first 6 years of life, while the children in the 1996–97 survey represent a partial exposure (3 years) to CWF during the development of their permanent teeth. The children in the 2002–03 survey had no exposure to CWF. When CWF ceased in 1992, the prevalence of dental fluorosis (measured using the Thylstrup and Fejerskov Index) decreased significantly between the 1993–94 survey cycle and the 1996–97 and 2002–03 survey cycles (from 58% in 1993–94 to 23% in 1996–97 and 24% in 2002–03; $p<0.0001$ between 1993–94 and 2002–03). The severity of dental fluorosis, measured by the proportion of children with moderate or severe dental fluorosis, also decreased across the three time points (from 9% in 1993–94 to 0% in both 1996–97 and 2002–03). The prevalence of dental fluorosis in 1993–94 was not significantly different for the CWF-only group (58%) and the group that was exposed to both CWF and fluoride supplements (57%) in the first 4 years of life. Results from regression analyses for each survey period failed to identify any statistically significant associations between dental fluorosis and bottled water consumption; fluoride mouth rinse frequency; breastfeeding; and the age at which solid food, cow's milk, and infant formula consumption began ($p<0.05$). Statistically significant associations were found for fluoride supplement use from birth to the age of 1 year in the 1996–97 survey (OR: 1.54; $p=0.040$) and for toothbrushing frequency three or more times per day (compared with once per day or less) in the 1996–97 (OR: 2.67; $p=0.014$) and 2002–03 (OR: 3.52; $p=0.045$) surveys [172]. Use of fluoride toothpaste was implied in the toothbrushing frequency variable.

3.3.4.2.1.2 Bal *et al.* (2015)

Bal *et al.* (2015) determined whether the adjustment of the fluoride concentration to 1 ppm in the drinking water supplied to the City of Blue Mountains, New South Wales, Australia since 1992 was associated with dental fluorosis prevalence [180]. In 2003, children attending schools in the City of Blue Mountains and in a control region (Hawkesbury fluoridated at 1 ppm since either 1967 or 1969), who had been randomly selected at baseline in 1992 and again in 2003, were examined for dental fluorosis (maxillary central incisors only) using Dean's Index of Fluorosis. A fluoride history for each child was obtained via a questionnaire. Associations between dental fluorosis and 58 potential explanatory variables were explored.

A total of 1,138 children aged 7–11 years with erupted permanent central incisors were examined for dental fluorosis in 2003. The prevalence of very mild to severe dental fluorosis was 39.2% in the City of Blue Mountains, 39.0% in Hawkesbury, and 39.0% in the two regions combined, which included 16 cases of moderate or severe dental fluorosis (1.4%). Dean's Index of Fluorosis values were above the 0.6 level nominated by Dean as indicative of a public health concern. Sixty-four percent of participants had been exposed to CWF from birth. In addition, children were exposed to other sources of fluoride, including the use of fluoridated water for infant formula reconstitution, toothbrushing with fluoride toothpaste before the age of 2 years, early use of fluoride rinses, and the use of fluoride supplements. Early use of fluoride mouth rinse was not associated with dental fluorosis. However, no numeric data were provided in Bal *et al.*'s paper [180]. The remaining results were reported in Section **Error! Reference source not found.**.

3.3.4.2.1.3 McLaren *et al.* (2021)

McLaren *et al.* (2021) examined the effect of CWF cessation on grade 2 schoolchildren's dental caries and dental fluorosis experience in the Canadian cities of Calgary, Alberta (which ceased CWF in 2011) and Edmonton, Alberta (which is still fluoridated) using a cross-sectional survey design 7–8 years after CWF cessation in Calgary [94]. The authors completed the survey in 2018–19 and compared their survey findings to earlier surveys (2004–05, 2009–10, and 2013–14). Data collection included a dental examination (to determine the prevalence of dental fluorosis measured using the Tooth Surface Index of Fluorosis (TSIF)) conducted in school by dental hygienists (who received standardised training), a questionnaire (including information on the general health of the child's mouth, whether the child brushed their teeth twice per day, consumption of sugary drinks, whether they took fluoride supplements at home, the provision of fluoride treatments at the dentist's office, the provision of fluoride treatments in a school programme, the use of fluoride toothpaste, and the use of fluoride mouth wash) completed by parents, and fingernail clippings for a small subsample. The crude and adjusted prevalence of dental fluorosis in permanent dentition was significantly lower (p<0.05) in Calgary (no CWF) than in Edmonton (still fluoridated). Adjusted dental fluorosis prevalence in 2018–19 was 7.7% (95% CI: 5.9–9.6; n=1,406) in Calgary and 18.3% (95% CI: 14.9–21.6; n=1,206) in Edmonton. Of those with any dental fluorosis, the percentage with staining or pitting (TSIF score of 4–7) was less than 1.0% in both cities (0.1% in Calgary and 0.5% in Edmonton). The use of fluoride mouth rinses was significantly higher in the fluoride cessation area (OR: 25.1; 95% CI: 23.3–27.0) compared with the still-fluoridated area (OR: 20.9; 95% CI: 19.1–22.8). However, the additive effect of fluoride mouth rinses plus CWF with regard to dental fluorosis was not calculated. The use of fluoride toothpaste and fluoride supplements was not different between the fluoride cessation area and the still-fluoridated area [94].

3.3.4.2.2 Exposure to fluoride mouth rinses only

3.3.4.2.2.1 Szpunar and Burt (1988)

Szpunar and Burt's (1988) cross-sectional survey found that the prevalence of dental fluorosis was significantly associated with the fluoride concentration in the community water supply [99]. About 36% of all children had dental fluorosis, ranging from 12.2% in fluoride-deficient Cadillac, Michigan to 49% in Redford, Michigan (with CWF at 1.0 ppm) and 51.2% in Richmond, Michigan (with 1.2 ppm of natural fluoride). All cases were classified as having very mild or mild dental fluorosis using the TSIF. The odds of experiencing very mild dental fluorosis increased in a stepwise manner for the two fluoride levels above the baseline (set as fluoride-deficient Cadillac), and also increased following the use of topical fluoride mouth rinses (OR: 1.57; 95% CI: 1.02–2.41) and with older age [99].

3.3.4.2.3 Feasibility assessment results

We completed a feasibility assessment in order to determine whether we should complete a meta-analysis on the effect of exposure to CWF plus topical fluorides during the first 6 years of life on the prevalence of mild to severe dental fluorosis. Our parameters for the feasibility assessment were study design, population, concentration of fluoride in the fluoridated water supply, topical fluoride (mouth rinse), the use of a comparator, dental fluorosis and its assessment measure, statistical measure including variance, and adjustment for named confounders. We included three studies examining the influence of fluoride mouth rinses on dental fluorosis; however, the limited numeric data provided on fluoride mouth rinses for two of the three studies did not permit meta-analysis.

3.3.4.2.4 Narrative synthesis: dental fluorosis

The association between the use of fluoride mouth rinses together with CWF and dental fluorosis is mixed in the four included studies; two studies reported no effect of fluoride mouth rinses on dental fluorosis prevalence [172,180], and a third study reported an increased prevalence of dental fluorosis [99]. The fourth study did not test the effect of fluoride mouth rinses together with CWF on dental fluorosis [94]. Other topical fluoride interventions were not studied.

3.3.4.2.5 Certainty or level of evidence

The certainty of evidence for the exposure of fluoride mouth rinses and the outcome of dental fluorosis is very low due to the inclusion of observation study designs, the likelihood of recall bias, the low quality of one of the three observational studies with regard to design and conduct, and the lack of consistency when measuring and reporting on the effects of the interventions.

3.4 Question 3: What are the recommendations in other countries currently implementing CWF for the use of topical fluorides in children aged under 6 years?

The Department of Health selected seven countries of interest to answer this question, as they have (or had) CWF programmes and existing clinical guidelines on the prevention of caries. The countries of interest were Australia, Brazil, Canada, Israel, New Zealand, the UK, and the USA.

The recommendations by other countries currently implementing CWF regarding the use of topical and systemic fluorides by children aged under 6 years are presented by country in Table 53.

Dietary fluoride supplements are not recommended for use by the population in Australia [191], Canada [192], or Israel [193,194], while the USA [195] does not recommend fluoride supplements in areas with optimal water fluoridation. For Australia, there is no mention of fluoride supplements in the most recent 2019 version of their practical guidelines [191]. In 2023, 89% of the Australian population has access to optimally fluoridated water [196]. Presumably, dentists and medical doctors no longer prescribe fluoride supplements in Australia.

The use of fluoride toothpaste by very young children with no dental caries risk is not recommended in Australia (until children are at least aged 18 months), Israel (until children are at least aged 24 months), or Canada (until children are at least aged 36 months). Instead, the teeth should be cleaned with a brush moistened with water. Brazil [197], England [198], New Zealand [199], Scotland [200], and the USA [195] recommend the use of a smear of toothpaste containing 1000 ppm fluoride twice per day once the teeth erupt. In Australia [191], toothpaste containing 500 ppm fluoride is recommended for use by children aged 18–59 months in text-based recommendations and 18–72 months in picture-based recommendations [201].

Fluoridated mouth rinses are not recommended for children aged under 6 years in Australia [191] [201], Canada [192], England [198], Israel [194], Scotland [200], or the USA [195]. Brazil [197] recommends fluoridated mouth rinses for high-risk children aged 3 years and over who live in fluoride-deficient areas. New Zealand's guidelines [199] do not address mouth rinses.

The guidance on the use of fluoride varnish for children aged under 6 years is country specific. For example:

- Fluoride varnish can be applied to the teeth of all children at moderate or high risk of dental caries up to four times per year in Australia [191], and to all high-risk children twice per year in Israel [194].
- Public Health England (now the United Kingdom (UK) Health Security Agency and the Office for Health Improvement and Disparities) recommends that all children aged 3 years and over have fluoride varnish (2.26% sodium fluoride (NaF) applied topically twice per year regardless of their risk of dental caries [198].
- The Consultants in Dental Public Health Group, Scotland and the US Preventive Services Task Force recommend the clinical application of fluoride varnish to the primary teeth of all infants and children starting at the time of primary tooth eruption [200,202].

The advice on fluoride gel is also country specific, with Australia not recommending it for children aged under 10 years [191] and the USA permitting it for very young children with a high risk of dental caries [195].

The visual presentation of clinical recommendations in Australia is a very good example of clear communication between dental professionals and the general public (**Error! Reference source not found.**) [201].

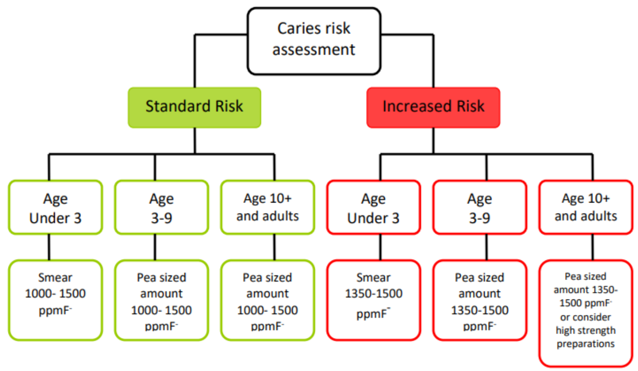
Table 53 Recommendations in countries currently implementing CWF regarding the use of topical fluorides in children aged under 6 years

Country	Year	Guideline title, link, and access date	Recommendations
Australia	2019 Updated from 2012 and 2005	*Practical Guidelines for use of Fluorides* [191] https://adavb.org/publicassets/17588702-96b6-ea11-a2b8-b0d6fd09413e/ADA-Fluoride-Guidelines-Resource-2020.pdf For more detailed guidance, please refer to: Do LG. Guidelines for use of fluorides in Australia: update 2019. Aust Dent J. 2020;65:30–38. [203] Available from: https://doi.org/10.1111/adj.12742 Accessed 18 February 2022	Australia has practical guidelines on the use of toothpastes and topical fluorides for all ages. *Toothpaste* The guidelines on the use of toothpaste for children aged 0–17 months advise that children with no caries risk do not use toothpaste and children with moderate or high caries risk use low-fluoride toothpaste (500 ppm). The guidelines on the use of toothpaste for children aged 18–59 months advise that children with no caries risk use a low-fluoride toothpaste (500 ppm) and children with moderate or high caries risk use a standard fluoride toothpaste (1000–1500 ppm). *Mouth rinses, fluoride gel, fluoride varnish, silver diamine fluoride, fluoride supplements, and fluoride foam* Fluoride mouth rinses (200–900 ppm) or fluoride gel (1500–12300 ppm) are not recommended for children aged under 6 years. *Fluoride varnish* Fluoride varnish (22600 ppm) can be applied to the teeth of all children who are at moderate or high risk of caries up to four times per year. It is advised that maximum dosages are not exceeded: 0.25 millilitres (mL) for primary dentition, 0.40 mL for mixed dentition, and 0.75 mL for permanent dentition. Silver diamine fluoride (38%) can be applied to the teeth of all children who are at moderate or high risk of caries twice per year where traditional approaches to caries management might not be possible. Fluoride supplements and/or foam should never be used. Australia's *Practical Guidelines for use of Fluorides* are presented in an easy-to-use, easy-to-follow format in **Error! Reference source not found.**, which follows this table.
Brazil	2022 2009	Guideline for Clinical Practice in Primary Health Care: Recommendations for Oral Hygiene in Childhood (no date) [197] https://egestorab.saude.gov.br/image/?file=20220214_I_GODECGuia-Recomendacaoparahigienebucalnainfancia-FINALCONSULTAPUBLICAcompressed_8346064593484712885.pdf Accessed 21 February 2023 Ministério da Saúde (2009) Guia de recomendações para o uso de fluoretos no Brasil. Brasília : Ministério da Saúde, 2009 [204]	The purpose of developing these clinical practice guidelines is to provide recommendations for oral hygiene for children aged up to 12 years in order to prevent and control dental caries. The guidelines recommend that: • All children start oral hygiene practices from the time of eruption of the first tooth by brushing with fluoride toothpaste. • All children should use fluoride toothpaste containing at least 1000 ppm fluoride in order to prevent and control tooth decay. The 2009 guidelines on the same topic recommend that children aged under 3 years should use small quantities of fluoride toothpaste (about 0.3 grams, which is equivalent to one grain of rice). • All children should brush with fluoride dentifrice at least twice per day in order to prevent and control dental caries. The 2009 guidelines on the same topic recommend the use of fluoride mouth rinses on a weekly basis (sodium fluoride 0.2%) for populations of children aged 3–12 years in fluoride-deficient areas; where less

Country	Year	Guideline title, link, and access date	Recommendations
		https://aps.saude.gov.br/biblioteca/visualizar/MTMxMg==	than 30% of the individuals in the population group are without dental caries at age 12; and for individuals wearing fixed orthodontic appliances. The 2009 guidelines on the same topic recommend the use of fluoride gels in high-risk populations and for individuals wearing fixed orthodontic appliances (no age limit was reported).
Canada	2012	*CDA Position on Use of Fluorides in Caries Prevention* [192] https://www.cda-adc.ca/_files/position_statements/fluoride.pdf Accessed 18 February 2022	*Toothbrushing and toothpaste* Children from birth to the age of 3 years should have their teeth and gums brushed by an adult. The use of fluoride toothpaste in this age group is determined by the level of risk. Parents should consult a healthcare professional in order to determine whether a child aged up to 3 years is at risk of developing tooth decay. If such a risk exists, the child's teeth should be brushed by an adult using a minimal amount (a portion the size of a grain of rice) of fluoride toothpaste. Use of fluoride toothpaste in small amounts has been determined to achieve a balance between the benefits of fluoride and the risk of developing fluorosis. If the child is not considered to be at risk of developing tooth decay, their teeth should be brushed by an adult using a toothbrush moistened only with water. By a child's first birthday, the parents should consult a healthcare professional who is knowledgeable about early childhood tooth decay and the benefits of fluoride. A child may be at risk of early childhood tooth decay if one or more of the following conditions exist: 1. The child lives in an area with a fluoride-deficient water supply or low natural fluoride levels (<0.3 ppm). 2. The child has a visible defect, notch, cavity, or white chalky area on a baby tooth in the front of the mouth. 3. The child regularly consumes sugar (even natural sugars) between meals. This includes the use of a bottle or sippy cup filled with any liquid other than water and consumption of sweetened medications. 4. The child has special healthcare needs that limit his or her cooperative abilities, thus making it difficult for the parent to brush the child's teeth. 5. The child's teeth are brushed less often than once a day. 6. The child was born prematurely with a very low birthweight of less than 1,500 grams (3 pounds). 7. The parent or caregiver has tooth decay. 8. The child has visible plaque, such as white or yellow deposits on the teeth. Children aged 3–6 years should be assisted by an adult in brushing their teeth. Only a small amount (a portion the size of a green pea) of fluoride toothpaste should be used. All children should be supervised or assisted until they develop appropriate manual dexterity. Fluoride mouth rinsing is not recommended for children aged under 6 years. *Professional topical applications of fluoride gels, foams, and varnishes* The Canadian Dental Association (CDA) recognises and supports the professional topical applications of fluoride gels, foams, and varnishes in the prevention of dental caries for individuals at risk of dental caries. *Fluoride supplements* Fluoride supplements in the form of chewable tablets, lozenges, or drops are not recommended for most Canadians. However, healthcare professionals may wish to prescribe fluoride supplements to high-risk

Country	Year	Guideline title, link, and access date	Recommendations
			patients in fluoride-deficient communities where individuals are not able to obtain fluoride in any other form (e.g. toothpaste) and after they have completed a thorough analysis of the patient's fluoride intake. In order to prevent fluorosis, fluorides should be consumed in a wise and correct manner. Do not supplement the diet with fluorides if tap water is already fluoridated. Avoid giving fluoride-rich toothpaste to infants and children who are unable to spit it out properly and who may swallow it. Teeth should be brushed with toothpastes containing fluoride at a concentration appropriate for an individual's age. One should avoid giving high-fluoride toothpastes to infants and children who do not spit well and may ingest the toothpaste. In view of this, children aged under 2 years should use a fluoride-free toothpaste. Between the ages of 2 and 6 years, a small quantity of toothpaste for children should be applied on the brush and the child should be supervised while brushing or helped to brush their teeth effectively. From the age of 6 years, adult toothpastes may be used. In the event of a child swallowing a large amount of fluoride drops or swallowing a large amount of toothpaste, it is recommended to give the child 1.5 cups of milk to drink, to encourage vomiting, and to go promptly to a physician or the emergency room.
Israel	2021	Frequently Asked Questions on Fluoride and Fluoridation of Drinking Water [193] https://www.gov.il/en/Departments/faq/faq-fluoride Accessed 18 February 2022 Dental Health Guidelines #3.2 Edition #4 Update date: 1 April 2021 the subject: prevention of dental caries [194] https://www.health.gov.il/hozer/DT02_03.pdf Accessed 21 February 2023 [194]	The Dental Health Guidelines (2021) recommend: *Toothpaste and toothbrushing* After the first tooth erupts, parents must start cleaning and brushing their children's teeth. Start cleaning with soft gauze and switch as soon as possible to a brush with a small head and soft fibres suitable for toddlers. Brushing is recommended twice per day – in the morning and in the evening (before bed) – for all children once the first tooth erupts. For toddlers (from the eruption of the first tooth until the age of 6 years), it is recommended to use a toothpaste containing fluoride at a concentration of 1000 ppm. From the eruption of the first tooth until the age of 2 years, it is recommended to use a minimal amount of toothpaste (i.e. approximately the size of a grain of rice). Between the ages of 2 and 6 years, the amount of toothpaste should be increased to the size of a pea. It is recommended to brush the teeth for about 2 minutes. The child should be encouraged to spit out the remains of the toothpaste from their mouth. Children aged up to 8 years should brush their teeth with the help and supervision of an adult and avoid swallowing toothpaste. The remains of the toothpaste must be spit out without rinsing the mouth with water, so that the effect of the fluoride on the teeth can be improved. *Daily mouth rinses with fluoride* Fluoride mouthwashes are intended for use only in those aged 6 years and over. *Fluoride preparations for use by professionals*

Country	Year	Guideline title, link, and access date	Recommendations
			Fluoride varnish may be used twice per year on deciduous and permanent teeth in order to prevent tooth decay. Fluoride varnish preparations are recommended in cases where individuals are at high risk of caries, in addition to regular toothbrushing. The product is safe to use from the eruption of the first tooth and may reduce the damage to the teeth from caries by over 35% in primary teeth and 40% in permanent teeth. Fluoride gel, such as acidulated phosphate fluoride containing fluoride ions at a concentration of 23.1% (12300 ppm) in an acidic environment, is only to be used for children aged 6 years and over.
New Zealand	No date	Fluoride and oral health [199] https://www.health.govt.nz/our-work/preventative-health-wellness/fluoride-and-oral-health Accessed 18 February 2022	Most fluoride toothpastes on sale in New Zealand contain 1000 ppm of fluoride (i.e. 0.221% sodium fluoride or 0.76% sodium monofluorophosphate). This is the recommended strength for adults and children, based on the consensus of many years of research on the effectiveness of different strengths of fluoridated toothpaste. Adults should us a pea-sized amount of fluoride toothpaste, and younger children should use just a smear of the same strength toothpaste on a small brush. Children should be discouraged from swallowing or eating toothpaste.
UK (England and Scotland)	2021 and 2022	*Delivering better oral health: an evidence-based toolkit for prevention* [198] https://www.gov.uk/government/publications/delivering-better-oral-health-an-evidence-based-toolkit-for-prevention Children's teeth [205] https://www.nhs.uk/live-well/healthy-body/taking-care-of-childrens-teeth/ Accessed 18 February 2022 *Consultants in Dental Public Health Group Recommendations on the use of fluoride toothpaste and fluoride supplements in Scotland (2022)* [200] https://www.scotphn.net/wp-content/uploads/2019/03/CsDPH-Fluoride-Recommendations-2022.pdf Accessed 21 February 2023	England *Toothpaste and toothbrushing* Public Health England (now the UK Health Security Agency and the Office for Health Improvement and Disparities) advises that all adults and children brush their teeth with fluoride toothpaste at least twice daily in order to help prevent tooth decay. Parents or carers should brush their 0–35-month-old children's teeth as soon as they erupt, twice per day for 2 minutes (last thing at night (or before bedtime) and on one other occasion during the day), with a toothpaste containing at least 1000 ppm fluoride, and using only a smear of toothpaste. As the child gets older (aged 3–6 years), a parent or carer should assist them to brush their own teeth on all tooth surfaces at least twice per day for 2 minutes (last thing at night (or before bedtime) and on at least one other occasion during the day), with toothpaste containing at least 1000 ppm fluoride, and using a pea-sized amount of the toothpaste. These children should spit out the toothpaste after brushing rather than rinsing, in order to avoid diluting the fluoride concentration. *Mouthwash* Public Health England (now the UK Health Security Agency and the Office for Health Improvement and Disparities) recommends the daily use of a fluoride mouthwash in adults and in children aged 7 years and over who are causing concern to their dentist (e.g. those with active caries, a dry mouth, or special needs). It should be used at a different time than toothbrushing in order to avoid removal of the beneficial effects of fluoride in toothpaste. Mouth rinses are not recommended for children aged under 7 years. *Fluoride varnish (Of note, only 10% of the UK has fluoridated water)* Public Health England (now the UK Health Security Agency and the Office for Health Improvement and Disparities) recommends that all children aged 3 years and over have fluoride varnish (2.26% sodium fluoride) applied topically twice per year regardless of their risk of developing dental caries. The application of fluoride varnish at least twice per year may also be considered in adults and children aged under 3 years who are causing concern to their dentist.

Country	Year	Guideline title, link, and access date	Recommendations
			Scotland *Tooth brushing, fluoride toothpaste, fluoride mouth rinse, fluoride varnish and fluoride supplement use is based on age and caries risk.* Toothbrushing should be completed before bed and at least one other time during the day, beginning when the first tooth erupts. Toothbrushing should be supervised by parents and assistance should be given until children are able to adequately clean all visible tooth surfaces on their own. Parents should encourage children to spit out toothpaste after brushing. Parents should discourage children from swallowing toothpaste or actively rinsing out their mouths after toothbrushing. The inserted figure presents guidance on fluoride toothpaste use by age and caries risk. Mouth rinses should only be used by children aged over 8 years. All children, regardless of caries risk, should have fluoride varnish applied at least twice per year. The use of additional fluoride supplements, such as fluoride tablets, drops, or gels, is no longer encouraged. **Fluoride toothpaste use is based on age and caries risk.** Advice on fluoride toothpaste use is based on age and caries risk and is summarised below.  Source: *Consultants in Dental Public Health Group Recommendations on the use of fluoride toothpaste and fluoride supplements in Scotland (2022)* [200]
USA	2021	Fluoride: Topical and Systemic Supplements [195] https://www.ada.org/resources/research/science-and-research-institute/oral-health-topics/fluoride-topical-and-systemic-supplements *Dietary Fluoride Supplements: Evidence-based Clinical Recommendations* [206]	The American Dental Association (ADA) recommends use of a fluoride toothpaste displaying the ADA Seal of Acceptance. Fluoride toothpastes available over the counter in the USA generally contain a fluoride concentration of 1000–1500 ppm. For most people (children, adolescents, and adults), brushing twice per day with a fluoride toothpaste – when they get up in the morning and before going to bed – is recommended. Children's toothbrushing should be supervised in order to ensure that they use the appropriate amount of toothpaste. For children aged under 3 years, parents and caregivers should begin brushing their children's teeth as soon as they begin to erupt by using fluoride toothpaste in an amount described as no more than a smear, or

Country	Year	Guideline title, link, and access date	Recommendations
		https://www.ada.org/-/media/project/ada-organization/ada/ada-org/files/resources/research/ada_evidence-based_fluoride_supplement_chairside_guide.pdf?rev=60850dca0dcc41038efda83d42b1c2e0&hash=FEC2BBEA0C892FB12C098E33344E48B4 Accessed 21 February 2023 Screening and Interventions to Prevent Dental Caries in Children Younger Than 5 Years: US Preventive Services Task Force Recommendation Statement US Preventive Services Task Force. Screening and Interventions to Prevent Dental Caries in Children Younger Than 5 Years: US Preventive Services Task Force Recommendation Statement. [202] JAMA. 2021;326(21):2172–8. Available from: https://doi.org/10.1001/jama.2021.20007	alternatively as the size of a grain of rice. For children aged 3–6 years, parents and caregivers should dispense no more than a pea-sized amount of fluoride toothpaste. *Fluoride mouth rinse* Fluoride mouth rinse is not recommended for use in persons aged under 6 years because of the risk of fluorosis if the mouth rinse is swallowed repeatedly. *Professionally applied fluorides* Professionally applied fluorides are in the form of a gel, foam, or rinse, and are applied by a dental professional during dental visits. These fluorides are more concentrated than self-applied fluorides (e.g. 1.23% fluoride ion), and therefore do not need to be used as frequently. Fluoride gel, generally applied at 3- to 12-month intervals, poses little risk for dental fluorosis, even among patients aged under 6 years. However, routine use of professionally applied fluoride gel or foam likely provides benefit only to persons at high risk for tooth decay, especially those who do not consume fluoridated water or brush daily with fluoride toothpaste. Fluoride varnishes are available as sodium fluoride (2.26% fluoride) or difluorsilane (0.10% fluoride) preparations. High-concentration fluoride varnish is painted by a dental or other healthcare professional directly onto the teeth and sets when it comes into contact with saliva. Fluoride varnish is not intended to adhere permanently; this method holds a high concentration of fluoride in a small amount of material in close contact with the teeth for several hours. Varnishes must be reapplied at regular intervals, with at least two applications per year needed for sustained benefit. The US Preventive Services Task Force recommends the clinical application of fluoride varnish to the primary teeth of all infants and children starting at the time of primary tooth eruption. The recommendation is given a ‘B’ grade, indicating that there is high certainty that the net benefit of the intervention is moderate or there is moderate certainty that the net benefit is moderate to substantial. According to the Centers for Disease Control and Prevention, there is no published evidence to indicate that professionally applied fluoride varnish is a risk factor for dental fluorosis, even among children aged under 6 years. Proper application technique reduces the possibility that a patient will swallow varnish during its application and limits the total amount of fluoride swallowed as the varnish wears off the teeth over a period of several hours. *Silver diamine fluoride* The Food and Drug Administration has classified silver diamine fluoride as a Class II medical device; it is cleared for use in the treatment of tooth sensitivity (which is the same type of clearance as fluoride varnish), and it must be professionally applied. A single application of silver diamine fluoride has been reported to be insufficient for sustained benefit. Its potential downsides include a reportedly unpleasant metallic taste, the potential to irritate gingival and mucosal surfaces, and the characteristic black staining of the tooth surfaces to which it is applied. *Dietary fluoride supplements*

Country	Year	Guideline title, link, and access date	Recommendations
			Dietary fluoride supplements are not recommended for use by the population in areas with optimal fluoride concentrations in drinking water (>0.6 ppm) but are recommended for children aged 6 months to 6 years who live in areas that are fluoride deficient. Please see inserted table for guidance. **Dietary fluoride supplements for children in the USA taking account of CWF level and high risk of developing dental caries**

Practitioners are encouraged to evaluate all potential fluoride sources and conduct a caries risk assessment before prescribing fluoride supplements.

For children at **low caries risk**, dietary fluoride supplements are **not recommended** and other sources of fluoride should be considered as a caries preventive intervention. **(D)**
For children at **high caries risk**, dietary fluoride supplements are **recommended** according to the schedule presented in the following table. **(D)**
When fluoride supplements are prescribed, they should be **taken daily** to maximize the caries prevention benefit. **(D)**

ADA dietary fluoride supplement schedule for children at high caries risk

Age (Years)	Fluoride Concentration in Drinking Water (ppm)*		
	<0.3	0.3-0.6	>0.6
Birth to 6 months	None **(D)**	None **(D)**	None **(D)**
6 months to 3 years	0.25 mg/day **(B)**	None **(D)**	None **(D)**
3 to 6 years	0.50 mg/day **(B)**	0.25 mg/day **(B)**	None **(D)**
6 to 16 years	1.0 mg/day **(B)**	0.50 mg/day **(B)**	None **(D)**

*1.0 ppm = 1 mg/liter

[1]Rozier, et al. Evidence-based clinical recommendations on the prescription of dietary fluoride supplements for caries prevention: a report of the ADA Council on Scientific Affairs. Evidence-based clinical recommendations on the prescription of dietary fluoride supplements for caries prevention. JADA 2010; 141:1480-1489. To see the full text of this article, please go to http://jada.ada.org/cgi/reprint/141/12/1480.

Source: Dietary Fluoride Supplements: Evidence-based Clinical Recommendations [206]

Practical Guidelines for use of Fluorides

AUSTRALIAN DENTAL ASSOCIATION

Home Care – Toothpastes

Age	Toothbrushing Instructions	Recommended Toothpaste Use	Special Considerations	
		Low Caries Risk*	Mod-High Caries Risk#	
0-17 months	Once or Twice Daily Begin to teach: Spit out Don't swallow Don't rinse	No Toothpaste	Begin using low fluoride toothpaste (500ppm) when first tooth erupts.	Use a smear of low fluoride toothpaste (500ppm).
18 months – 6 years	Twice Daily Spit out Don't swallow Don't rinse	Low fluoride toothpaste (500ppm)	Standard fluoride toothpaste (1000-1500ppm).	Use a pea-sized amount of low fluoride toothpaste (500ppm) or a smear of standard toothpaste (1000-1500ppm)
6 – 12 years	At least Twice Daily Spit out Don't swallow Don't rinse	Standard fluoride toothpaste (1000-1500ppm)	Standard fluoride toothpaste (1000-1500ppm).	Brush more frequently than twice daily.
13 years and over	At least Twice Daily Spit out Don't swallow Don't rinse	Standard fluoride toothpaste (1000-1500ppm)	Standard fluoride toothpaste (1000-1500ppm). **Or** on professional advice: Use high concentration fluoride toothpaste (5000ppm) twice daily.	Brush more frequently than twice daily.

* Low Caries Risk – Reside in community water fluoridation region. Child: No new cavitated or non-cavitated lesion themselves or parent/carer and siblings;
Adult: Without any moderate-high risk factors listed below. Adapted from CAMBRA (https://www.cdafoundation.org/Portals/0/pdfs/cambra_handbook.pdf)

Mod-High Risk Factors – Active caries, Inadequate fluoride exposure; High sugar diet; Poor- fair oral hygiene; Low saliva flow; Individual or Family history of untreated caries; Orthodontic/dental appliances; Other individual factors such as hypomineralised teeth, multiple medications, special health care needs. Adapted from CAMBRA (https://www.cdafoundation.org/Portals/0/pdfs/cambra_handbook.pdf)

^ These products do not have sufficient evidence to support their use (see over)

Adapted from Guidelines for the use of fluorides in Australia: update 2019. Aust Dent J 2020; 65: 30–38

Practical Guidelines for use of Fluorides

AUSTRALIAN DENTAL ASSOCIATION

Home Care – Other Fluoride Products

Product	Toothbrushing Instructions	Recommended Use	Special Considerations	
		Low Caries Risk*	Mod-High Caries Risk#	
Mouthrinses (200-900ppm F)	Spit out. Don't swallow.	Not Recommended	Not for young children. For children over 6 years to adults.	Should not replace twice daily toothbrushing. Use at a different time of day than twice daily toothbrushing.
Fluoride Supplements – Drops or Tablets	DO NOT USE^	DO NOT USE^	DO NOT USE^	DO NOT USE^

Professionally-Applied Fluoride Products

Product	Instructions	Recommended Use	Special Considerations	
		Low Caries Risk*	Mod-High Caries Risk#	
Fluoride Varnish (22,600ppm F)	Apply up to 4 times per year.	Not Recommended	All people at risk of caries.	Do not exceed max dosage: 0.25ml for primary dentition 0.4ml for mixed dentition 0.75ml for permanent dentition
Fluoride Gel (1500-12,300ppm F)	Use where other forms of fluoride are not available or suitable.	Not Recommended	Not for children under 10 years. For children over 10 years to adults.	
Silver Diamine Fluoride (38%)	Apply twice a year.	Not Recommended	May be indicated where traditional approaches to caries management might not be possible.	
Fluoride Foam	DO NOT USE^	DO NOT USE^	DO NOT USE^	DO NOT USE^

AD0421

Figure 25 Practical guidelines for fluoride use, Australia

Source: Australian Dental Association, n.d. [201]

4 Discussion

4.1 Key findings

This systematic review collates the evidence on the effect of artificial CWF on dental caries and fluorosis between 1948 and 2023 and includes both before and after studies and single point in time studies. It also attempted to establish if there is a dose response ratio for CWF with dental caries and with dental fluorosis at different CWF levels between 0.5ppm and 1.2ppm. We did not find evidence of a dose response at different levels between 0.5ppm and 1.2ppm and did find a reduction in dental caries and an increase in dental fluorosis.

The certainty of the evidence for all dental caries outcomes and the intervention CWF is low or very low. The majority of dental caries outcomes in primary dentition indicated a reduction in cavitated caries that favoured CWF areas over the fluoride deficient areas. The findings for one outcome (dmft at two time points) were mixed. The findings for permanent dentition outcomes indicated a reduction in cavitated caries for all except one outcome and the reduction favoured the CWF areas over the fluoride deficient areas. The findings for one outcome (DMFT at two time points) were mixed.

The certainty of evidence for the prevalence of fluorosis across countries with CWF is very low. The prevalence of dental fluorosis in permanent teeth of 10–15-year-old children living in CWF areas, using Dean's Index of Fluorosis, ranged from 1.3% to 47.7%. The prevalence of dental fluorosis in permanent teeth of schoolchildren and young people living in CWF areas, using the Tooth Surface Index of Fluorosis, ranged from 18.3% to 69.2%, and was similar among schoolchildren using the Thylstrup and Fejerskov Index (ranging from 13.3% to 69.6%). The vast majority of cases had very mild or mild dental fluorosis. The prevalence of dental fluorosis increased over time in Brazil, Ireland, and the USA, and this increase was observed both in areas with and without CWF. This meta-analysis indicated that children living in CWF areas had three times higher adjusted odds of dental fluorosis than children living in fluoride-deficient areas. In Brazil, the prevalence of both moderate and severe dental fluorosis in children living in CWF areas was 18.0% (no severe cases), compared with 9% in Canada, 3% in England, and 1% in Ireland (no severe cases). The prevalence of both moderate and severe dental fluorosis was higher in CWF areas compared with fluoride-deficient areas in the three countries.

The results of five studies indicate there is very low certainty of evidence of mixed findings for the relationship between using fluoride toothpaste in a CWF area during the first 6 years of life and dental caries, with two studies reporting a protective effect and three studies reporting no relationship. Eight studies in CWF areas identified a relationship between oral hygiene practices related to the use or misuse of fluoride toothpaste commenced during the first 6 years of life and dental fluorosis, indicating low certainty evidence that there may be a relationship between exposure to fluoride toothpaste and how it is used, and the outcome of dental fluorosis in permanent teeth.

Two randomised controlled trials, based on very low-certainty evidence, reported mixed findings on fluoride varnish use for caries prevention in primary dentition. The certainty of evidence for no effect of topical fluoride therapies (including mouth rinses) during the first 6 years of life and the outcome of dental caries is very low. The association between the use of fluoride mouth rinses together with CWF, when children living in areas with CWF were aged under 6 years, and dental fluorosis is mixed in the four included studies and the evidence is very low certainty.

Dietary fluoride supplements are not recommended for use by the population in Australia, Canada, or Israel, while the USA does not recommend fluoride supplements in areas with optimal water fluoridation. The use of fluoride toothpaste by children with no dental caries risk is not recommended in Australia until (children are at least aged 18 months), Israel (until children are at least aged 24 months), or Canada (until children are at least aged 36 months). Brazil, England, New Zealand, Scotland, and the USA recommend the use of a smear of toothpaste containing 1000 ppm fluoride twice per day once the teeth erupt. In Australia, toothpaste with 500 ppm fluoride is recommended for use by children aged 18–59 months. Brazil was the only country recommending the use of fluoride mouth rinses, and it recommends fluoride mouth rinses for high-risk children aged 3 years and over who live in fluoride-deficient areas. The guidance on the use of fluoride varnish for children aged under 6 years is country specific. All countries examined (except Brazil) recommend fluoride varnish use. The advice on fluoride gel is also country specific, with Australia not recommending it for children aged under 10 years and the USA permitting it for very young children with a high risk of dental caries.

The evidence provided in this evidence review does not provide adequate evidence to discontinue CWF in Ireland. Overall, CWF has a positive effect on reducing caries in teeth and the prevalence of moderate and severe fluorosis is low. In 2017, the prevalence of moderate dental fluorosis was under 1%, and there were no cases of severe dental fluorosis in the studies of CWF area in Ireland.

4.2 Comparison with other research

4.2.1 Methods

In 2015 and again in 2024, Iheozor-Ejiofor *et al.* [41,56], the Cochrane Review authors, updated the dental health aspects of McDonagh *et al.*'s 2000 systematic review [57], by evaluating the effects of water fluoridation (artificial or natural) on the prevention of dental caries and on the prevalence of dental fluorosis [41], and with some acknowledged differences in design, the Health Research Board (HRB) is updating Iheozor-Ejiofor *et al.*'s systematic review.

Iheozor-Ejiofor *et al.* included intervention populations of all ages receiving fluoridated water (artificial or natural) and comparator populations receiving non-fluoridated water [41], whereas we (the HRB authors) included intervention populations receiving artificial CWF only, and we have concentrated on children in our analysis. We concentrated on artificial CWF because this is the water fluoridation intervention of interest to the Irish Department of Health, and we concentrated on children because very few studies of adults met our inclusion criteria. Iheozor-Ejiofor *et al.* reported that for artificially fluoridated water, the 'optimum level' is considered to be around 1 ppm [41], whereas we defined CWF as water with artificial fluoride levels of 0.4–1.5 ppm. Iheozor-Ejiofor *et al.* defined non-fluoridated or fluoride-deficient water as having a fluoride concentration of 0.4 ppm or under [41], whereas we defined it as 0.3 ppm or under.

Like this evidence review, Iheozor-Ejiofor *et al.*'s primary outcomes of interest were changes in the average number of decayed, missing, or filled primary teeth (dmft); decayed, missing, or filled permanent teeth (DMFT); decayed, missing, or filled primary surfaces (dmfs); and decayed, missing, or filled permanent surfaces (DMFS) [41]. In addition, they measured the incidence of dental caries (cavitated or not) and the percentage of children without dental caries (cavitated or not) [41]. Iheozor-Ejiofor *et al.* also recorded data on disparities in dental caries across different groups of people, as reported in the included studies [41]. We did not examine the influence of socioeconomic status, as this would have required the inclusion of an additional body of literature, and neither time nor resources were adequate in order to fully examine this aspect and advantage of CWF. Iheozor-Ejiofor *et al.* reported that their secondary outcome was dental fluorosis [41], which we included as a primary outcome. Iheozor-Ejiofor *et al.* measured dental fluorosis in children using Dean's Index of Fluorosis, the Thylstrup and Fejerskov Index, the Tooth Surface Index of Fluorosis (TSIF), and the modified Developmental Defects of Enamel index [41], whereas we did not include the modified Developmental Defects of Enamel index because our understanding was that that particular index measures enamel mottling more generally and would overestimate the prevalence of dental fluorosis.

For caries outcome data, Iheozor-Ejiofor *et al.* included only prospective studies with a concurrent control that compared at least two populations – one receiving fluoridated water and the other receiving non-fluoridated water – and evaluated at least two points in time; groups had to be comparable in terms of fluoridated water consumption at baseline [41]. For studies assessing the initiation of CWF, the groups had to be from non-fluoridated areas at baseline, with one group subsequently having fluoride added to the water [41]. For studies assessing the cessation of CWF, the groups had to be from fluoridated areas at baseline, with one group subsequently having CWF discontinued [41]. We also included multiple-time-point studies, but in addition, we included single-time-point cross-sectional surveys with a comparator group; our criteria were that studies had to provide the concentration of artificial fluoride for each intervention area and of natural fluoride for each comparator area, and we were surprised at the number of studies that did not provide such basic dose-related data, which are a basic premise for this intervention (see Appendix C of Section 6, specifically subsections 6.3.2 and 6.3.3). For dental fluorosis outcome data, Iheozor-Ejiofor *et al.*'s review included any study design with a concurrent control that compared populations exposed to different natural and artificial water fluoride concentrations up to 5 ppm [41], whereas we included cross-sectional, case-control, and prospective or retrospective cohort studies and studies of artificial CWF only, as Ireland's Department of Health (the primary user of this document) is principally interested in the intervention of CWF and how it compares to fluoride-free or fluoride-deficient areas.

4.2.2 Findings

4.2.2.1 Number of studies included

Iheozor-Ejiofor *et al.*, the Cochrane Review authors, included 22 studies on the effects of fluoridated water on dental caries and 135 studies on its effects on dental fluorosis [41,56] whereas we (the HRB authors) included 87 studies on the effects of CWF on dental caries and 33 studies on its effects on dental fluorosis. Iheozor-Ejiofor *et al.* reported on 20 studies that assessed the effects of starting a CWF scheme [41,56]. Those 20 studies compared the dental caries incidence in two communities around the time that CWF in one of the communities began. After several years, a second survey was done to see what difference CWF had made. Around 60% (n=13) of these studies were conducted before 1975 [41]. Other, more recent studies comparing fluoridated and non-fluoridated communities have been conducted between 1975 and 2022. However, Iheozor-Ejiofor *et al.* excluded them from their Cochrane Review because the more recent studies did not carry out initial surveys of dental caries prevalence around the time CWF started, so Iheozor-Ejiofor *et al.* were unable to evaluate changes in those levels following the introduction of CWF [41,56]. We included single-time-point studies and handled their differences in our analysis. Iheozor-Ejiofor *et al.* reviewed only one study that compared tooth decay in two CWF areas before CWF was stopped in one area, and conducted a second survey after several years to see what difference it made [41,56], whereas we included any studies of areas that discontinued CWF and that met our eligibility criteria.

4.2.2.2 Children

Our data for two points in time is comparable to Iheozor-Ejiofor *et al.* of 2015 and we found similar benefits for dmft, DMFT, % without cavitated caries in primary and permanent dentition. Iheozor-Ejiofor *et al.* found that CWF was effective at reducing levels of cavitated dental caries among children [41,56] as did we. In 2015, Iheozor-Ejiofor *et al.* found the introduction of CWF resulted in children 1.81 fewer dmft (95% CI: 1.31–2.31) than in a fluoride-deficient area, and 1.16 fewer DMFT (95% CI: 0.72–1.61 than in a fluoride-deficient area). Iheozor-Ejiofor *et al.* had limited confidence in the size of this effect due to the high risk of bias within the included studies and the lack of contemporary evidence. They also found that CWF led to a 15% (95% CI: 11–19%) increase in the percentage of children with no cavitated caries in their primary teeth and a 14% (95% CI: 5–23%) increase in the percentage of children with no cavitated caries in their permanent teeth [41] as did we. In 2024, Iheozor-Ejiofor *et al.* analysed studies taking account of year of conduct before 1975 and after 1975 [56].

Iheozor-Ejiofor *et al.* reported dmft results for two studies conducted after 1975, one in Australia published in 2015 and one in England published in 2022, and the authors calculated the change in mean dmft for the two post 1975 studies from baseline to follow-up for the fluoridated and the non-fluoridated/low-fluoridated groups and reported that the mean dmft decreased over time (baseline to follow-up) in both groups. Iheozor-Ejiofor *et al.* concluded that “the difference in the change in mean dmft between groups shows that initiation of water fluoridation may lead to a slightly greater reduction in dmft” (MD 0.24, 95% CI -0.03 to 0.52; P = 0.09, I^2 = 26%; 2 studies, 2,908 participants; low-certainty evidence) p23[56].

Iheozor-Ejiofor *et al.* reported DMFT results for four studies conducted after 1975, one in Australia published in 2015, one in Canada published in 1987, and two in England published in 1982 and 2022, and the authors calculated the change in mean DMFT for the four post 1975 studies from baseline to follow-up for the fluoridated and the non-fluoridated/low-fluoridated groups. Iheozor-Ejiofor *et al.* concluded that “the change in mean DMFT between groups shows that initiation of water fluoridation may lead to a slightly greater reduction in DMFT, but the evidence is very uncertain” (MD 0.27, 95% CI -0.11 to 0.66; P = 0.16, I^2 = 83%; 4 studies, 2,856 participants; very low-certainty evidence) p24[56].

Iheozor-Ejiofor *et al.* reported DMFS results for one study conducted after 1975 in England published in 1982, and the authors calculated the change in mean DMFS for the study from baseline to follow-up for the fluoridated and the non-fluoridated/low-fluoridated groups. A smaller caries increment was observed for the water fluoridation group (6.73) than for the control group (9.19). Iheozor-Ejiofor *et al.* concluded that “initiation of community water fluoridation may lead to a lower DMFS increment, but the evidence is very uncertain” p24 (MD 2.46, 95% CI 1.11 to 3.81; 1 study, 343 participants; very low-certainty evidence) [56].

Iheozor-Ejiofor *et al.* reported change in the proportion of caries-free for study participants with primary dentition for two studies conducted after 1975, one in Australia published in 2015 and one in England published in 2022, and the authors noted that the proportion of caries-free children increased over time in both the fluoridated and non-fluoridated/low-fluoridated groups. Iheozor-Ejiofor *et al.* concluded that “these pooled summary estimates, the difference in the change in the proportion of caries-free children between groups shows that the initiation of water fluoridation may lead to a slightly greater increase in the proportion of caries-free children (MD -0.04, 95% CI -0.09 to 0.01; P = 0.12, I^2 = 0%; 2 studies, 2,908 participants; low-certainty evidence). This absolute increase of 0.04 in the proportion of caries-free children in fluoridated areas may be considered a small but important effect” [56].

Iheozor-Ejiofor *et al.* reported change in the proportion of caries-free for study participants with permanent dentition for two studies conducted after 1975, one in Australia published in 2015 and one in England published in 2022, and the authors concluded that “the difference in the change in the proportion of caries-free children between groups shows that the initiation of water fluoridation may increase the proportion of caries-free children, but the applicability of the evidence to a contemporary setting is very uncertain” (MD -0.06, 95% CI -0.14 to 0.02; P = 0.13, I^2 = 93%; 4 studies, 6,219 participants; very low-certainty evidence) p26[56].

Iheozor-Ejiofor *et al.* studies come from countries with both fluoride toothpaste and general dental services are affordable to and accessible for children in Australia (allowed up to AUD 1,095 over two consecutive calendar years) [207], Canada (free or small out of pocket payment if your net annual income is less than CAD 90,000 and you have no dental insurance) [208] and the UK (free) [209], and these two interventions also help prevent against caries, whereas in Ireland, free dental services are only available through a limited number of HSE dental clinics which are usually accessed in a dental emergency or school service referrals[210].

Sharma *et al.* (2023) completed a review of all children's dental health studies in Ireland, including national-, regional-, and county-level studies conducted from 1950 to 2021 [211]. Sharma *et al.* describe trends in dental caries prevalence and compare the dental caries experience of children living in areas with and without CWF in Ireland. The outcomes of interest were dental caries measured using dmft/dmfs for primary teeth or DMFT/DMFS for permanent teeth; decayed or filled primary teeth (surfaces) (dft(s)) and decayed or filled permanent teeth (surfaces) (DFT(S)); dt(s)/DT(S); and the percentage of children with (cavitated-)caries-free dentition (or dmft/DMFT=0). The study designs of interest were prospective or retrospective longitudinal cohort studies, case-control studies, and cross-sectional surveys. Sharma *et al.* searched seven databases (Embase, Ovid MEDLINE, PubMed, the Cochrane Library, Web of Science, Scopus, and Lenus: The Irish Health Repository) using search strategies that included relevant terms for dental health surveys; dental diseases, including dental caries and other conditions; children; and the Republic of Ireland. The search was followed by searches of the reference lists of included studies. Studies evaluating the caries experience of children living in Ireland were eligible for inclusion, and two authors completed two-stage screening in order to identify eligible studies. Two authors extracted the data into the Joanna Briggs Institute's standardised data extraction form and independently evaluated the quality of included studies using the Joanna Briggs Institute Critical Appraisal Checklist for Studies Reporting Prevalence Data [212]. After removing 1,840 duplicates, a total of 3,226 titles and abstracts were screened using the predefined eligibility criteria. Sixty-nine studies were identified for full-text review, and of these, 31 studies were included in Sharma *et al.*'s systematic review. The age groups of children examined varied among the national surveys conducted between 1952 and 1983, while the age groups of children have been the same in all national surveys conducted since 1984. CWF and fluoride-deficient comparison data were only available from 1984 onwards. The national mean dmft score for children aged 5 years has decreased, from 5.66 (±5.59) in 1960 (before CWF) to 1.00 in CWF areas and 1.70 in fluoride-deficient areas in 2002. The national mean DMFT score has also decreased, from 4.77 (±4.14) in 1960 (before CWF) to 1.20 in CWF areas and 1.40 in fluoride-deficient areas in 2002. The percentage of caries-free children aged 5 years has increased, from 17% in 1960 to 63% in CWF areas and 45% in fluoride-deficient areas in 2002, as has the percentage of caries-free children aged 12 years, from 6% in 1960 to 46% in CWF areas and 38% in fluoride-deficient areas in 2002. A similar pattern of decreases in dmft, DMFT, and percentage of participants who are (cavitated-)caries-free was observed at regional and county level and in 8- and 15-year-old children. The decline in the incidence of dental caries observed throughout the country was greater in children living in areas with CWF. Between 1960 and 2002, the mean dmft scores for 5-year-old children living in Ireland were reduced by 82% and 69% for the fluoridated and fluoride-deficient groups, respectively, and the mean DMFT scores for 12-year-olds reduced by 75% and 71% for the fluoridated and fluoride-deficient groups, respectively. The international research results from our systematic review support Sharma *et al.*'s Ireland-based systematic review. However, these results and results from Cochrane and our systematic reviews should be interpreted in the context of the widespread use of fluoride toothpaste in Ireland since 1975 and the halo effect of fluoridation.

The Office of the Prime Minister's Chief Science Advisor in New Zealand supports our summary findings. It states that adding fluoride to water continues to have a positive impact by reducing the incidence of dental caries in New Zealand [213].

The 'halo effect' of water fluoridation occurs when residents of fluoride-deficient or fluoride-free communities are exposed to some of the benefits of CWF by consuming water in places of work, education, or daycare that receive fluoridated water [214]. In addition, beverages that are manufactured and processed in communities with CWF are consumed by residents of fluoride-deficient or fluoride-free communities [214]. Higher coverage of CWF increases the impact of the halo effect, as there is more opportunity for those living in fluoride-deficient communities to be exposed to CWF. Griffin *et al.* quantified the wider benefits of CWF in the USA by examining the differences in tooth decay rates in 12-year-old children who lived in states where at least 50% of the communities had CWF and compared their experience of tooth decay with that of children who lived in states where less than 25% of the communities had CWF [215]. The study found that the children residing in the higher fluoridated states experienced less tooth decay each year than children who lived in states where water fluoridation was less common. For example, a 12-year-old child who lives in a fluoride-deficient community in a state where at least 50% of the communities have CWF would typically have one fewer cavity each year than a child living in a state where less than 25% of the communities have CWF [215]. In the USA, due to the halo effect, CWF reduces the prevalence of dental decay from 50% to 18–40% [216]. The halo effect is likely to be fairly effective in Ireland and should be considered when interpreting differences between caries data from CWF and fluoride-deficient areas in Ireland. The halo effect is one of the factors that reduces differences in the proportion of the population without cavitated caries in fluoride-deficient communities compared with CWF communities. Other effective fluoride interventions to prevent caries include topical fluoride products, the most common being fluoride toothpaste. The halo effect may contribute to increasing the proportion of people with very mild and mild dental fluorosis (or non-problematic dental fluorosis).

4.2.2.3 Adult population

Iheozor-Ejiofor *et al.* did not report any research on the benefits of CWF for adults [41], whereas the HRB included a handful of studies including adults. We recognise that the benefits of CWF continue into adulthood, but existing CWF evaluations mainly include schoolchildren. In 2007, Griffin *et al.* published a systematic review on the effectiveness of fluoride in preventing dental caries in adults [217]. According to the nine studies which satisfied their inclusion criteria, CWF significantly reduced caries experience ($p<0.001$): from the results of the five included studies that were published between 1979 and 2007, the prevented fraction was 27% (95% CI: 19–34%). Four research studies (set in Australia) that have been published since 2007 have supported Griffin *et al.*'s conclusions. Mahoney *et al.* (2008) [218] examined whether exposure to fluoride in drinking water was associated with caries experience in a cross-sectional survey of 876 serving army personnel aged 17–56 years in Australia [218]. The percentage of lifetime exposure to fluoridated drinking water for each participant was assessed using residential locations recorded each year for the period 1964–2003. Participants were classified into one of four categories of percentage of lifetime living in areas with fluoridated water: <10%, 10–49%, 50–89%, and ≥90%. After adjustment for age, sex, years of service, and rank, mean DMFT was 24% lower among people with ≥50% exposure to fluoridated water compared with the <10% exposure group [218]. Hopcraft *et al.* (2008) reported that army recruits in Australia with lifetime exposure to fluoridated drinking water had a mean DMFT of 3.02 while recruits with no exposure had a mean DMFT of 3.87, and concluded that recruits with lifetime exposure to fluoridated drinking water had 25% less caries experience (after adjusting for the effects of age, sex, education, and socioeconomic status) compared with recruits who had no exposure to fluoridated drinking water [219]. Slade *et al.* (2013) estimated the effects of exposure to fluoridated drinking water on dental caries in adults in Australia by comparing a pre-fluoridation cohort born before 1960 (n=2,270; no CWF exposure) with a fluoride-exposed cohort born between 1960 and 1990 (n=1,509), and found that the 1960–1990 cohort had 10–11% fewer DMFT compared with the pre-1960 cohort (p<0.0001) [220]. Crocombe *et al.* (2015) examined whether the level of lifetime CWF exposure was associated with lower dental caries experience in younger adults aged 15–46 years residing outside Australia's capital cities and who were born between 1960 and 1990 [221]. Residential history questionnaires were used in order to determine each person's percentage of lifetime exposure to fluoridated water. Crocombe *et al.* reported that a higher percentage of lifetime exposure to water fluoridation was associated with a lower mean DMFT (−2.45; p<0.01) and a lower mean number of filled teeth (−2.52; p<0.01) after controlling for the effect of other covariates on the outcome [221].

4.2.2.4 Socioeconomic situation

The HRB did not examine the outcome socio-economic status in our evidence review where as Iheozor-Ejiofor *et al.* reported insufficient information as to whether CWF reduces differences in dental caries levels between children from deprived and affluent backgrounds in the studies that they included [41,56]; Ejiofor *et al.* identified four studies reporting data according to socioeconomic status, and reported that only one of the four presented usable unbiased data, and this study [58] found no evidence that deprivation influenced the relationship between water exposure and caries status (as measured by dmft/DMFT counts or proportion of caries-free participants). Like us, Ejiofor *et al.* agree a separate systematic review would be required in order to test this theory in a transparent manner. McDonagh *et al.* (2000) stated that there appears to be some evidence that CWF reduces inequalities in dental health across social classes in 5- and 12-year-old children using the dmft/DMFT measure [57]. Six out of seven studies conducted in CWF and comparator areas of the UK [66,115,222–226] have shown differences in child caries incidence between areas of high and low deprivation, including comparisons between fluoridated and non-fluoridated populations, suggesting that CWF may reduce inequalities in health relating to dental caries by reducing the social gradient effect [57]. Public Health England (now the UK Health Security Agency and the Office for Health Improvement and Disparities) analysed national data in England in 2014 and suggested that the effect of CWF is greatest within the most deprived communities [42]. Cho *et al.* (2014) assessed the prevalence of dental caries in 11-year-old children related to water fluoridation and family affluence scale as an indicator of socioeconomic status in South Korea, and concluded that CWF could not only lead to a lower prevalence of dental caries, but could also help to reduce the effect of socioeconomic status on inequalities on dental health [227]; Kim *et al.* (2017) confirmed this finding in South Korea in a subsequent paper [228]. In Australia, Spencer *et al.* (2018) examined associations between lifetime exposure to fluoridated water (based on the percentage of an individual's lifetime spent living in a CWF area) and childhood caries (based on dental examination) using data from a national child oral health survey of 24,664 children aged 5–14 conducted in 2012–2014 [229]. Two caries measures were employed: percentage of caries (cavitated or not), measured as dmfs/DMFS >0; and average experience of caries in the population, measured as dmfs/DMFS. The authors found that caries prevalence and experience were higher among 5–8-year-old children who had lower lifetime exposure to CWF (46.9% with caries; a mean of 4.27 surfaces affected) than among those with 100% lifetime exposure to CWF (31.5% with caries; a mean of 1.98 surfaces affected), and among the 9–14-year-old children who had lower lifetime exposure to CWF (37.0% with caries; a mean of 1.34 surfaces affected) than among those with 100% lifetime exposure to CWF (25.0% with caries; a mean of 0.67 surfaces affected). The multivariate models for caries prevalence and caries experience for the primary dentition of 5–8-year-old children found that those with no or less than 50% lifetime exposure to CWF had significantly higher prevalence and experience of dental caries after adjusting for the other covariates. Socioeconomic covariates (high deprivation, parents born outside Australia, low education, and low income) were also significantly associated with the prevalence and experience of dental caries in the primary dentition [229]. Do *et al.* (2018) completed further analysis using the same data and found that CWF was associated with lower caries experience and reduced inequality among children [230]. The Office of the Prime Minister's Chief Science Advisor in New Zealand reported that CWF is particularly important in reducing socioeconomic dental health inequities [213].

4.2.2.5 Wider benefits of CWF

The positive effect of CWF is generally demonstrated by a change in dmft/DMFT, dmfs/DMFS, a reduction in the incidence of (cavitated) caries, or an increase in the proportion of the population without cavitated caries. Rugg-Gunn *et al.* (2016) reported that CWF has wider dental effects, including reductions in non-cavitated caries, edentulousness (toothlessness), dental pain, dental abscesses, prescription of antibiotics, dental treatment for children under general anaesthetics, and admissions to hospital [231]. They also found that CWF reduces costs of dental treatment to the individual and community. Finally, CWF mediates the effect of social deprivation on dental caries as mentioned in Section 4.2.2.5. Rugg-Gunn *et al*. conclude that the positive effects of CWF on dental health extend into the adult years [231].

4.2.2.6 Outcomes of CWF cessation

Iheozor-Ejiofor *et al.* reported that they found insufficient information about the effects of stopping CWF [41]. However, McDonagh *et al.* concluded in their 2000 paper that the available evidence from studies following cessation of CWF indicated that caries prevalence increased, approaching the level of the fluoride-deficient group in 12 of the 20 papers retrieved [57]. Only two studies (six papers), from Finland and Canada, indicated that not all negative dental caries outcomes increased after discontinuing CWF [57]. The Australian National Health and Medical Research Council's (NHMRC's) 2008 review concurred with McDonagh *et al.*'s conclusions [59]. Only one additional relevant paper was identified in the NHMRC's review [150], which found no difference with respect to caries outcomes following the discontinuation of CWF in Finland. According to the NHMRC's report, the Finnish authors of that paper suggested that this may have been the result of a concurrent policy change in Finland which aimed to specifically target caries-preventive measures to children and adolescents based on individual needs [59]. We found one additional study (two papers) by McLaren *et al.* [94,138] that was not included in the McDonagh *et al.* or NHMRC reviews, and this study supports the finding that caries prevalence increased approaching the level of the fluoride-deficient group following CWF cessation.

4.2.2.7 Dental fluorosis

In 2015 Iheozor-Ejiofor *et al.* reported that around 73% of dental fluorosis studies were conducted in places with naturally occurring fluoride in their water, and that some had fluoride levels of up to 5 ppm [41]. In addition, Iheozor-Ejiofor *et al.* reported that the studies of naturally occurring fluoride did not have controlled doses of fluoride and that doses could be several times higher than doses experienced in areas using CWF [41]. Iheozor-Ejiofor *et al.* reported that their results from the studies on dental fluorosis suggest that, where the fluoride level in water is 0.7 ppm, the prevalence of dental fluorosis was 40% (95% CI: 35–44%) and estimated that there is a chance of around 12% (95% CI: 8–17%) of people having dental fluorosis that may cause aesthetic concern; however, they had limited confidence in the size of this effect due to the high risk of bias and substantial between-study variation [41]; these data were not updates in the 2024 systematic review. Iheozor-Ejiofor *et al.* did not define 'aesthetic concern to the patient'; however, they reported using the systematic review approach of McDonagh *et al.*, who reported that the definition of the number of people who have dental fluorosis that may cause 'aesthetic concern to the patient' was taken from a UK survey of 12-year-old children and corresponded to a TSIF score of 2 or more, a Thylstrup and Fejerskov Index score of 3 or more, or a Dean's Index of Fluorosis classification of mild or worse [57]. We note that although Iheozor-Ejiofor *et al.* calculated an overall prevalence of very mild to severe dental fluorosis with 95% CIs and an overall prevalence of dental fluorosis that may cause 'aesthetic concern to the patient' [41], we are not sure of the reliability of these calculations. Our review of the existing dental fluorosis surveys in CWF areas indicated that only 4 of the 26 studies had 95% CIs around their prevalence estimates, and given that the surveys were based on a cluster sample design requiring design effect calculations and few studies presented the design effect factor employed, it would be impossible to calculate accurate variance including CI estimates. In addition, our review of dental fluorosis prevalence by dental fluorosis index used indicated no real pattern of fluorosis within indices. It seems that dental fluorosis is difficult to diagnose, and the level of agreement between assessors indicates that misdiagnoses are common even among well-trained dental professionals. We identified that the prevalence of dental fluorosis in permanent teeth of 10–15-year-old children living in CWF areas, using Dean's Index of Fluorosis, ranged from 1.3% to 47.7%. The prevalence of dental fluorosis in permanent teeth of schoolchildren and young people living in CWF areas, using the Tooth Surface Index of Fluorosis, ranged from 18.3% to 69.2%, and was similar among schoolchildren using the Thylstrup and Fejerskov Index (ranging from 13.3% to 69.6%). The vast majority of cases had very mild or mild fluorosis. In Brazil, the prevalence of both moderate and severe dental fluorosis in children living in CWF areas was 18.0% (no severe cases), compared with 9% in Canada and 3% in England. As already stated, the prevalence of dental fluorosis is likely linked to other geographical, dietary and dental care factors. The Office of the Prime Minister's Chief Science Advisor in New Zealand supports our summary findings on fluorosis. The office states that excessive fluoride intake can cause dental fluorosis. However, at the levels used for water fluoridation in New Zealand, this is generally mild (i.e. of no health concern and little-to-no cosmetic concern) [213].

4.3 Strengths and limitations

The methodology employed for the searches for Questions 1, 2A, and 2B was carefully considered, with the intention of capturing all relevant studies that would best answer these three systematic review questions for use by policy-makers and service planners in Ireland. The principal strength of these searches is that they were expert, peer-reviewed, comprehensive searches, they were conducted across a range of highly regarded databases and sources, and they employed best practice methods, all of which strengthens the validity of the search results. Staging the searches in order to meet the process of the review – scoping, conducting the main database searches, conducting the supplementary and grey literature searches, conducting the reference and citation chasing searches, and conducting the final date-specific database searches – provided a full indication of available evidence.

Regarding the limitations of the searches for Questions 1, 2A, and 2B, only English-language studies were considered for full-text inclusion. As the topic includes confounding language (e.g. multiple types of fluorine/fluoride), the use of a simple translator (e.g. Google Translate) risked mistranslating technical phrases and details. Neither time nor resources would allow the recruitment of a professional translator. However, in the interest of transparency, we present tables of potential studies that were excluded on language (see Appendix C of Sections 6 (Subsection 6.3.5), 7 (Subsection 7.3.5), and 8 (Subsection 8.3.4)).

Studies of areas with natural water fluoridation within the recommended range were excluded from this review. The main reason for this is that areas with water fluoride concentration levels exceeding the 1.5 ppm, the World Health Organization (WHO) guideline level, may also have other toxic materials (e.g. heavy metals such as arsenic and lead) in the water, and so the effect of naturally occurring fluoride cannot be assessed in isolation. In addition, there is a well-accepted dose response between fluoride intake and the likelihood of developing dental and/or skeletal fluorosis in high-fluoride endemic areas. Finally, exposure to natural fluoride is not a useful reference point for policy decisions being taken in

Ireland. While this has led to the loss of some data, it has allowed for a much more specific and more appropriate analysis with a tightly defined exposure.

We have limited data on adults in our review findings, but we have addressed the advantages of CWF for this population in our discussion. We did not intend to address socioeconomic gradient in this review but acknowledge that it is a major advantage of CWF, and we have highlighted the findings of other studies on this important topic in our discussion.

We have overcome two major limitations of the Iheozor-Ejiofor *et al.* review which were highlighted by Rugg-Gunn *et al.* in 2016 [231]. First, we included single cross-sectional surveys of dental caries and fluorosis in CWF and fluoride-deficient communities, and we restricted the study eligibility for dental fluorosis studies to include cross-sectional, case-control, and prospective or retrospective cohort studies of artificial CWF only, as these cover the water fluoridation intervention that is of interest to the Irish Department of Health. Second, we only included dental fluorosis data from the three most commonly used indices: Dean's Index of Fluorosis [9], the Thylstrup and Fejerskov Index (developed in 1978) [34], and the TSIF (developed by Horowitz *et al.* in 1984) [36] . We excluded all other indices used in dental fluorosis studies, as they are not specific to dental fluorosis.

A large number of our included studies did not calculate variance (standard deviations or 95% CIs) for their outcomes of interest, and we could not calculate the missing variance data retrospectively, as the included study designs were based on cluster samples and the design effect was not known.

Iheozor-Ejiofor *et al.* assessed each study for the quality of the methods used and how thoroughly the results were reported [41]. They had concerns about the methods used, or the reporting of the results, in the vast majority (97%) of their included studies. For example, Iheozor-Ejiofor *et al.* reported that many of their included studies did not take full account of all the factors that could affect children's risk of dental caries or dental fluorosis. The authors went on to say that there was substantial variation between the results of the studies, many of which took place before the widespread introduction of fluoride toothpaste (circa 1975). This makes it difficult to be confident in the size of the effect of CWF on dental caries or the number of people likely to develop dental fluorosis at different levels of fluoride in the water [41]. We concur with Iheozor-Ejiofor *et al.* on these points.

The dental caries studies used to answer Question 1 were a mix of prospective cohort studies (n= 4) and cross-sectional surveys (n=51) (see Section 3.1.2). CWF in these studies was examined as an exposure rather than an intervention. Therefore, we used the National Heart, Lung, and Blood Institute (NHLBI) to assess the quality of the observational studies included in our review. We did this because there was a tool for cohort and cross-sectional studies and a separate tool for case-control studies. As stated in the methods, the rationale for choosing the five items was based on essential criteria for high-quality longitudinal cohort studies, cross-sectional surveys, and case-control studies as per *Epidemiology in Medicine*. [72]. For longitudinal cohort studies and cross-sectional surveys, five items from the respective NHLBI's tool were selected and scored as outlined in Table 7, and for case-control studies five items were chosen from the specific case-control studies tool and scored as outlined in Table 8. The items chosen identified the aspects of studies that were most likely to introduce bias to the results through unrepresentative sampling (proxy for effect of assignment or exposure), sample size (proxy for ability to detect true differences in outcomes), loss to follow-up (proxy for missing outcome data and proxy for complete reporting of outcomes and experiences), and confounding (proxy for randomisation). The five criteria were chosen to mimic risk of bias. With respect to the scoring system, any study scoring below 5 is at high or unclear risk of bias using standards applied to intervention studies. On the other hand, observational studies have inherent biases due to self-selection, recall, and confounding that are very difficult to control for, and holding such study designs to the same quality standards as intervention studies makes risk/quality assessment a futile exercise as it could be assumed at the start of the systematic review that all would be at high risk of bias. The exact scoring system is explained in Section 2.8. For each paper reporting on a longitudinal cohort study, cross-sectional survey, or case-control study, the scores were summed (for a total score ranging from 0.0 to 5.0). Papers scoring less than 3.0 were rated 'low quality', papers scoring 3.0 were rated 'moderate quality', and papers scoring 3.5 or more were rated 'high quality'. As many studies were cross-sectional in nature (point-in-time surveys) and scored 0.0 on item 13 (loss to follow-up not applicable), the maximum possible score for papers reporting on these types of studies was effectively capped at 4.0; for this reason, the threshold for 'high quality' was set at 3.5, rather than 4.0, in order to allow more effective differentiation of papers at the upper end of the range of scores. We did consider the ROBINS I tool but this was designed for interventional longitudinal prospective studies (non-randomised trials) rather than point in time (or cross-sectional studies). Most of our studies were cross-sectional studies and so did not follow the same people overtime. Where cross-sectional studies were repeated overtime, they used the same or similar methods to examine a similar population usually between 1 and 10 years after the introduction of CWF. The essential (quality) criteria that we selected were those that would lead to internal bias, so it is a similar as possible to ROBINS I but more appropriate for the study design (in particular, cross-sectional design). As most of our studies were cross-sectional, they received a not applicable for loss to follow-up which was treated like a zero and therefore the included moderate quality cross-sectional studies were missing one or less essential criteria. We have included all studies with lifetime exposure in our narrative synthesis and used the moderate- and high-quality studies in our meta-analysis. Of course, it should be noted that all observational studies have biases with respect to confounding regardless of what quality assessment tools are employed. Therefore, all observational studies have selection biases, and such studies could never be classified as low risk of bias. In fact all studies would be at high-risk of bias based on ROBINS I so we could not discriminate the better conducted surveys from the really low-quality or untrustworthy surveys that followed WHO best practice. Before completing meta-analysis, we completed a feasibility assessment to ensure it was safe to pool the low-, moderate- and high-quality studies (Section 4.3). There are two schools of thought on meta-analysis, one is to include the better quality studies, and the other is to include all studies and remove them during sensitivity analysis. Both have advantages and disadvantages. Following statistical advice, we decided to use the latter and this decision leads to wider confidence intervals and may overestimate of the benefits of CWF. However, we attempted to control for the overestimates by excluding from the meta-analysis studies that were statistical outliers; the majority of studies that were statistical outliers were judged to be low quality.

Though not always successfully, we did attempt to isolate the independent contribution of CWF, fluoride toothpaste, and other topical fluorides to dental caries and dental fluorosis when answering our research questions. In addition, we addressed the different levels of CWF and the introduction of fluoride toothpaste in our subgroup analysis, where feasible. Finally, we examined each study for five groups of confounding variables obtained from scoping the literature and validated during extraction (demographic, socioeconomic, nutrition, other sources of dental fluoride, and access to and affordability of dental services). However, we did not examine the studies specifically for oral hygiene education as a confounder which may be a gap in our findings.

A strength of this review is that it provides data on the benefits of CWF alone and in combination with fluoride toothpaste, as well as on the most common negative dental health effect of CWF: dental fluorosis. In addition, it presents practical, real-world information on current national guidelines for the use of fluoridated dental products in children aged under 6 years living in CWF areas. However, the seven case countries selected by the Department of Health for review of guidelines is not representative of guidelines in all countries with CWF and this may represent a bias towards Anglophone countries.

4.4 Future research

The quality of the planning, conduct, and reporting of research in public health dentistry requires improvement, specifically with regard to CWF. We excluded numerous studies during full-text screening because they did not describe the concentration of fluoride in the intervention and/or comparison groups, and/or they did not specify whether the fluoride in the water was naturally occurring or artificially added, although we are sure that all authors had this information to hand and it would thus have been very easy to provide (see Appendix C of Section 6: Subsections 6.3.2 and 6.3.3). It was often difficult to work out which papers were linked to each other and were part of the same study, so it would have been very useful if the authors had referenced all the previously published linked papers in the methods of the newer papers (where applicable), as this would have provided us (and other authors) with the certainty that we had complete data. The reported study design employed was sometimes incorrect or not provided, which is a basic requirement of all research papers. Most of the studies we identified were cross-sectional survey series, as they included schoolchildren of the same age every few years. The accuracy of dental caries and dental fluorosis diagnoses had a moderate proportion of error, which is strange, considering that dental caries are a very common diagnosis in everyday primary care dentistry. It appears from our review that dental fluorosis diagnosis and grading is very difficult to complete consistently, as the prevalence of dental fluorosis was quite variable across different studies. Many studies did not report how they calculated their sample size or how they adjusted their sample to take account of design effect associated with cluster sampling, which is a key requirement for generalising the results to the complete population from which the sample was taken, which in turn is the main objective of a prevalence survey. In addition, many authors did not report whether they took account of design effect when calculating the variance around the key outcome measures, which may overestimate the number of statistically significant findings. These aforementioned deficits forced us to exclude many studies from our analyses. The status of participants with regard to lifetime exposure to CWF was not provided in some studies, and again we were limited in how we could use study results from studies that did not classify their study population by percentage of lifetime exposure. We identified five groups of confounding factors (demographic factors, socioeconomic factors, nutritional factors, other sources of dental fluoride, and access to and affordability of dental services) from reviewing existing research which need to be assessed in all future fluoride studies or surveillance-based evaluations in order to adjust the prevalence of each outcome as well as to identify the independent contribution of each factor. Many of the logistic regression tables in the findings sections of the primary papers did not report the number of events with the confounding factor of interest in the exposed population or the number of events with the confounding factor of interest in the unexposed population for each confounding factor, which limits the use of these analyses in systematic reviews. These issues should be addressed in any new CWF evaluations.

It is recognised that oral diseases can have varying impacts on people and their well-being and quality of life. Dental diseases cause pain and discomfort; affect proper physical functions like chewing, talking, and smiling; and can influence an individual's social roles. We did not identify any studies examining the relationship between oral-health-related quality of life with dental caries and fluorosis, and we suggest that this outcome is measured in future studies to determine if there is a relationship.

There is a need to update the systematic review of the effects of CWF on adults completed by Griffin *et al*. in 2007 [217]. In addition, a systematic review examining the relationship between socioeconomic status and the effects of community water fluoridation would be very useful. Finally, we need a systematic review to examine the association between infant formula and CWF and dental fluorosis.

4.5 Policy implications

The evidence provided in this evidence review suggests no reasons to discontinue CWF in Ireland. Overall, CWF has a positive effect on reducing caries in teeth. For example, the national mean dmft score for children aged 5 years has decreased from 5.66 (±5.59) in 1960 (before CWF) to 1.00 in CWF areas and 1.70 in fluoride-deficient areas in 2002. The national mean DMFT score has also decreased, from 4.77 (±4.14) in 1960 (before CWF) to 1.20 in CWF areas and 1.40 in fluoride-deficient areas in 2002. The percentage of (non-cavitated) caries-free children aged 5 years has increased, from 17% in 1960 to 63% in CWF areas and 45% in fluoride-deficient areas in 2002, as has the percentage of (non-cavitated) caries-free children aged 12 years, from 6% in 1960 to 46% in CWF areas and 38% in fluoride-deficient areas in 2002. In addition, in 2017, the prevalence of moderate fluorosis in Ireland was under 1.0%, and there were no cases of severe dental fluorosis in CWF areas.

In Ireland, there is a small beneficial difference between dental outcomes for populations living in CWF areas compared with those living in fluoride-deficient areas. Policy-makers in Ireland will need to consider whether additional interventions are required for fluoride-deficient areas in order to address the differences between the CWF and fluoride-deficient areas.

The introduction of CWF requires legislation, the installation and maintenance of equipment, the technical training of water treatment plant operators, the development of and adherence to procedures and processes, and continuity of supply and regular monitoring. It also requires that obsolete plant equipment be replaced on a continuous basis. Many of the early evaluations of the effectiveness of CWF were repeated cross-sectional surveys in schools, clinics, and daycare centres, in both new CWF and fluoride-deficient comparator communities, and the sample population was usually lifetime residents of the respective areas. In the future, CWF needs to be evaluated using contemporary methods which are appropriate for evaluating complex public health interventions (including continuous surveillance), and future systematic reviews need to take this into account. Ireland needs to upgrade its surveillance of the addition of fluoride to drinking water, the incidence and prevalence of dental caries and dental fluorosis in CWF and fluoride-deficient areas, and the incidence and prevalence of the potential systemic health effects of CWF. The surveillance system needs to be sophisticated enough to detect and monitor dental caries and dental fluorosis while reassuring the public that the dose of fluoride is monitored on a continuous basis and is safe. Any over- or underdoses must be addressed within an acceptable period of time and the public informed of such instances. Ireland needs to harness existing national and international cohort studies in order to monitor the potential systemic health effects of fluoride (including endocrine and neurological conditions). The cohort studies need to be able to link individual households' water source to individuals' health outcomes.

5 Conclusion

This systematic review collates the evidence on the effect of artificial CWF on dental caries and fluorosis between 1948 and 2023 and includes mainly before and after studies (cohort or cross-sectional) and single point in time studies (cross-sectional). It also attempted to establish if there is a dose response ratio for CWF with dental caries and with dental fluorosis at different CWF levels between 0.5ppm and 1.2ppm. We did not find evidence of a dose response at different CWF levels between 0.5ppm and 1.2ppm and the outcomes dental caries and dental fluorosis.

The certainty of the evidence for all dental caries outcomes and the intervention CWF is low or very low. The majority of dental caries outcomes in primary dentition indicated a reduction in cavitated caries that favoured CWF areas over the fluoride deficient areas. The findings for one outcome (dmft at two time points) were mixed. The findings for permanent dentition outcomes indicated a reduction in cavitated caries for all except one outcome and the reduction favoured the CWF areas over the fluoride deficient areas. The findings for one outcome (DMFT at two time points) were mixed.

The certainty of evidence for the prevalence of fluorosis across countries with CWF is very low. The prevalence of dental fluorosis in permanent teeth of 10–15-year-old children living in CWF areas, using Dean's Index of Fluorosis, ranged from 1.3% to 47.7%. The prevalence of dental fluorosis in permanent teeth of schoolchildren and young people living in CWF areas, using the Tooth Surface Index of Fluorosis, ranged from 18.3% to 69.2%, and was similar among schoolchildren using the Thylstrup and Fejerskov Index (ranging from 13.3% to 69.6%). The vast majority of cases had very mild or mild dental fluorosis. The prevalence of dental fluorosis increased over time in Brazil, Ireland, and the USA, and this increase was observed both in areas with and without CWF. This meta-analysis indicated that children living in CWF areas had three times higher adjusted odds of dental fluorosis than children living in fluoride-deficient areas. In Brazil, the prevalence of both moderate and severe dental fluorosis in children living in CWF areas was 18.0% (no severe cases), compared with 9% in Canada, 3% in England, and 1% in Ireland (no severe cases). The prevalence of both moderate and severe dental fluorosis was higher in CWF areas compared with fluoride-deficient areas in the four countries.

The results of five studies indicate there is very low certainty of evidence of mixed findings for the relationship between using fluoride toothpaste in a CWF area during the first 6 years of life and dental caries, with two studies reporting a protective effect and three studies reporting no relationship. Eight studies in CWF areas identified a relationship between oral hygiene practices related to the use or misuse of fluoride toothpaste commenced during the first 6 years of life and dental fluorosis, indicating low certainty evidence that there may be a relationship between exposure to fluoride toothpaste and how it is used, and the outcome of dental fluorosis in permanent teeth.

Two randomised controlled trials, based on very low-certainty evidence, reported mixed findings on fluoride varnish use on primary dentition. The certainty of evidence for no effect of topical fluoride therapies (including mouth rinses) during the first 6 years of life and the outcome of dental caries is very low. The association between the use of fluoride mouth rinses together with CWF, when children living in areas with CWF were aged under 6 years, and dental fluorosis is mixed in the four included studies and the evidence is very low certainty.

Dietary fluoride supplements are not recommended for use by the population in Australia, Canada, or Israel, while the USA does not recommend fluoride supplements in areas with optimal water fluoridation. The use of fluoride toothpaste by children with no dental caries risk is not recommended in Australia until children are at least aged 18 months, in Israel until children are at least aged 24 months, or in Canada until children are at least aged 36 months. Brazil, England, New Zealand, Scotland, and the USA recommend the use of a smear of toothpaste containing 1000 ppm fluoride twice per day once the teeth erupt. In Australia, toothpaste with 500 ppm fluoride is recommended for use by children aged 18–59 months. Brazil was the only country recommending the use of fluoride mouth rinses, and it recommends fluoride mouth rinses for high-risk children aged 3 years and over who live in fluoride-deficient areas. The guidance on the use of fluoride varnish for children aged under 6 years is country specific. All countries examined (except Brazil) recommend fluoride varnish use. The advice on fluoride gel is also country specific, with Australia not recommending it for children aged under 10 years and the USA permitting it for very young children with a high risk of dental caries.

The evidence provided in this evidence review does not provide adequate evidence to discontinue CWF in Ireland. Overall, CWF has a positive effect on reducing caries in teeth and the prevalence of moderate and severe fluorosis is low. In 2017, the prevalence of moderate dental fluorosis was under 1%, and there were no cases of severe dental fluorosis in the studies of CWF area in Ireland.

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