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National Health and Medical Research Council

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Draft Information Paper:
Effects of water fluoridation on dental
and other health outcomes

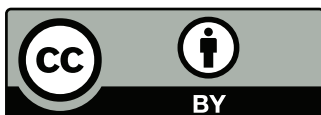
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Plain language summary

Take-home message

This Information Paper summarises an analysis of the National Health and Medical Research Council (NHMRC) review on the health effects of adding fluoride to drinking water supplies. The findings add to a long history of research that shows water fluoridation helps to reduce tooth decay in children and adults.

Fluoride occurs naturally in all Australian water supplies, but in most places the levels are too low to help reduce tooth decay. In 2013, NHMRC advised that it still strongly supports its 2007 advice that water fluoridation is safe and effective in helping to prevent tooth decay in the ranges recommended for use across Australia.^a

This current review shows that community water fluoridation within the current Australian range does not cause harm. Some people may experience a slight change in the cosmetic appearance of their teeth due to an increase in the overall intake of fluoride. This is often not readily visible but can look like white lines on the surface of the teeth (known as very mild or mild dental fluorosis). Mild and very mild fluorosis have no effect on the function of teeth.

Why is this work important?

Tooth decay is the most common health problem in Australia. It can cause pain, difficulty eating and sleeping, and may make people feel unhappy about their appearance. Tooth decay is more common in people with lower income and education levels (those from a lower socio-economic background). In addition those living in regional and remote areas and people from a lower socio-economic background may have limited access to dental services and/or may face other barriers to seeking treatment for tooth decay.

Australia mostly has very low levels of naturally occurring fluoride in its drinking water, and this is not enough to help prevent tooth decay. Therefore, Australian water authorities use chemicals under strict controls to bring fluoride levels up to a range that can help to prevent or minimise tooth decay. This has been happening across Australia for many decades. These chemicals are recommended for use in the NHMRC *Australian Drinking Water Guidelines*^b, and their management and safety are monitored by state and territory governments. These technical issues were not considered in this review.

Some regions, however, do have levels of naturally occurring fluoride which fall within the recommended range and water authorities do not need to add fluoride to the water supply.

The NHMRC develops health advice for the Australian community, doctors and governments. For more than thirty years, NHMRC has provided consistent advice on the benefits and safety of adding a small amount of fluoride to drinking water. In 2014, NHMRC commenced a new review of the research to ensure that the body of evidence that underpins its Public Statement is up to date

a *Public Statement: The Efficacy and safety of fluoridation 2007*, accessible at <https://www.nhmrc.gov.au/health-topics/health-effects-water-fluoridation>

b *The NHMRC Australian Drinking Water Guidelines (ADWG)* available at: <https://www.nhmrc.gov.au/guidelines-publications/eh52>

and relevant for the Australian community. The findings of this comprehensive review (called the 2016 NHMRC Evidence Evaluation) are summarised in this Information Paper, and can be read in full at <https://www.nhmrc.gov.au/health-topics/health-effects-water-fluoridation>.

A committee of health, dental and other experts has guided this work – the Fluoride Reference Group. Details of this committee are at <https://www.nhmrc.gov.au/health-topics/health-effects-water-fluoridation/fluoride-reference-group>. The NHMRC will consider whether its current public statement needs to be reviewed, once this information paper has been finalised.

Who will be interested in this draft Information Paper?

- People who are interested in knowing about the effects of adding fluoride to drinking water.
- Government decision makers – those involved in dental and public health policy, as well as those monitoring water quality.
- Dentists and oral health therapists.

What questions did the evidence evaluation answer?

- What is the effect on tooth decay of drinking water with fluoride in it?
- What is the effect on dental fluorosis of drinking water with fluoride in it?
- Are there any other health effects from drinking water with fluoride in it?

Which studies were included in the evidence evaluation?

In order to find out the answers to these questions, the 2016 NHMRC Evidence Evaluation updated previous reviews (2000 York^c and 2007 NHMRC reviews) by identifying and assessing new studies published between 2006 and 2015. This current review focussed on water fluoridation, tooth decay, dental fluorosis and other health effects by considering:

- the 2015 Cochrane review^d of water fluoridation, tooth decay and dental fluorosis
- additional studies from 2006-2015 on tooth decay that are relevant to Australia
- studies from 2006-2014 reporting on any health effects (other than tooth decay or dental fluorosis).

These all compared:

- a group with fluoridated water and a group without fluoridated water; or
- two groups with different levels of fluoridated water.

Comparative studies are important, as they help to determine whether any reported health outcomes might be explained by the different levels of fluoride in drinking water.

Toothpastes and some foods are another source of fluoride, and NHMRC took this into account as the evidence was reviewed and analysed.

c 2000 York review: *A Systematic Review of Public Water Fluoridation*, accessible at: <http://www.nhs.uk/conditions/fluoride/documents/crdreport18.pdf>

d 2015 Cochrane review: *Water fluoridation for the prevention of dental caries*, accessible at: http://www.cochrane.org/CD010856/ORAL_water-fluoridation-prevent-tooth-decay

Research studies can vary in quality, and this affects how much confidence we can have in the findings. Sometimes factors that affect health are different in the groups studied, such as age, income and diet. If these factors are different between the two groups being studied, they may affect the results. These are called confounding factors (or confounders).

There is more confidence in study findings when:

- the study includes large numbers of people
- there are many studies showing the same results
- the studies have taken into account confounding factors.

More emphasis is placed on study findings which are relevant to Australia (for example, they have a similar level of fluoride in drinking water, similar dental services and similar socio-economic factors like income, levels of poverty, and access to dental care).

An internationally established system (GRADE^e) was used to assess the quality of evidence provided by research studies and the strength of the conclusions presented in the information paper.

This Information Paper:

1. summarises the processes that were followed in the 2016 NHMRC Evidence Evaluation
2. presents the conclusions of the 2000 York review and the 2007 NHMRC review
3. summarises evidence on tooth decay and tooth mottling from the 2015 review conducted by the Cochrane Collaboration (referred to as the 2015 Cochrane review)
4. presents the findings of other reviews and studies on tooth decay and possible health effects examined in the 2016 NHMRC Evidence Evaluation
5. makes conclusions based on all of these reviews.

What does the evidence from the review tell us?

Tooth decay

Over sixty years of research supports the conclusion that fluoridating water helps to prevent tooth decay, by protecting against damage and helping with the repair of teeth.

All of the studies in previous reviews and in the 2016 NHMRC Evidence Evaluation found that water fluoridation reduces tooth decay by 26-44% in children, teenagers and adults.

Dental fluorosis

Dental fluorosis is a change in the cosmetic appearance of teeth, most commonly appearing as white lines on tooth surfaces. Dental fluorosis is caused by an increased intake of fluoride from multiple sources during the time when teeth are developing. Sources include toothpaste, fluoride supplements and fluoridated drinking water. Most of the dental fluorosis in Australia is very mild or mild, is not readily visible, and has no effect on the function of teeth. Research suggests that this is unlikely to be of concern to those affected.

^e *Grading of Recommendations Assessment, Development and Evaluation (GRADE)*, accessible at: <http://www.gradeworkinggroup.org/>

International studies in the review showed that fluoride in drinking water is linked to the amount and severity of fluorosis. Water fluoridation levels in the countries of these studies are much higher than in Australian drinking water, however, making it difficult to apply these results to Australia.

Other health effects

The review found that water fluoridation at levels used in Australia does not cause any negative health effects.^f

Conclusion

Water fluoridation in Australia is effective in reducing the occurrence and severity of tooth decay. Some people may experience a slight change in the cosmetic appearance of their teeth due to an increase in the overall intake of fluoride but this does not affect the function of teeth. There is no evidence that water fluoridation within the current Australian range is associated with any negative health effects.

^f The studies reported on cancer, Downs syndrome, IQ, mortality, muscle and skeletal effects (hip fracture, osteosarcoma, Ewing sarcoma, skeletal fluorosis), chronic kidney disease, heart disease and high blood pressure, kidney stones, low birth weight, muscle and skeletal effects (musculoskeletal pain, osteoporosis), thyroid function, and self-reported health outcomes (gastric discomfort, headache, insomnia)

Introduction

Purpose of this document

This Information Paper provides Australians with a summary of evidence on the health effects of the addition of fluoride to drinking water. It is based on the findings of the comprehensive 2016 NHMRC Evidence Evaluation and the input from experts on the Fluoride Reference Group.¹

What is fluoride?

Fluoride is a naturally occurring mineral found in rocks and soil, water, plants and animals. Fluoride is found in all natural waters but the amount varies depending on the region and source of water. In Australia, the amount of naturally occurring fluoride in water is mostly very low (<0.1 mg/L), with the exception being some central Australian well water supplies.^{2,3} Naturally occurring fluoride levels are much higher in water found in parts of the United States of America (USA), South America, Africa, the Middle East, China and the Indian subcontinent. Levels of fluoride greater than 3 mg/L are common⁴⁻¹⁰ and may be considerably higher in these regions.^{5,11,12}

Fluoride prevents tooth decay by protecting against damage and helping with repair. Tooth decay is very common with five out of every ten children and nine of every ten Australian adults having some decay in their teeth.¹³ This makes it the most common health problem in Australia.¹⁴ The consequences of tooth decay include infection, pain, difficulties chewing, concern about the appearance of the teeth, absence from work or school, costly dental treatment and hospitalisation for treatment of complications.¹⁵ The number of affected tooth surfaces increase over a person's lifespan. Although fluoride contributes to protection against tooth decay, too much fluoride can change the appearance of teeth by creating white lines or areas on the tooth surface, an effect known as dental fluorosis.

Water fluoridation in Australia

The intentional addition of a precise amount of fluoride to the water supply is a public health measure to benefit dental health. Fluoride was first added to the water supply in Australia over 60 years ago. Beaconsfield, Tasmania¹⁶, was the first community to receive fluoridated drinking water in 1953, followed by Yass, New South Wales (NSW), in 1956.¹⁷

In 2007, NHMRC published *A Systematic Review of the Efficacy and Safety of Fluoridation*.³ Based on this work, NHMRC issued a *Public Statement: The Efficacy and Safety of Fluoridation 2007*¹¹ recommending that

'water be fluoridated in the target range of 0.6 to 1.1 mg/L, depending on climate, to balance reduction of dental caries and occurrence of dental fluorosis'.

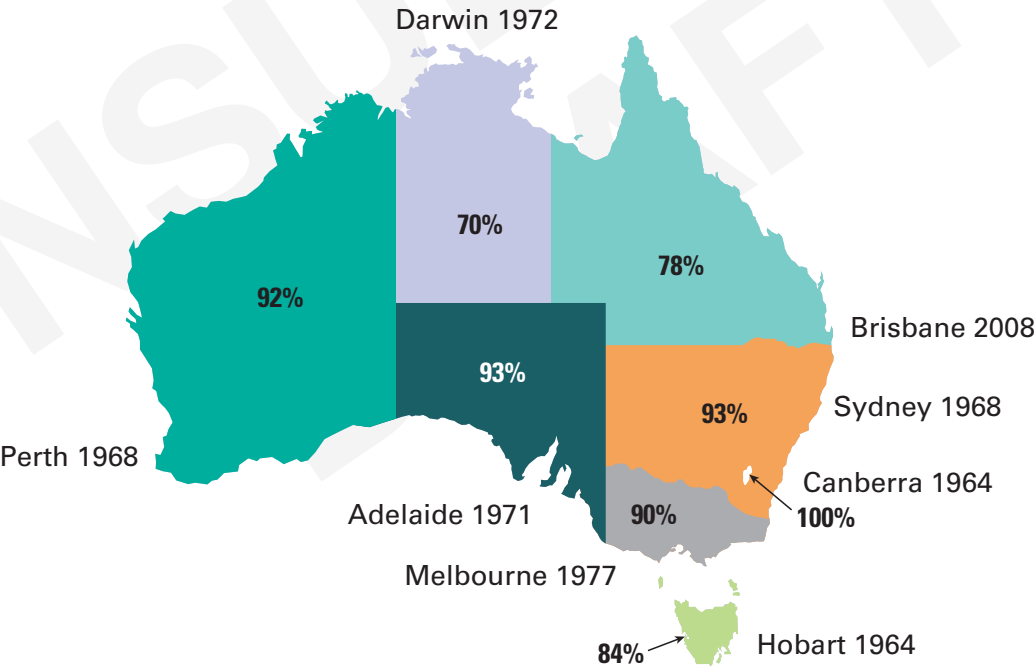
At this level, the only known adverse health effect is very mild or mild dental fluorosis, which is unlikely to cause concern to those who have it.

Although Australia mostly has very low levels of naturally occurring fluoride, some regions do have levels of naturally occurring fluoride which fall within the recommended range. In these regions, water authorities do not add fluoride to the water supply.

The addition of fluoride to the water supply is controlled by laws and government policies within each Australian state and territory, as listed in Appendix D. All Australian states and territories provide some water fluoridation; however there are variations in population coverage across Australia (see Figure 1 below).

Historically, Queensland has had much lower rates of water fluoridation than other states and territories. In 2008 the Queensland Government mandated the addition of fluoride to water supplies in the state. This legislation was amended by the government in 2012, transferring the decision to add fluoride to water from state to local council level. The coverage of water fluoridation in Queensland has decreased by about ten per cent since this time.¹⁸

Figure 1 Percentage of population with access to fluoridated water^g as at August 2016 (source: Jurisdiction communication 2016) and dates of introduction of water fluoridation to Australian capital cities (source: NHMRC 2007. *A Systematic Review of the Efficacy and Safety of Fluoridation*)



^g Fluoridated water includes naturally occurring fluoride in the water as well as artificial community water fluoridation.

Why NHMRC is conducting this work

NHMRC is responsible for ensuring that Australians receive the best available, evidence-based advice on health and on preventing, diagnosing and treating disease.

Since the 2007 NHMRC review³ new research has been published examining the relationship between fluoride levels in drinking water and possible impacts on health. Some community members have also expressed concern about the health effects from drinking water fluoridated within Australia's recommended range.

Therefore, in 2014-15, NHMRC decided to investigate recent research on the health effects of water fluoridation relevant to the Australian context. The findings of this comprehensive 2016 NHMRC Evidence Evaluation were released in 2016 and are summarised in this Information Paper.

This Information Paper does not consider the management and safety of specific chemicals that are used for water fluoridation, or monitoring of fluoride intake from other sources. A summary of the relevant government policy advice on these issues and other matters related to fluoride is provided at Appendix E.

Overview of the NHMRC process

Oversight by the Fluoride Reference Group

In May 2014, NHMRC established the Fluoride Reference Group. The Fluoride Reference Group's role was to guide a review of the evidence on the possible health effects of water fluoridation in humans and to develop this NHMRC Information Paper.

The Fluoride Reference Group members have expertise in public health, oral health, epidemiology, child health, toxicology, cancer, bone biology, neurodevelopment, Aboriginal and Torres Strait Islander health, water management and health ethics. The Fluoride Reference Group included a member of the *NHMRC Water Quality Advisory Committee*, which advises on the NHMRC's *Australian Drinking Water Guidelines 2011*, and another member with expertise in urban water and water resources management. Information on the membership and terms of reference of the Fluoride Reference Group is included in Appendix A.

The Fluoride Reference Group:

- guided the search for relevant studies on the dental effects and any other health effects of water fluoridation and the review of this evidence
- reviewed and commented on drafts of the 2016 NHMRC Evidence Evaluation
- provided scientific advice on the meaning of some of the research studies, based on members' knowledge and expertise
- helped to find additional material that was relevant in the Australian context
- considered the results of the 2016 NHMRC Evidence Evaluation along with other factors including the overall balance of benefits and harms, the likely values and preferences of the community, the effects of water fluoridation on disadvantaged Australians, the costs of tooth decay versus water fluoridation, and other ethical considerations raised by water fluoridation
- guided the development of the Information Paper
- guided the identification of key issues to be considered by the Council and CEO of NHMRC.

The Fluoride Reference Group will consider comments received during public consultation on the draft Information Paper in finalising this work.

2016 NHMRC Evidence Evaluation

In examining the possible health effects of water fluoridation in humans, NHMRC contracted the Clinical Trials Centre, University of Sydney, to conduct an independent evidence evaluation of all of the relevant scientific research on water fluoridation. The Clinical Trials Centre used internationally recognised systematic review methods to perform the evidence evaluation to the highest possible standard. This approach provided the most rigorous way for finding out the dental and health effects of adding fluoride in water.

The findings of this comprehensive independent evidence evaluation are presented in the Evidence Evaluation Report¹ and Technical Report¹⁹, which were released by NHMRC in 2016. This work is referred to in this document as the 2016 NHMRC Evidence Evaluation.

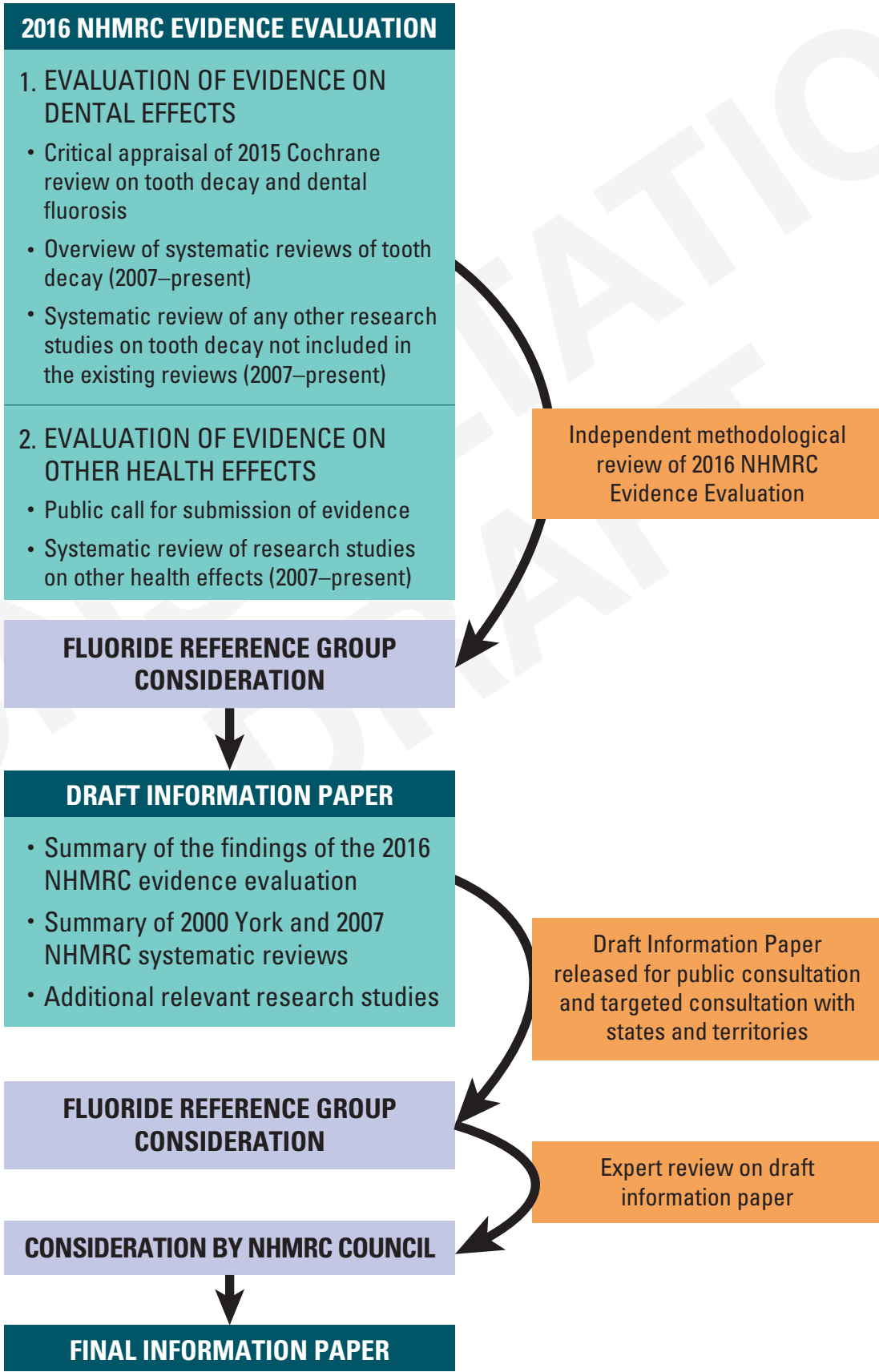
Quality assurance processes

NHMRC takes care to ensure that its health advice is of the highest possible quality. Some of the steps taken to ensure the quality of the advice include:

- all Fluoride Reference Group members are required to make a public declaration of their interests and manage any perceived or real conflicts of interest that are identified
- the methodology of the 2016 NHMRC Evidence Evaluation is reviewed by an independent body
- public consultation on the Information Paper
- further review of the Information Paper by the Fluoride Reference Group and other experts to take account of public comments.

These processes are summarised in Figure 2. More detail on the processes used to ensure the quality of the 2016 NHMRC Evidence Evaluation and development of the Information Paper is in Appendix B.

Figure 2 Overview of the 2016 NHMRC Evidence Evaluation and quality assurance processes in the development of the *NHMRC Information Paper: Effects of water fluoridation on dental and other health effects*



Evaluating the evidence

The 2016 NHMRC Evidence Evaluation¹ was designed to update the previous systematic review conducted by NHMRC in 2007.³ Similarly, the 2007 NHMRC review updated an earlier 2000 review from the United Kingdom (UK) (referred to as the 2000 York review)²⁰ by identifying new studies published since the 2000 report. Given this fairly complicated history, where the findings are reported for dental and other health outcomes in the section ‘Findings of the 2016 NHMRC Evidence Evaluation’ of the Information Paper, the findings of the two previous reviews are presented first, followed by the findings from the 2016 NHMRC Evidence Evaluation.

The 2016 NHMRC Evidence Evaluation involved several quite complex steps:

- a critical appraisal of a review published in 2015 by the Cochrane Collaboration, a global evidence-synthesis network (see www.cochrane.org), evaluating the effects of water fluoridation on tooth decay and dental fluorosis²¹
- a review of other reviews of water fluoridation and tooth decay published after 2007
- a systematic review of research studies published since October 2006 that were not already included in the existing reviews on tooth decay and water fluoridation
- a systematic review of research studies since October 2007 on any other health effects of water fluoridation.

As well as reporting on the findings of the 2000 York review, 2007 NHMRC review, and the 2016 NHMRC Evidence Evaluation as described above, this Information Paper includes information from other studies (“additional considerations”) which were considered by the Fluoride Reference Group as being important for making decisions about water fluoridation in Australia (See Figure 3).

Identification of the evidence

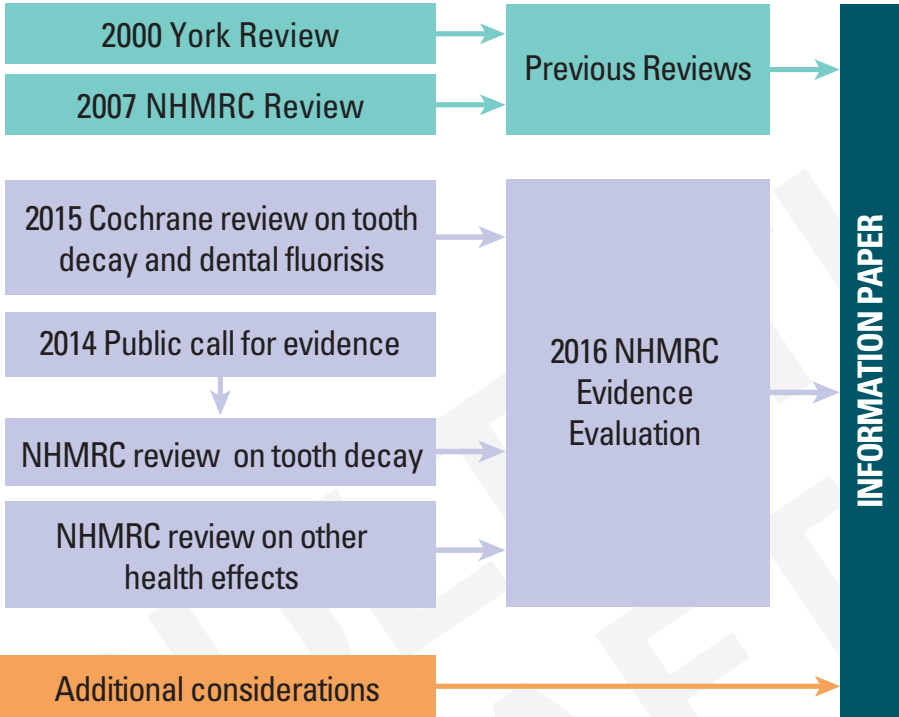
The 2016 NHMRC Evidence Evaluation identified relevant studies using standardised methods. A comprehensive search followed pre-approved review protocols and search strategies. These methods are described in detail in the 2016 NHMRC Evidence Evaluation¹ and Technical Report.¹⁹

Scientific literature that might be relevant for the 2016 NHMRC Evidence Evaluation was identified by:

- searching electronic databases for published reviews which followed a systematic approach to evaluate research studies on tooth decay
- searching electronic databases for research studies on tooth decay, other dental effects and/or health effects of water fluoridation
- searching for research studies in national and international government, health and water authority websites and the Fluoride Action Network website
- checking the reference lists of relevant systematic reviews and studies included in the report.

In July 2014, NHMRC called for public submissions of relevant published studies to be evaluated as part of the systematic review of other health effects.

Figure 3 Evidence sources that contributed to the Information Paper



Selection of the evidence

Evidence on water fluoridation and tooth decay

The 2016 NHMRC Evidence Evaluation captured evidence from a critical appraisal of a systematic review of tooth decay and dental fluorosis published by the Cochrane collaboration in 2015.²¹

The 2015 Cochrane review included only studies on tooth decay that compared the introduction or cessation of water fluoridation in a new community over a period of time with a community without water fluoridation over the same period of time. This meant that many of the recent studies conducted in Australia and other similar countries with longstanding water fluoridation programs were not considered.

An additional search was conducted in November 2015 to capture these studies that are relevant to Australia, and important for decision making.

The NHMRC review on tooth decay included scientific literature that was either:

1. a published review which followed a systematic approach to examine the effect of water fluoridation on tooth decay; or
2. a research study not included in a published review which:
 - reported on tooth decay
 - studied water fluoridation
 - compared a group exposed to non-fluoridated (defined as lower than current Australian guideline levels) water with a group exposed to water fluoridated within current Australian levels
 - included confounders in its analysis
 - was the most recent publication if it was based on information from a regular survey.

The systematic literature searches described above included evidence on water fluoridation and tooth decay published between 1 October 2006 and 12 November 2015 (the date that the searches were conducted).

Three existing reviews (Figure 6, Appendix C) and 25 research studies (Figure 7, Appendix C) were identified in this component of the 2016 NHMRC Evidence Evaluation.

Evidence on water fluoridation and dental fluorosis

The 2016 NHMRC Evidence Evaluation, which included the critical appraisal of the 2015 Cochrane review, formed the basis of NHMRC's consideration of the effects of fluoridation on dental fluorosis. The 2015 Cochrane review had broad inclusion criteria for studies on dental fluorosis. All study designs were included in this component of the review, as long as the study compared two communities with different levels of fluoride in drinking water (natural or artificial) and looked at the occurrence of dental fluorosis in these communities. The range of fluoride levels in the included studies extended well above fluoride levels recommended for water fluoridation in Australia.

Evidence on any other health effects of water fluoridation

The NHMRC review of other health effects included research studies which:

- reported on any health effects (other than tooth decay or dental fluorosis) in humans
- studied fluoride in drinking water.

These studies compared two groups exposed to different levels of fluoride:

- fluoride at a given concentration versus non-fluoridated water (defined as lower than current Australian guideline levels); or
- fluoride at a given concentration versus fluoride at a different concentration.

This systematic literature search included evidence on water fluoridation and other health effects published between 1 October 2006 and 14 October 2014 (the date that the search was conducted).

A total of 41 studies were identified on other health effects in this component of the 2016 NHMRC Evidence Evaluation (Figure 8, Appendix C).

General selection criteria

The 2016 NHMRC Evidence Evaluation included only studies where the full text was available, published in English and reported results in a form that could be used in the review (for example, the results for an outcome had to be reported for both fluoride levels being compared).

Non-systematic reviews, letters, editorials, laboratory studies, and technical reports were not included in the 2016 NHMRC Evidence Evaluation. These types of reports can raise the possibility of health effects from water fluoridation. However, only high quality research that compares different levels of fluoride in water can show whether reported health outcomes are associated with exposure to fluoridated water.

Animal studies were excluded because the 2016 NHMRC Evidence Evaluation focussed on health effects in humans only. Although animal studies might suggest mechanisms to explain how fluoride could affect health, the applicability of these studies to human health is uncertain due to biological differences between species.²² In particular, extrapolating animal study findings to humans and establishing the equivalent dose in humans is especially difficult and prone to inaccuracies.²³

Additional considerations identified by the Fluoride Reference Group

The Fluoride Reference Group recognised that, due to the rigorous systematic review processes that were adopted in the 2016 NHMRC Evidence Evaluation, some evidence relevant to Australian water fluoridation was not identified or was excluded from the review activities described above. Where this evidence was considered important for decision making, despite not being included in the 2016 NHMRC Evidence Evaluation, the Fluoride Reference Group included this evidence under the 'additional considerations' sections throughout the Information Paper.

Additional considerations were raised by Fluoride Reference Group members on the following issues:

- how water fluoridation may be able to reduce oral health inequalities
- the effect of water fluoridation in preventing hospital admissions for the treatment of tooth decay
- perceptions of dental fluorosis in today's society.

In order to be included as 'additional considerations', studies needed to be:

- based on scientific research (i.e. data that had been systematically collected and analysed)
- relevant to water fluoridation and human health
- publicly available findings, published in English, either as a full text article in a peer-reviewed journal or as an abstract from international conference proceedings.

Critical appraisal of the evidence

Critical appraisal is a process to assess the quality (strengths and weaknesses) of published research. High quality research has more valid (true) results than poor quality research. The more valid the results, the more useful they are in answering the review questions.²⁴

There are several aspects to the critical appraisal of individual research studies. The two most important questions are:

- Is the study design able to answer the research question?
- What are the key methodological features of this design?

Specific features that are important in critically appraising research on the association between water fluoridation and health effects include:

- the way in which participants were selected
- how information about the participants' exposure to water fluoridation and health outcomes was collected
- whether the study took account of possible confounding factors
- whether the study took account of likely alternative explanations for any association between water fluoridation and health outcomes
- the suitability of the statistical methods used
- the interpretation of the findings
- how applicable the study was to the Australian context
- any conflicts of interest of the authors.²⁵

Each existing review was assessed by the evidence reviewers using an established valid checklist [the AMSTAR (A Measurement Tool to Assess Systematic Reviews) tool²⁶]. The individual studies making up each review were not assessed for quality – any quality assessment made by the review authors was

accepted by the evidence reviewers.

Each individual study was assessed by the evidence reviewers against an agreed checklist.²⁷⁻²⁹

Each study was then rated as:

- High quality – the majority of criteria in the relevant checklist were met, indicating that there is little or no risk of bias in the study's results.
- Acceptable quality – most criteria in the relevant checklist were met, however there were some flaws in the study with an associated risk of bias in the study's results.
- Low quality – either most criteria in the relevant checklist were not met, or there were significant flaws relating to key aspects of the study design, meaning there is a high risk of bias in the study's results.

It should be emphasised that these ratings relate to the quality of the individual studies. The quality rating for each individual study contributed to the overall quality of the body of evidence (i.e. the group of studies about the same health outcome), which was assessed in a subsequent process (see the section 'The GRADE approach to assess the evidence on dental/health outcomes and reach a conclusion about the intervention of water fluoridation').

Study design

All of the studies included in the 2016 NHMRC Evidence Evaluation were observational studies. This means that the study investigators measured the health outcomes in groups of participants supplied with fluoridated water and compared those findings to participants with either non-fluoridated water supplies or water supplies containing different levels of fluoride. However, in these studies it is possible that associations between water fluoridation and health outcomes may be biased due to other factors ('confounding factors' or 'confounders'). Bias is less likely to occur in studies where participants are randomly allocated to different levels of fluoride. For this reason, many observational studies are assessed as low quality (they have less valid results) than research studies where the participants are randomly assigned to different groups.

Studies included in the 2016 NHMRC Evidence Evaluation were either:

- Ecological studies – these studies measure exposure to water fluoridation at a population level and the health outcome is either measured at a population level or individual level.³⁰ Given ecological studies do not involve randomisation, it is more difficult to account for other factors that may affect the health outcomes in question. These studies are generally unable to show whether a health outcome occurred (or changed in severity) before, during or after the exposure to fluoride, however; in the case of water fluoridation this may not be relevant because often the outcome is measured many years after water fluoridation was introduced. Despite this limitation, ecological studies are convenient, cheap to do and are appropriate given that water fluoridation is a population-wide exposure.
- Cross-sectional studies – in these studies, health outcomes in communities with differing levels of fluoride in water supplies were compared at a single point in time.²⁵ These studies are also generally unable to show whether a health outcome occurred (or changed in severity) before, during or after the exposure to fluoride but, again, are appropriate for water fluoridation for the reasons stated above.
- Prospective cohort studies – these studies follow the same group (cohort) of participants over a period of time and measure health outcomes in those in the cohort with fluoridated water supplies and those in the cohort with non-fluoridated water supplies.²⁵ These studies help to find out how likely it is that an exposure causes particular health effects as they can show that the health outcome occurred during or after the exposure.

Sample size

There were varying numbers of participants in the studies included in the 2016 NHMRC Evidence Evaluation. Larger numbers provide greater certainty that any observed association between water fluoridation and a health outcome is not due to chance. Larger numbers are particularly important if fluoridation is likely to have only a small effect on health, or when a health outcome is rare in the study population.

Bias

In research studies, there are a number of reasons why the results may not be accurate or valid. These are called biases. Bias can come from poorly designed studies, or from problems in the collection, analysis, reporting, publication or review of study data. Bias can lead to invalid results.²⁵ The research reviewers identified that bias may be of concern in many of the studies included in the 2016 NHMRC Evidence Evaluation.

One source of bias occurs if only some of the people who are asked to be part of a study agree to participate in it. This can cause bias if the people who do participate are different in relevant ways compared to those who do not participate. Many of the included studies did not include this information.

Some studies used self-report to measure the health outcome (for example, how many headaches the participants had in the past). This may introduce bias as people do not tend to recall health details accurately. More important, if people already have a view about the health effects of fluoride and are aware of the purpose of the study, they may more readily recall having more headaches than the group with non-fluoridated water. This can lead to an invalid finding about an association between fluoride and headaches. This kind of bias can be avoided if participants and researchers do not know which participants have been exposed to fluoridated water (this is called 'blinding'). The studies included in the 2016 NHMRC Evidence Evaluation were mostly not blinded and this may be unavoidable in studies of water fluoridation. This lack of blinding is common in observational studies and contributes to them being considered to be low quality.

Confounding

When there seems to be an association between exposure to fluoride in water and a health outcome, we need to find out whether this is actually due to water fluoridation, or due to another factor linked to both the exposure and the outcome. These are called confounding factors.²⁵ Confounding factors can lead to invalid results, by making a study show an association between water fluoridation and a health outcome when in reality there is no association or alternatively, to show no association even if there is one.

For example, a child's measured intelligence is likely to be higher if the child's parents are well educated. If people in a fluoride study who lived in an area with low levels of fluoride in their drinking water were, on average, better educated than people who lived in an area with high fluoride levels, then children's IQ would be higher in areas with lower fluoride levels. But this association might have nothing to do with fluoride in the water supply.

Exposure to fluoride from other sources, such as fluoridated toothpaste or some kinds of food, can make it seem as if there is an association between fluoride in water and health outcomes. This is difficult to assess without good measurement of exposure to other sources of fluoride. Many of the included studies did not report on other sources of fluoride.

It can be very difficult for researchers to identify and account for all of the potential confounding factors in studies. In many of the studies included in the 2016 NHMRC Evidence Evaluation, potential confounding variables were not consistently measured or taken into account when analysing the data. This reduces the validity of these studies.

Applicability

The aim of the 2016 NHMRC Evidence Evaluation was to inform decisions about water fluoridation in Australia. Although there are variations, people in Australia generally have access to fluoridated toothpaste and to dental care, and the level of fluoride in fluoridated drinking water is within the Australian target range (0.6 to 1.1 mg/L). Studies that took place in Australia, or in countries with similar conditions to Australia, are considered highly applicable. This is a way of saying that these results are very relevant to making decisions about water fluoridation in Australia.²⁵

Some of the included studies were conducted in countries that are very different from Australia, making their results less relevant. For example, some studies were performed in areas where the water has naturally many times higher levels of fluoride than water fluoridation levels in Australia. Other studies are less relevant because they are conducted in countries that have different dental care systems and social structures than Australia.

Consistency

Usually several studies are necessary before we can be confident that there is a cause-and-effect relationship. If an association in one study is consistently found in other studies, then we are more likely to think that there is a cause-and-effect relationship. Similarly, when study results are not consistent, it is more likely that any association in a single study is due to chance, bias, or confounding.

This is important to bear in mind when examining the effect of water fluoridation. There is a large body of studies which show a consistent effect for the outcomes of tooth decay and dental fluorosis. For the other health outcomes, there is frequently only a small number of studies with less consistent findings.

Further details about critical appraisal can be found in the 2016 NHMRC Evidence Evaluation¹ and the Technical Report.¹⁹

The GRADE approach to assess the evidence on the dental/health outcomes and reach a conclusion about the intervention of water fluoridation

Judgements about the quality of evidence in research studies and the health advice based on those judgements should be as transparent and explicit as possible. To help with this process, NHMRC uses *Grading of Recommendations Assessment, Development and Evaluation* (GRADE) which is an internationally recognised system for rating the quality of evidence and strength of recommendations in healthcare. GRADE is designed to be an explicit, comprehensive, transparent, and pragmatic way of making decisions.³¹

The Fluoride Reference Group followed three steps in applying the GRADE process:

Assessing the quality of the evidence

Under the GRADE framework, research results are assigned a quality rating based on an assessment of how valid (true) the findings are likely to be, and so how much confidence we can have in them.

Our confidence in the evidence is classified as follows:

- High – we are very confident in the results.
- Moderate – we are moderately confident in the results.
- Low – we have limited confidence in the results.
- Very low – we are not confident in the results.

As discussed in the section 'Critical appraisal of the evidence', there are many ways in which research may produce invalid results. Because of these risks, GRADE classifies observational studies as low level evidence. However, in the 2016 NHMRC Evidence Evaluation, observational study designs with a low risk of bias were initially rated as moderate quality. This decision reflects the level of confidence we can have in these types of evidence for public health interventions like water fluoridation. This approach has been adopted based on a proposal for using GRADE in public health.³²

From the initial GRADE rating, the quality of the evidence can be upgraded or downgraded based on various factors that influence our confidence in the results. However, it is difficult to upgrade observational studies due to the inherent risk of bias in this study design. For this reason, observational studies on water fluoridation are unlikely to be assessed as high or moderate quality under the GRADE framework, even though these may be the best study types for this question.

The GRADE assessments of the quality of the evidence for each health outcome are identified and presented in the 2016 NHMRC Evidence Evaluation.¹ The Fluoride Reference Group confirmed each of the GRADE assessments and considered the overall quality rating in interpreting the body of evidence on each health outcome.

Developing Evidence Statements

Evidence Statements on the effects of water fluoridation for each dental and other health outcome were developed by the Fluoride Reference Group.

The Evidence Statements presented in the Information Paper take into consideration all of the evidence captured in the 2000 York review, the 2007 NHMRC review and the 2016 NHMRC Evidence Evaluation (see Figure 3). The Evidence statements also take into account the additional material brought forward by the Fluoride Reference Group that was considered to be important for making decisions about water fluoridation in Australia.

Some of the important factors considered by the Fluoride Reference Group when developing the Evidence Statements were:

- level of confidence that the findings reported by each individual study were valid
- the consistency of the findings from the body of evidence
- any limitations of the body of evidence which, for some outcomes, included the small number of studies, the poor methodological quality of many of the studies and the rarity of health outcomes
- the applicability of the body of evidence to the Australian context.

The Fluoride Reference Group adopted consistent language in the Evidence Statements to reflect these factors. The Evidence Statements generally fit within one of the following categories:

- *Consistent evidence of a health outcome* – this wording was used when the Fluoride Reference Group was confident that the body of evidence was valid, applicable to the Australian context and consistently did show an association between water fluoridation and the health outcome.
- *The evidence shows no association of a health outcome* – this wording was used when the Fluoride Reference Group was confident that the body of evidence was valid, applicable to the Australian context and consistently demonstrated that there was no association between water fluoridation and the health outcome.
- *Limited evidence of a health outcome* – this wording was used when there was some evidence either no association or of an association between water fluoridation and the health outcome, but the Fluoride Reference Group was uncertain about this finding due to limitations in the body of the evidence.
- *Insufficient evidence to draw any conclusion* – this wording was used when the Fluoride Reference Group was not convinced that there was enough valid evidence to draw any conclusion about the relationship between water fluoridation and the health outcome. While it may be highly unlikely, the Fluoride Reference Group was unable to definitively rule out the possibility of these health outcomes.

The Office of NHMRC conducted a quality assurance process to ensure that the evidence was summarised consistently across all of the outcomes and reflected the overall quality ratings from the GRADE assessment.

Making a decision about water fluoridation

When making health care decisions, the GRADE framework helps to determine the strength of a recommendation for a particular course of action. These decisions are influenced by the strength of the evidence supporting the healthcare option and the overall balance of desirable and undesirable consequences.

In its 2007 Public Statement, NHMRC recommends that fluoride should be added to drinking water within the target range of 0.6 to 1.1 mg/L, depending on climate, to prevent tooth decay. The purpose of the 2016 NHMRC Evidence Evaluation is to update the body of evidence underpinning this recommendation and to assess the relevance of any new evidence to Australian conditions.

At this stage, the GRADE framework has been used to develop an overall conclusion on the potential health effects of water fluoridation within the current recommended range in Australia.

In the assessment of water fluoridation, the Fluoride Reference Group explicitly considered:

- the overall confidence in the estimates
- balance of benefits and harms
- community values and preferences
- impact on health equality
- acceptability to key stakeholders
- costs and resource implications
- feasibility.

All of these issues were discussed and the factors that influenced the Fluoride Reference Group's decisions were documented. This process resulted in the development of an overall conclusion in this draft Information Paper on the effectiveness and safety of water fluoridation within the optimal range recommended by NHMRC in the 2007 Public Statement.

Following public consultation on this draft Information Paper, the Council of NHMRC will consider whether the advice in the 2007 Public Statement needs to be updated. This may include consideration of the recommended optimal range for water fluoridation in the Australian context.

Findings of the 2016 NHMRC Evidence Evaluation

Water fluoridation and dental effects

Summary

Tooth decay

There is consistent evidence^h that water fluoridation at current Australian levels is associated with decreased occurrence and severity of tooth decay by 26-44% in children, adolescents and adults.

Inequalities

While the findings are mixed across the previous reviews and the 2016 NHMRC Evidence Evaluation, there is limited evidenceⁱ that suggests water fluoridation reduces inequalities in dental health across socio-economic groups. Findings of a recent unpublished study conducted in Queensland support this conclusion. Further high quality research is needed on the impact of water fluoridation in reducing the difference in tooth decay across socio-economic groups.

Hospital visits

A small number of published and unpublished studies in Australia and the UK suggest that the rate of hospital admissions for dental treatment is lower in areas with water fluoridation.

Tooth loss

There is insufficient evidence^j to draw a conclusion about any association between tooth loss and water fluoridation at current Australian levels. Tooth loss is influenced by tooth decay, periodontal disease and access to dental care.

Delayed eruption and tooth wear

Two studies show that water fluoridation is not associated^k with delayed eruption of adult teeth and one study shows no association^k with tooth wear.

h *Consistent evidence of a health outcome* – this wording was used when the Fluoride Reference Group was confident that the body of evidence was valid, applicable to the Australian context and consistently did show an association between water fluoridation and the health outcome.

i *Limited evidence of a health outcome* – this wording was used when there was some evidence either no association or of an association between water fluoridation and the health outcome, but the Fluoride Reference Group was uncertain about this finding due to limitations in the body of the evidence.

j *Insufficient evidence to draw any conclusion* – this wording was used when the Fluoride Reference Group was not convinced that there was enough valid evidence to draw any conclusion about the relationship between water fluoridation and the health outcome. While it may be highly unlikely, the Fluoride Reference Group was unable to definitively rule out the possibility of these health outcomes.

k *The evidence shows no association of a health outcome* – this wording was used when the Fluoride Reference Group was confident that the body of evidence was valid, applicable to the Australian context and consistently demonstrated that there was no association between water fluoridation and the health outcome.

Tooth decay

Introduction

Tooth decay, the breakdown of the outer layers of teeth, is one of the most common health problems in Australia. Tooth decay can lead to pain, infection and tooth loss. These symptoms can lead to a reduction in overall wellbeing and quality of life affecting people's eating, sleeping and socialising. Untreated tooth decay can result in avoidable hospitalisation.³³ Tooth decay causes people concern and affects their quality of life.³⁴⁻³⁷

Treating tooth decay is costly. The financial impact on individuals is greater than for other health problems as most dental treatments are not covered by Medicare. A number of schemes financing some aspects of dental services, mostly for means tested eligible children and adolescents, have been implemented across the last decade, but each has had a limited period of operation. While states and territories provide public oral health services for school-aged children and adults with a concession card, the eligibility criteria, co-payments, level of dental services and waiting periods vary across jurisdictions.³⁸

Teeth are constantly undergoing repair as they are damaged by acids produced by bacteria in the mouth. Diet affects the amount of acid damage, with sugar consumption increasing the risk of damage. Fluoride both reduces the damage and helps with repair. Tooth brushing with toothpaste containing fluoride and eating a healthy diet are measures an individual can take to prevent tooth decay. The fluoridation of drinking water is another measure to reduce tooth decay. It differs from tooth brushing and diet in that water fluoridation can prevent tooth decay for large numbers of people without individuals needing to change their behaviour. It also provides a regular source of fluoride to teeth over the course of the day which may contribute to dental benefits.

Tooth decay is measured in studies by counting the number of teeth a person has which are decayed, missing (due to decay) and filled (as this is a sign of treated decay) and adding them together. They are written as 'dmft' for deciduous/primary (baby) teeth and 'DMFT' for permanent (adult) teeth. Some studies count the number of tooth surfaces which are decayed, missing or filled rather than the number of teeth, this measure is written as 'dmfs' for deciduous teeth and 'DMFS' for permanent teeth. On occasion the 'missing' component is not measured and this is written as 'dft', 'DFT', 'dfs' or 'DFS' depending on whether deciduous or permanent teeth or surfaces are being measured. Another measure of tooth decay is the percentage of people (often children) who have no decay, or alternatively, the percentage with decay.

Description of evidence

Reviews

The 2000 York review included 26 studies in which water fluoridation was commenced or ceased during the study period in one group and there was a second group with no change in water fluoridation.²⁰ Sixteen analyses used DMFT or dmft as a measure of tooth decay and of these 15 showed significantly less decayed, missing and filled teeth after fluoridation compared to the non-fluoridated area. Thirty analyses¹ measured the percentage of children with no tooth decay, of these 19 found significantly more children with no tooth decay after fluoridation compared to the non-fluoridated area. One study found the reverse and the remaining studies did not have conclusive results. The review calculated that six people needed to receive fluoridated water to prevent one of those six having any tooth decay.

No additional studies were included in the 2007 NHMRC review.

¹ Note there can be more than one analysis in a single study.

The 2015 Cochrane review included the same type of studies as the 2000 York review but unlike the 2000 York review results for dmft and DMFT were separated. Fifteen studies were included overall.²¹ Results from individual studies were combined to generate findings.

Table 1 Summary of findings from the 2015 Cochrane review

Measure	No of studies	Findings
dmft	9	35% reduction with fluoridation
DMFT	10	26% reduction with fluoridation
% children without tooth decay (deciduous teeth)	10	15% increase with fluoridation
% children without tooth decay (permanent teeth)	8	14% increase with fluoridation

Two further reviews were identified in the 2016 NHMRC Evidence Evaluation.^{39;40}

The first was assessed as low quality in terms of the AMSTAR criteria.³⁹ It included comparative studies which provided dmft, dft^m, dmfs, dfsⁿ, DMFT, DMFS and DFS^o information for fluoridated and non-fluoridated communities. The results of the included studies were not combined.

Table 2 Summary of findings from Rugg-Gunn (2012)

Measure	No of studies	Findings (range)
dmft	19	44% median reduction with fluoridation (29% - 68%)
dft	2	47% median reduction with fluoridation (34% - 59%)
dmfs	7	38% median reduction with fluoridation (14% - 66%)
dfs	1	17% reduction with fluoridation
DMFT	37	37% median reduction with fluoridation (5% - 85%)
DMFS	12	29% median reduction with fluoridation (0% - 50%)
DFS	2	27% median reduction with fluoridation (10% - 44%)

The second review, which focused on dental decay in adults, was assessed as acceptable quality.⁴⁰ It included a total of nine comparative studies. The combined results of these studies showed that fluoridated water prevents 35% of tooth decay (measured using DMFT). When results were combined using only studies published after 1979 (when fluoridated toothpaste became widely available), the results showed that 27% of tooth decay was prevented in areas with fluoridated drinking water compared to areas without. This review included three studies from areas with higher levels of fluoride in drinking water than occurs in Australia; however when the analysis was repeated without these studies the findings were similar.

Additional studies identified in the 2016 NHMRC Evidence Evaluation

All of the additional studies identified in the 2016 NHMRC Evidence Evaluation were ecological studies except for one prospective cohort study.⁴¹

m number of decayed & filled deciduous teeth.

n number of decayed & filled surfaces of deciduous teeth.

o number of decayed & filled surfaces of permanent teeth.

Deciduous teeth

Three studies found that water fluoridation reduced tooth decay in children's deciduous teeth (as measured by dmft).⁴²⁻⁴⁴ Two of these studies were conducted in Australia and one in England (which has similar healthcare systems, dental care and income levels) so they are highly relevant. All of the studies made adjustment for known confounders.

Four studies found that water fluoridation reduced tooth decay in the deciduous teeth of children (as measured by dmfs).^{41;45-47} Two of these studies were conducted in Australia and one in the USA. These studies were considered to be highly relevant to water fluoridation in Australia. One study was less relevant as it was conducted in Vietnam which has a different healthcare system, access to dental care and different levels of income among other factors. All made adjustments for known confounders.

One Australian study found more Aboriginal and Torres Strait Islander children without decay in areas with water fluoridation (27.3%) compared with areas without water fluoridation (22.9%) but the effect was not statistically significant.⁴⁸ The study did not adjust for all confounders including sugar consumption, tooth brushing and socio-economic status.

Seven studies found that water fluoridation reduced the percentage of children with tooth decay in deciduous teeth.^{42;44;45;47;49-51} There were small differences in how this was measured across the studies. Four of these studies were conducted in Australia^{44;45;47;50}, one in the USA⁴⁹ and one in England⁴² and so are highly relevant. The other was set in South Africa.⁵¹ All were of acceptable quality except one which was assessed as being of low quality.⁴⁹

Of the studies conducted in Australia:

- The reduction of tooth decay ranged from 14% to 8.5% across three different time points in one study.⁴⁴
- Exposure to fluoridated water from birth to three years of age was estimated to prevent 34% of cases of tooth decay at 6 years of age in another study.⁵⁰
- Lack of water fluoridation was estimated to account for 21% of tooth decay.⁴⁵

Table 3 summarises the findings for deciduous teeth from the additional studies identified in the 2016 NHMRC Evidence Evaluation.

Table 3 Summary of findings for deciduous teeth

Measure	No of studies	Relevance	Findings
dmft	3	3/3 highly relevant	All studies found reduced tooth decay with fluoridation
dmfs	4	3/4 highly relevant	All studies found reduced tooth decay with fluoridation
% children without tooth decay (deciduous teeth)	1	Highly relevant	Increased % without tooth decay with fluoridation
% children with tooth decay (deciduous teeth)	7	6/7 highly relevant	All studies found a reduced % with tooth decay with fluoridation

Permanent teeth

Six studies found that water fluoridation reduced tooth decay in permanent teeth (measured with DMFT).^{42;43;52-55} Four of the studies were conducted in Australia and one in England so they are highly relevant and all made adjustments for known confounders.

Three highly relevant studies from Australia found that water fluoridation reduced tooth decay in permanent teeth (measured with DMFS).^{45;47;55} One other less relevant study found that water fluoridation did not significantly reduce tooth decay in Vietnam. This study was also of lower quality.⁴⁶

One Australian study found that water fluoridation increased the percentage of children without tooth decay in their permanent teeth. This was found for both Aboriginal and Torres Strait Islander children and non-Aboriginal and Torres Strait Islander children.⁴⁸

A second study from Brazil found that water fluoridation did not significantly change the percentage of children without decay in their permanent teeth.⁵² This study was considered to be less relevant due to likely differences in Brazil's access to dental care, dental healthcare systems and other socio-economic factors (for example, levels of poverty, income and education).

Seven studies found that water fluoridation reduced the proportion of people with tooth decay in their permanent teeth.^{42;45;49;53;54;56;57} There were small differences in how this was measured across the studies. One of these studies from Australia estimated that not having fluoride in drinking water contributes to 31% of all tooth decay.⁴⁵ Three studies were conducted in Australia, two in the UK and one in the USA and so their findings were considered to be highly relevant to water fluoridation in Australia. The other was from Brazil and was less relevant.

Two studies did not find any association between water fluoridation and the proportion of people with tooth decay in their permanent teeth.^{47;58} One study was from Australia and the other from South Korea.

Table 4 summarises the findings for permanent teeth from the additional studies.

Table 4 Summary of the findings for permanent teeth from the additional studies

Measure	No of studies	Relevance	Findings
DMFT	6	5/6 highly relevant	All studies found reduced tooth decay with fluoridation
DMFS	4	3/4 highly relevant	All of the highly relevant studies found reduced tooth decay with fluoridation
% children without tooth decay (permanent teeth)	2	1/2 highly relevant	The highly relevant study found an increased % without tooth decay with fluoridation
% children with tooth decay (permanent teeth)	9	7/9 highly relevant	Six of the highly relevant studies found a reduced % with tooth decay with fluoridation

Evidence Statement

There is consistent evidence^p that water fluoridation at current Australian levels is associated with decreased occurrence and severity of tooth decay in children, adolescents and adults.

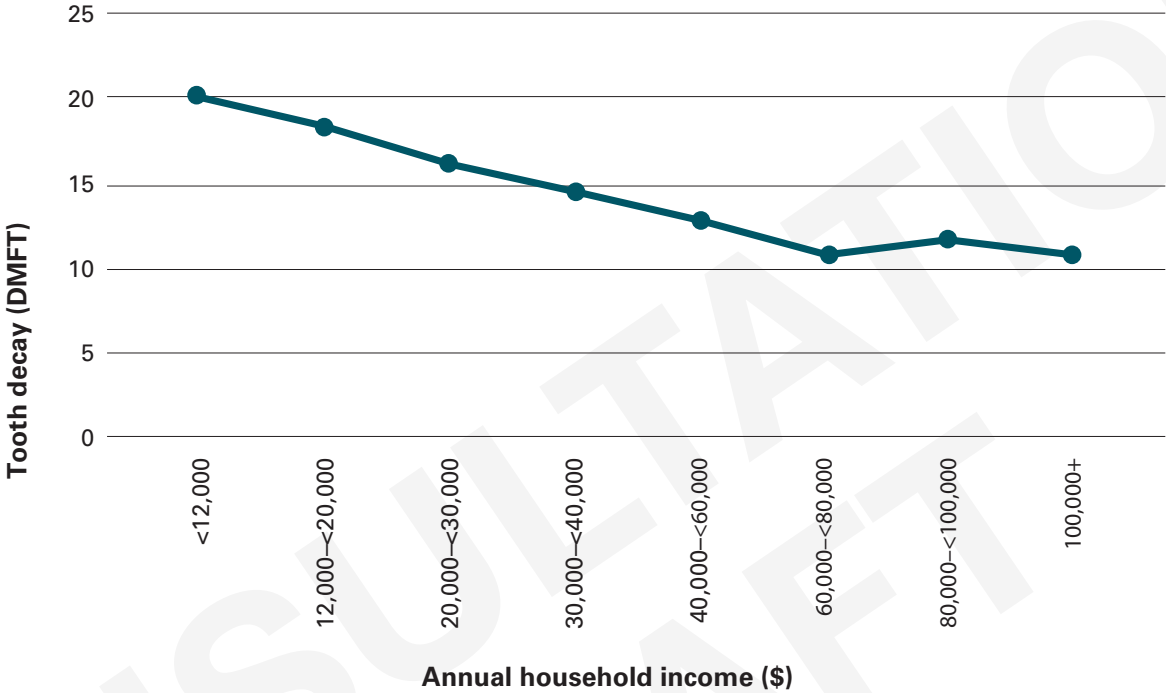
Inequality and tooth decay

Introduction

Health varies according to social factors such as income, education, Aboriginal and Torres Strait Islander status and where people live. In an Australia-wide survey, the average tooth decay (measured by DMFT) was much higher in people living in households with incomes of less than \$12,000 per year compared to households with incomes of \$60,000 per annum. Above this income level there was less variation (see Figure 4).¹⁴

^p *Consistent evidence of a health outcome* – this wording was used when the Fluoride Reference Group was confident that the body of evidence was valid, applicable to the Australian context and consistently did show an association between water fluoridation and the health outcome.

Figure 4 Tooth decay measured by average DMFT by household income (source: Chrisopoulos S & Harford JE 2013. Oral health and dental care in Australia: key facts and figures 2012.)



Australians living in regional and remote areas are more likely to experience tooth decay compared with those living in major cities. Adults in these areas also have higher levels of tooth loss and untreated decay, and are more likely to report having difficulties paying dental bills compared with those living in urban areas.³⁸

People in low income households are also likely to have more untreated decay reflecting poorer access to dental care. In 2012, the *National Advisory Council on Dental Health* reported that 39.8% of people in low income households had untreated decay compared to 17.3% of high income households. Untreated decay was also strongly associated with Aboriginal and Torres Strait Islander status.³³

A population-based survey of 24,500 Australian children aged 5-14 years was conducted in 2012-14 by the *Australian Research Centre for Population Oral Health* in collaboration with the states and territories (*the National Child Oral Health Survey 2012–2014*). Early analysis of the findings from this survey indicate that children of low socio-economic background and Aboriginal and Torres Strait Islander children had significantly higher rates of tooth decay, unfavourable dental and general health behaviours and were less likely to access dental services for regular check-ups.^q A full report on the findings of this survey will be released later in 2016. Data from Queensland was collected at the start of the survey (in 2010-12) and published in 2014.⁵⁹ Queensland children were more likely to experience tooth decay if they were Aboriginal and Torres Strait Islander, consumed more than four sugary drinks per day, were from a low income household, their parents had only school education or they lived in an area without water fluoridation.⁴⁵

q Media release University of Adelaide 2016 <http://www.adelaide.edu.au/news/news84922.html>

Adding fluoride to drinking water may reduce oral health inequalities because water fluoridation does not rely on individual actions or access to dental and/or health services: meaning everyone benefits. People in lower socio-economic groups may benefit most from water fluoridation, given they have a higher risk of tooth decay⁶⁰ and are less likely to access dental services for routine check-ups.⁶¹ This is an example of proportionate universalism, as water fluoridation ensures that fluoride is universally available in order to ensure it reaches those who are most in need.⁶²

While the 2016 NHMRC Evidence Evaluation did not involve a separate search for evidence on the effect of water fluoridation in reducing inequalities in oral health, relevant evidence on this issue was collected from the research studies^{42,48,57} and existing reviews^{20,21} on tooth decay included in the evaluation.

Description of the evidence

The 2000 York review included 15 studies from the UK which reported on the effect of water fluoridation across different social groups. Six studies reported on the percentage of children and young people without tooth decay. In five of the six studies, water fluoridation increased the number of children and young people without tooth decay across all social groups. However, water fluoridation did not reduce the gap in the occurrence of tooth decay between the most advantaged and least advantaged groups. When the review considered tooth decay measured using dmft/DMFT, the results were mixed. The review concluded that there appeared to be some evidence that water fluoridation reduced the inequalities in dental health across social classes in 5 and 12 year olds, but this effect was not found for children of other ages. The authors of this review were cautious in interpreting these results, given there was a small number of low quality studies with differences between them.

The 2015 Cochrane review²¹ included three studies which considered the effect of the introduction of water fluoridation on inequality between socio-economic groups. However, the authors of this review were not able to draw any conclusions due to the poor quality of these studies.

The 2016 NHMRC Evidence Evaluation included three studies which reported on fluoride in drinking water and tooth decay inequalities.^{42,48,57}

An Australian study found that the difference in the proportion of non-Aboriginal and Torres Strait Islander children to Aboriginal and Torres Strait Islander children without tooth decay in their deciduous teeth increased from 13.4% in the non-fluoridated areas to 25.2% in the fluoridated areas.⁴⁸ There was also an increase for permanent teeth without decay (from 9.5% to 20%). This study did not find that fluoridated water reduced the difference in tooth decay between Aboriginal and Torres Strait Islander children and non-Aboriginal and Torres Strait Islander children. Instead, fluoridation improved the oral health of non-Aboriginal and Torres Strait Islander children more than Aboriginal and Torres Strait Islander children, making the gap bigger. This study was considered to be of low quality as it did not adjust for known confounders (for example sugar intake, use of fluoridated toothpaste, and family income). Although no reduction in inequality was found, fluoride was associated with less tooth decay for both Aboriginal and Torres Strait Islander children and non-Aboriginal and Torres Strait Islander children.⁴⁸

The other two studies (one of acceptable quality and one of low quality) were conducted in the UK.^{42,57} These studies found that the gap in the rate of tooth decay (measured by DMFT) between the most deprived social group and less deprived social groups was reduced in the areas with fluoridated water compared to areas without.^{42,57}

Additional considerations

The Fluoride Reference Group recognised that some evidence on the impact of water fluoridation on oral health inequalities was not identified or was excluded from the 2016 NHMRC Evidence Evaluation because the systematic review was not designed to specifically locate studies about inequalities. Any studies about inequalities included in the 2016 NHMRC Evidence Evaluation were studies that met all the inclusion criteria for tooth decay and also included information about inequalities. In addition, the included reviews have restricted evidence to studies from one country²⁰ or of one study design.²¹ Given that public water fluoridation appears to offer a dental health benefit across the population, the Fluoride Reference Group considered it important to look at additional studies relevant to Australia in order to assess the effect of fluoridation on oral health inequalities.

Studies from Australia and New Zealand conducted in the 1980s provided evidence that water fluoridation was effective in reducing tooth decay among low socio-economic groups. However, these studies were inconclusive regarding whether water fluoridation helped to reduce the gap in oral health between high and low socio-economic groups.⁶³⁻⁶⁵ A New Zealand study published in 1994 also found that while there were significant differences in tooth decay in 14-year-old children across socio-economic groups (measured by DMFT and DMFS), water fluoridation did not impact on this inequality.⁶⁶

One Australian study conducted in the 1990s looked at tooth decay (measured by dmfs and DMFS) in a large random sample of children from Queensland and South Australia participating in school dental services. This study found that children from low income households, and children with parents who had a low level of education, were more likely to experience tooth decay. This inequality existed despite all children having access to free, regular dental care for prevention and treatment of tooth decay through school dental services. The inequality between children of lower and higher socio-economic status was most pronounced in non-fluoridated areas.⁶⁷ The authors of this study concluded that water fluoridation helped to reduce the gap in oral health amongst children from lower socio-economic groups.

A 2011 study conducted in Korea considered the impact of water fluoridation on socio-economic differences in tooth decay experienced by 11-year-old children. This study found that tooth decay (measured by DMFT) was similar across different socio-economic groups in fluoridated and non-fluoridated areas. However, after adjusting for confounders, tooth decay was more common in lower socio-economic groups in non-fluoridated areas, but not in fluoridated areas. The authors concluded that water fluoridation may have helped to reduce the disparity in tooth decay across socio-economic groups.⁶⁸ This finding was supported by a study of 12-year-old children in two communities without water fluoridation in Northern England. Following the introduction of water fluoridation in one of these communities, the biggest reduction in tooth decay was seen amongst children living in socio-economically disadvantaged areas of this community.⁶⁹

A more recent population-based study conducted in Queensland in 2010-12 also considered the effect of water fluoridation in reducing socio-economic inequalities in tooth decay (measured by dmfs/DMFS). This study found that children in lower socio-economic groups had significantly higher rates of tooth decay compared to other children, even when oral health behaviours and dental visiting patterns were taken into account. Rates of tooth decay were much higher among socially disadvantaged children in areas without water fluoridation but not in areas with water fluoridation. The study authors concluded that water fluoridation can deliver larger benefits for socially disadvantaged children who are at higher risk of experiencing tooth decay. The findings of this study were presented to the *European Organisation for Caries Research* in 2015.⁷⁰

Recent research has also been published on reducing the disparities in tooth decay between Australians living within and outside of capital cities. Data from the *Australian National Survey of Adult Health 2004-06* indicated that people located outside of capital cities experienced more dental decay than their urban counterparts. After taking into account differing socio-economic characteristics and dental visiting patterns, people living outside of Australian capital cities experienced more tooth decay only when they had not lived in an area with access to fluoridated water supply over the course of their life.⁷¹

A number of studies have considered the possible benefits of water fluoridation in preventing tooth decay among Aboriginal and Torres Strait Islander Australians living in remote communities in the Northern Territory. The majority of these communities have naturally low levels of fluoride in their water supplies (less than 0.6 mg/L). A study using data from Northern Territory School Dental Service estimated that the implementation of water fluoridation in these communities has the potential to reduce tooth decay in Aboriginal and Torres Strait Islander children by between 7% and 28%.^{2,72} Another study focused on the effectiveness of a dental health program in remote Aboriginal communities in the Northern Territory, but also took into account the impact of fluoride levels in the drinking water. This analysis was based on modelling and found that having optimal fluoride levels in drinking water may be associated with reduced tooth decay in Aboriginal and Torres Strait Islander children, independent of any benefits from the dental health program.⁷³

The Fluoride Reference Group identified the need for further high quality research within the Australian context on the impact of water fluoridation in reducing inequalities in tooth decay experienced across socio-economic groups, by some Aboriginal and Torres Strait Islander people and in rural and regional areas.

Evidence Statement

Taking into account the findings of the 2016 NHMRC Evidence Evaluation and the additional considerations of the Fluoride Reference Group, there is consistent evidence^r that water fluoridation reduces tooth decay across socio-economic groups. There is limited evidence^s that suggests water fluoridation reduces inequality in tooth decay experienced by those in lower socio-economic groups and those living in regional areas. However, this evidence should be interpreted with caution given that previous reviews and the 2016 NHMRC Evidence Evaluation identified a limited amount of evidence from the Australian context and many of these studies were of low quality with varying results. Further, the additional material identified by the Fluoride Reference Group was not assessed through a systematic process, so all relevant material may not have been considered.

Hospital visits for tooth decay

Introduction

Treatment of tooth decay is a common cause of hospital admission in children. Hospital admission for treatment of tooth decay is costly for the health system and for the family involved who may need to take time off work and cover any out-of-pocket expenses.

^r *Consistent evidence of a health outcome* – this wording was used when the Fluoride Reference Group was confident that the body of evidence was valid, applicable to the Australian context and consistently did show an association between water fluoridation and the health outcome.

^s *Limited evidence of a health outcome* – this wording was used when there was some evidence either no association or of an association between water fluoridation and the health outcome, but the Fluoride Reference Group was uncertain about this finding due to limitations in the body of the evidence.

While the 2016 NHMRC Evidence Evaluation did not involve a separate search for evidence on the effect of water fluoridation in reducing hospital admissions, relevant evidence on this issue was collected from the research studies and existing reviews on tooth decay included in the 2016 NHMRC Evidence Evaluation.

Description of the evidence

There were no studies in the 2000 York review or the 2007 NHMRC review that looked at hospital visits for tooth decay.

One acceptable quality ecological study was identified in the 2016 NHMRC Evidence Evaluation.⁴² This study was conducted in England and compared hospital admission for tooth decay in 1-4 year old children in fluoridated compared to non-fluoridated areas. This study also looked at the inequality in the rate of hospital admissions for tooth decay across socio-economic groups. Among the most disadvantaged children, the rate of hospital admissions was 75% lower in areas with fluoridated drinking water compared with non-fluoridated areas. After adjusting for the socio-economic inequality between groups, there were 55% fewer hospital admissions for tooth decay among children in areas with fluoridated water.

Additional considerations

The 2016 NHMRC Evidence Evaluation was not designed to specifically locate studies about water fluoridation and the prevention of hospital admissions for the treatment of tooth decay. Any studies about hospital admissions included in the 2016 NHMRC Evidence Evaluation met all the inclusion criteria for tooth decay and also included information about preventing hospital admissions. The Fluoride Reference Group considered that additional material should be considered on the prevention of hospital admissions for the treatment of tooth decay, given the financial implications for individual patients and the health system.

The results of one Australian study were presented to the conference of the *International Association for Dental Research* in 2010.⁷⁴ This study looked at dental hospital admissions of children in an area that started water fluoridation in 2002. The study found a significant decrease in hospitalisation of children for dental treatment after the introduction of water fluoridation. A similar town which did not start water fluoridation also had reduced admissions, but this was not statistically significant. Another study from Western Australia showed that children born between 1980-1998 were more likely to be admitted to hospital for treatment of tooth decay when they were under two years old if they lived in an area without fluoridated drinking water.⁷⁵

Evidence Statement

There is insufficient evidence^t from the 2016 NHMRC Evidence Evaluation to reach a conclusion about any association between hospital admissions for tooth decay in children and water fluoridation at current Australian levels. The additional material considered by the Fluoride Reference Group provides limited evidence^u that children living in regions with water fluoridation may be less likely to be admitted to hospital for the treatment of tooth decay. However, this evidence was not identified through a systematic process and its quality has not been formally assessed.

t *Insufficient evidence to draw any conclusion* – this wording was used when the Fluoride Reference Group was not convinced that there was enough valid evidence to draw any conclusion about the relationship between water fluoridation and the health outcome. While it may be highly unlikely, the Fluoride Reference Group was unable to definitively rule out the possibility of these health outcomes.

u *Limited evidence of a health outcome* – this wording was used when there was some evidence either no association or of an association between water fluoridation and the health outcome, but the Fluoride Reference Group was uncertain about this finding due to limitations in the body of the evidence.

Tooth loss

Introduction

Missing teeth may be an indicator that a person has experienced tooth decay, as severe decay may need to be treated by tooth extraction. However, tooth loss may also be due to other causes such as trauma or gum disease and may be the result of treatment decisions.

Description of the evidence

The 2000 York review and the 2007 NHMRC review did not include tooth loss as an outcome.

The 2016 NHMRC Evidence Evaluation identified five studies that looked at tooth loss and water fluoridation. Three of these studies were from Brazil^{52,76,77}, one from the USA⁷⁸ and one from Australia.⁷⁹ The Australian and USA studies were highly relevant and the Brazilian studies less relevant for the reasons discussed in the earlier section on tooth decay.

The three Brazilian studies found an association between tooth loss and lack of water fluoridation, but these studies have limited relevance for Australia.

The USA study⁷⁸ found that reduced tooth loss was associated with being exposed to fluoridated water at birth. There was no association between tooth loss and current access to fluoridated drinking water. The Australian study found no significant association between water fluoridation and tooth loss.

Evidence Statement

There is insufficient evidence^v to reach a conclusion about any association between tooth loss and water fluoridation at current Australian levels.

Delayed tooth eruption

Introduction

Delayed tooth eruption happens when teeth come through the gums later than usual. This may lead to orthodontic problems as the delayed teeth may be crowded by other teeth.

Description of evidence

One study was included in the 2000 York review that reported on the number of erupted teeth per child before and after water fluoridation was started.⁸⁰ The difference was very small and in opposite directions in the two age groups examined (8 and 12 year olds).

There were no studies in the 2007 NHMRC review that looked at delayed tooth eruption.

The 2016 NHMRC Evidence Evaluation located two studies that assessed tooth eruption and levels of fluoride in drinking water.^{81,82} One study looked at children aged from 5-17 years old from three areas with different levels of fluoride in water and found no difference in the number of permanent teeth.⁸¹ The study took place in the USA which has similar water fluoride levels to that used in Australia and so the results were considered very relevant to Australia. The second study from India suggested

^v *Insufficient evidence to draw any conclusion* – this wording was used when the Fluoride Reference Group was not convinced that there was enough valid evidence to draw any conclusion about the relationship between water fluoridation and the health outcome. While it may be highly unlikely, the Fluoride Reference Group was unable to definitively rule out the possibility of these health outcomes.

that children living in areas with high water fluoride levels had fewer permanent teeth. The level of fluoride was much higher [average level 2.7 parts per million (ppm)] than that used in Australia for water fluoridation and so was not particularly relevant to the Australian situation. The dental healthcare system, access to dental care and other factors like levels of poverty also contribute to this study not being relevant to the Australian situation. The results could be caused by things other than fluoride in drinking water like the way the teeth were assessed as being delayed, confounding factors (for example, preterm birth or injuries) or by chance alone.⁸²

Evidence Statement

The evidence shows that there is no association^w between delayed tooth eruption and water fluoridation at current Australian levels.

Tooth wear

Introduction

Exposure to fluoride may make teeth less prone to wear.

Description of the evidence

The 2000 York review and the 2007 NHMRC review did not include tooth wear as an outcome.

One study was identified in the 2016 NHMRC Evidence Evaluation which compared tooth wear and water fluoridation exposure.⁸³ This study was conducted in Ireland, is very relevant to the Australian context and did not find any association.

Evidence statement

The evidence shows that there is no association^w between the prevalence of tooth wear in adults and adolescents and water fluoridation at current Australian levels.

^w *The evidence shows no association of a health outcome* – this wording was used when the Fluoride Reference Group was confident that the body of evidence was valid, applicable to the Australian context and consistently demonstrated that there was no association between water fluoridation and the health outcome.

Water fluoridation and dental fluorosis

Summary

There is an increased risk of dental fluorosis with increasing fluoride levels in water supplies. However, most of this evidence comes from countries where the levels of naturally occurring fluoride in water supplies is up to five times greater than levels used in Australia for water fluoridation. The measurement of fluorosis and the definitions used to identify levels of fluorosis that may cause concern in these studies were not consistent with the ways that fluorosis is measured and defined in Australia.

About one in four children show signs of dental fluorosis in Australia, with the proportion being higher in fluoridated (25%) than non-fluoridated (17%) areas.^{50;84} Most of the dental fluorosis in Australia is very mild or mild.^{50;84} Research suggests that this level of dental fluorosis is unlikely to be of concern to affected children and adolescents or their parents. Moderate dental fluorosis is uncommon and severe dental fluorosis is rare in Australia. Moderate dental fluorosis may cause concern to those few people who have it.

Dental fluorosis

Introduction

Dental fluorosis affects the appearance of teeth. It can range from faint white lines (classified as very mild fluorosis) to pitting and loss of the enamel surface of teeth (classified as severe fluorosis). Dental fluorosis occurs as teeth are developing before they emerge into the mouth, so children are only at risk of developing fluorosis during the first six years of life.³⁶

Dental fluorosis is measured using a standard scale such as Dean's Fluorosis Index or the Thylstrup-Fejerskov (TF) Index.³ In some research studies, a score of more than or equal to three on the TF index or a Dean's score of mild or worse is described as fluorosis that 'may be of aesthetic concern'.^{3;20} Other more recent research has found that mild or very mild fluorosis (TF 1-2) does not concern affected children and adolescents or their parents.³⁴⁻³⁷ Moderate dental fluorosis, if represented by a TF score of three, may also not be of concern.³⁵ Therefore studies that use the thresholds described above for fluorosis of "aesthetic concern" may overestimate the impact of fluorosis on people's quality of life.

Description of evidence

The 2000 York review included 88 studies on dental fluorosis.²⁰ These studies included levels of fluoride in water from less than 0.3 ppm to 4-7 ppm (well above that used in Australia for water fluoridation). The findings from this review suggested that at a fluoride level of 1.0 ppm, approximately 12.5% of the population would have fluorosis of aesthetic concern.

The 2007 NHMRC review³ included ten new studies published after the 2000 York review. These studies compared the amount of fluorosis in groups of people with non-fluoridated water with the amount of fluorosis in groups of people with fluoridated water at Australian levels. The findings from this review suggested that there was about a fourfold risk of developing fluorosis of aesthetic concern with fluoride levels of 0.8-1.2 ppm compared to ≤ 0.4 ppm.

The association of fluoride in water supplies and fluorosis was assessed in the 2015 Cochrane review.²¹ The review included 90 studies and updated the 2000 York review. Fluoride could be at any level in these studies. The findings of this review suggested that about 12-15% of people would have fluorosis of aesthetic concern with water fluoridation in the current Australian range.

There are serious limitations with the way in which these three reviews looked at dental fluorosis and its relationship with fluoride levels in water. The York²⁰ and Cochrane²¹ reviews investigated the dose-response relationship between water fluoride levels and dental fluorosis. The Fluoride Reference Group raised concerns that some of the fluoride levels were much higher than that used in Australia (up to 5 ppm). In addition, all three reviews did not consider other sources of fluoride (for example, toothpaste), and research indicates that the cut-off point used to define the level of fluorosis that was considered to be of “aesthetic concern” was defined inconsistently.^{3,20,21} Recent evidence suggests that mild and very mild fluorosis in children is not of concern to children or their parents.³⁴⁻³⁷ Moderate fluorosis, if represented by a TF score of three may also not be a concern.³⁵ These concerns limited the applicability of these reviews’ dental fluorosis evidence to the Australian context. The Fluoride Reference Group decided to address these concerns by including some of this recent evidence under ‘additional considerations’.

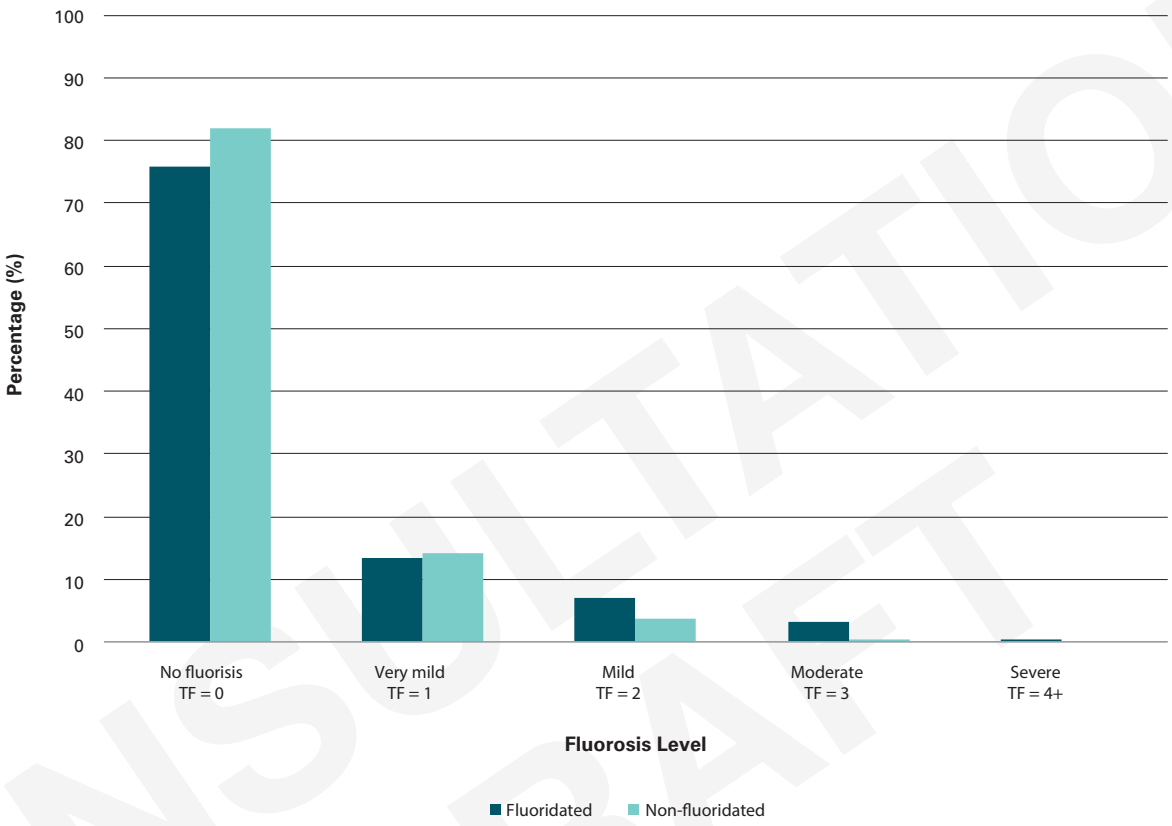
Additional considerations

In Australia, recent studies show that:

- 25% of children have fluorosis, of which the vast majority have very mild or mild fluorosis⁸⁴
- mild and very mild fluorosis in children often diminishes over time³⁶
- moderate fluorosis is uncommon (3.0% among children in NSW⁸⁴, 0.4% among children in Queensland⁵⁹ and 1.9% among children in South Australia³⁵)
- severe fluorosis is rare (0.4% among children in NSW⁸⁴ and 0.1% among children in Queensland⁵⁹)
- dental fluorosis which may be of aesthetic concern is uncommon (3.4% in NSW⁸⁴, 1.9% in South Australia³⁵ and 0.4% in Queensland⁵⁹).

Fluorosis is more common in children who live in areas with fluoridated water. In NSW there are six per cent more 11-12 year old children with fluorosis in areas with fluoridated water than in areas without fluoridated water (Figure 5) shows this data and also shows that most cases of fluorosis in children are very mild.

Figure 5 Amount of fluorosis in NSW Children aged 11-12 and water fluoridation status. Source: NSW Child Dental Health Survey 2007



Dental fluorosis changes the appearance of teeth but does not affect dental function. The main concern is how people feel about the changed appearance of their teeth. Recent research has asked people about this and whether dental fluorosis affects their quality of life. They then compared the answers to these questions with the amount of dental fluorosis people have. These studies found that:

- in both Australian studies and studies from other countries, very mild and mild fluorosis either causes no concern or was sometimes associated with a greater satisfaction concerning dental appearance and a small improvement in oral health related quality of life³⁴⁻³⁷
- moderate dental fluorosis may be of concern to some people who have it³⁴⁻³⁷
- severe dental fluorosis causes concern to some people who have it and may affect their quality of life.³⁴⁻³⁷

These studies show that the definition of “fluorosis of aesthetic concern” that was used in the 2000 York review and 2015 Cochrane review may not be relevant to the Australian context. In fact, some of the dental fluorosis included in “fluorosis of aesthetic concern” in these reviews is not of any concern to Australians. Moderate fluorosis, represented by a TF score of three, may not be of concern to Australians⁸⁶, but was not considered separately in the 2000 York or 2015 Cochrane reviews. It is generally accepted that severe fluorosis may be of concern to some people who have it, because this level of fluorosis involves loss of tooth enamel. In Australia, moderate dental fluorosis is uncommon and severe dental fluorosis is rare.

x This reflects people’s comfort when eating, sleeping and engaging in social interaction; their self-esteem; and their satisfaction with respect to their oral health⁸⁵

Rates of dental fluorosis increased in Australia in the 1980s. This increase was associated with the addition of fluoride to toothpaste and the use of other fluoride containing products such as supplements. Current rates are lower due to the availability and promotion of low fluoride toothpastes for children, and public health messages about the appropriate use of these products (e.g. use only a small pea-sized amount; encourage children not to swallow toothpaste).⁸⁶

Concern is often raised about the possibility of dental fluorosis affecting babies who are fed using infant formula powder that is mixed with water containing fluoride. The *Australia New Zealand Food Standard Code 2016* ensures that infant formula products exceeding the optimal level of fluoride are labelled to highlight to risk of dental fluorosis (for more details, see Appendix E).⁸⁷ An Australian study conducted in 2011, found that in non-fluoridated areas children who were fed with infant formula had an increased risk of very mild and mild dental fluorosis, compared with children who were breastfed. The same study found that children in fluoridated areas had an increased risk of very mild and mild dental fluorosis compared with children in non-fluoridated areas, regardless of whether or not they were fed with infant formula. Children in fluoridated areas were also found to have lower rates of tooth decay.⁸⁸

Evidence Statement

There is consistent evidence^y that an increased level of fluoride in the water supply is associated with an increase in the occurrence and severity of dental fluorosis. However, the majority of this evidence applies to countries where naturally occurring fluoride levels are up to five times greater (5 ppm) than water fluoridated at current Australian levels. In Australia, at current water fluoridation levels, dental fluorosis is found in one in four children, slightly higher in fluoridated (25%) than non-fluoridated (17%) areas. The dental fluorosis found in Australia is predominantly very mild or mild. Moderate dental fluorosis is uncommon and severe fluorosis is rare in Australia. Moderate dental fluorosis may be of concern to some people who have it. It is generally accepted that severe fluorosis is of concern to some people who have it.

^y *Consistent evidence of a health outcome* – this wording was used when the Fluoride Reference Group was confident that the body of evidence was valid, applicable to the Australian context and consistently did show an association between water fluoridation and the health outcome.

Water fluoridation and any other health effects

Summary

The evidence shows that there is no association^z between water fluoridation at current Australian levels and:

- Cancer
- Down syndrome
- Intelligent quotient (IQ)
- Mortality
- Muscle and skeletal effects (Hip fracture, Osteosarcoma, Ewing sarcoma, Skeletal fluorosis).

There is insufficient evidence^{aa} to reach a conclusion about any association between water fluoridation at current Australian levels and:

- Chronic kidney disease
- Heart disease and high blood pressure
- Kidney stones
- Low birth weight
- Muscle and skeletal effects (Musculoskeletal pain, Osteoporosis)
- Thyroid function
- Self-reported health outcomes (Gastric discomfort, Headache, Insomnia).

Cancer

Introduction

Cancer is a disease in which cells in the body grow in an uncontrolled way. This can be caused by exposure to harmful substances but can also be due to chance, genetics or due to lifestyle factors or a combination of these factors. Cancer can arise in different parts of the body. Cancer which develops in the bone is rare (for example, 120 new cases recorded in Australia in 2012 compared to 8,239 new cases of bowel cancer in the same year).⁸⁹ Two types of bone cancer are considered here, osteosarcoma and Ewing sarcoma.

Description of the evidence

Ten studies in the 2000 York review²⁰ assessed the relationship between water fluoridation and the occurrence of any type of cancer and death due to any cancer.⁹⁰⁻⁹⁹ The results from eight studies suggested no association. One other study suggested higher rates of cancer in areas with fluoridated water, while another study suggested a lower death rate due to cancer in fluoridated areas. The review authors' concluded that there was no clear association between water fluoridation and overall cancer occurrence and death from any cancer.

^z *The evidence shows no association of a health outcome* – this wording was used when the Fluoride Reference Group was confident that the body of evidence was valid, applicable to the Australian context and consistently demonstrated that there was no association between water fluoridation and the health outcome

^{aa} *Insufficient evidence to draw any conclusion* – this wording was used when the Fluoride Reference Group was not convinced that there was enough valid evidence to draw any conclusion about the relationship between water fluoridation and the health outcome. While it may be highly unlikely, the Fluoride Reference Group was unable to definitively rule out the possibility of these health outcomes.

The 2007 NHMRC review³ included a further three ecological studies.¹⁰⁰⁻¹⁰² The authors of the 2007 NHMRC review rated these studies as poor quality (largely due to no consideration of confounders) and noted the limited applicability of the fluoride levels considered in these studies compared with water fluoridation in the Australian context. Two of these studies looked at the occurrence of cancer.^{100,101} One study found an increase in the occurrence of cancer in 23 of 36 body sites, a decrease in four sites and no change in nine sites.¹⁰¹ The other study found that the lower the fluoride level in drinking water, the higher the deaths from cancer.¹⁰⁰ The review authors advise that these results should be interpreted with caution. The third study found that the death rate from cancer was generally similar in fluoridated and non-fluoridated areas.

The 2000 York review²⁰ included seven studies assessing osteosarcoma and water fluoridation in their review.¹⁰³⁻¹⁰⁹ Five studies found no association between water fluoridation and osteosarcoma, one study found a reduced risk of developing osteosarcoma, and the final study reported an increase in osteosarcoma in men only. The 2000 York review concluded that, overall, there was no clear association between water fluoridation and osteosarcoma. Four other studies assessed other bone related cancers and the results suggested no clear association.

The 2007 NHMRC review³ included one study that suggested a higher risk of osteosarcoma associated with water fluoridation in 7-year-old boys.¹¹⁰ This was part of a larger incomplete study and the results could be explained by factors other than water fluoridation. Final analysis of the full data was published in 2011 and concluded that there was no association between water fluoridation and osteosarcoma.¹¹¹

The 2016 NHMRC Evidence Evaluation included two studies that assessed the occurrence of cancers (other than bone cancer) and water fluoridation.^{42,112} One was a large study which found no difference between the rate of cancer in fluoridated and non-fluoridated areas and that the rate of bladder cancer was lower in fluoridated areas.⁴² The result for bladder cancer was considered to be probably due to confounding or bias. The other study suggested that the number of people with cancer of the eye was less in areas with fluoridated water.¹¹² However, the Fluoride Reference Group considered that this result was most likely due to chance. The countries in which these studies were done (UK and USA) have fluoride levels similar to Australia. Levels of income and health systems are somewhat similar in these countries, making these results very relevant to Australia.

The 2016 NHMRC Evidence Evaluation included six studies that assessed osteosarcoma and water fluoridation.^{42,113-117} Five studies, conducted in four different countries (the UK, USA, Republic of Ireland and New Zealand), that included large numbers of people found that there was no association between water fluoridation and osteosarcoma.^{42,113;114;116;117} These studies used trustworthy information about cancer that was collected regularly by each country. The results are very relevant to Australia because the countries all fluoridate their water to levels that are very similar to that used in Australia. The sixth study suggested that osteosarcoma was related to fluoride levels in drinking water. However, the Fluoride Reference Group considered that the result from this low quality study was most likely due to the high risk of bias in the study or due to chance, given the small numbers of people included (twenty, ten with osteosarcoma and ten without).¹¹⁵

The 2016 NHMRC Evidence Evaluation identified one study that assessed another type of bone cancer called Ewing sarcoma and water fluoridation.¹¹³ This study used trustworthy national data that was regularly collected. The results suggested no association between Ewing sarcoma and water fluoridation.

Evidence Statement

The evidence shows that there is no association^{ab} between overall cancer incidence or mortality and water fluoridation at current Australian levels.

The evidence shows that there is no association^{ab} between incidence of osteosarcoma and water fluoridation at current Australian levels.

The evidence shows that there is no association^{ab} between incidence of Ewing sarcoma and water fluoridation at current Australian levels.

Chronic kidney disease

Introduction

Chronic kidney disease refers to all conditions in which there is loss of function of the kidneys.

Description of the evidence

Both the 2000 York review and the 2007 NHMRC review did not include any studies that assessed the association of water fluoridation and chronic kidney disease.

One additional ecological study of low quality was identified in the 2016 NHMRC Evidence Evaluation.¹¹⁸ This study found no clear association between water fluoride levels and the prevalence of chronic kidney disease of unknown aetiology.

Evidence Statement

There is insufficient evidence^{ac} to reach a conclusion about any association between chronic kidney disease and water fluoridation at current Australian levels.

Down syndrome

Introduction

Down syndrome (also referred to as Trisomy 21) is a genetic disorder caused by an extra copy of all or part of chromosome 21. The biggest risk factor for Down syndrome is maternal age, with older mothers at much greater risk of having a baby with Down syndrome.

Description of the evidence

The 2000 York review included six studies that considered the relationship between fluoride exposure and Down syndrome.¹¹⁹⁻¹²⁴ All six studies were assessed as being of poor quality and only one study controlled for maternal age.

ab *The evidence shows no association of a health outcome* – this wording was used when the Fluoride Reference Group was confident that the body of evidence was valid, applicable to the Australian context and consistently demonstrated that there was no association between water fluoridation and the health outcome.

ac *Insufficient evidence to draw any conclusion* – this wording was used when the Fluoride Reference Group was not convinced that there was enough valid evidence to draw any conclusion about the relationship between water fluoridation and the health outcome. While it may be highly unlikely, the Fluoride Reference Group was unable to definitively rule out the possibility of these health outcomes.

The 2007 NHMRC review identified the six studies in the 2000 York review and one additional ecological study of poor quality that found no significant association between water fluoridation and Down syndrome.³⁰

The 2016 NHMRC Evidence Evaluation found one additional population-based ecological study of acceptable quality on Down syndrome.⁴² After adjustment for maternal age, there was no association between Down syndrome and water fluoridation at current Australian levels.

Evidence Statement

The evidence shows that there is no association^{ad} between incidence of Down syndrome and water fluoridation at current Australian levels.

Heart disease and high blood pressure

Introduction

The cardiovascular system includes the heart and arteries and veins of the body. Diseases of this system include high blood pressure, heart disease and hardening of the arteries (atherosclerosis). They are common causes of illness and death.

Description of the evidence

There were no studies in the 2000 York review that looked at the cardiovascular effects of water fluoridation.²⁰ The 2007 NHMRC review reported one study that assessed deaths caused by coronary heart disease.³

The 2016 NHMRC Evidence Evaluation included one study from China that assessed the presence of atherosclerosis in neck arteries (carotid artery) and levels of fluoride in drinking water.⁶ The results suggested that the risk of having atherosclerosis was greater in areas with high water fluoride levels. As this study included fluoride levels that were well above that used in Australia for water fluoridation (>3.0 ppm), these results have limited applicability to Australia. In addition, there were a number of potential confounding factors not included in the study such as levels of income, living conditions and high rates of smoking.

Four studies assessed high blood pressure and water fluoride levels.^{9;118;125;126} Two studies had opposite results and their findings could be explained by other factors that are known to be related to high blood pressure.^{125;126} Another study found an increased risk of having high blood pressure in areas with high fluoride levels in water. These levels were up to two times higher than levels used in Australia for water fluoridation. The final study simply reported how common high blood pressure was in two regions. These results can be explained by chance or by other factors known to be related to high blood pressure.

^{ad} *The evidence shows no association of a health outcome* – this wording was used when the Fluoride Reference Group was confident that the body of evidence was valid, applicable to the Australian context and consistently demonstrated that there was no association between water fluoridation and the health outcome.

Evidence Statement

There is insufficient evidence^{ae} to reach a conclusion about any association between atherosclerosis and water fluoridation at current Australian levels.

There is insufficient evidence^{ae} to reach a conclusion about any association between hypertension and water fluoridation at current Australian levels.

Intelligent quotient (IQ)

Introduction

Intelligence is measured using an IQ test. Although there are different tests used, intelligence measured in a test reflects not only a person's innate ability, but also their access to education and other social factors which influence learning and development. These are important confounders which should be measured in studies investigating whether IQ is associated with another factor.

Description of the evidence

Both the 2000 York review and the 2007 NHMRC review included the same study that assessed the relationship between fluoride and cognitive function.¹²⁷ They reported a decreased risk of cognitive impairment with exposure to fluoride but no measure of the statistical significance of this effect was provided.

One additional study of acceptable quality was identified in the 2016 NHMRC Evidence Evaluation which reported no association between fluoride levels in drinking water and cognitive performance.¹²⁸

The same two studies on IQ were identified in the 2000 York review and the 2007 NHMRC review.^{129;130} While both found a decrease of IQ in children exposed to fluoride in water; the studies were of insufficient quality for the review authors to be able to make any definitive conclusions about any relationship between water fluoride levels and IQ. In one study the levels of fluoride were much higher (4 ppm) than that used in Australia for water fluoridation. The results of the other study were very likely confounded by iodine exposure. Neither of the studies took account of other confounders known to influence IQ such as parental education.

The 2016 NHMRC Evidence Evaluation found 11 additional studies investigating the relationship between water fluoride levels and IQ.^{7;10;12;131-138} Eight of these studies found that average IQ was lower in the areas that had higher levels of fluoride (all higher than Australian levels) in their drinking water. Three studies found no difference in IQ between areas with different water fluoride levels.

One study was a high quality prospective cohort study, with a low risk of bias. This study took account of known confounding factors including gender, socio-economic status, breastfeeding, childhood maltreatment, perinatal insults, birth weight and educational achievement. The fluoride levels in this study were similar to that used in Australia and the study was done in a country with similar socio-economic and healthcare system characteristics (New Zealand). This study found that there was no significant difference in IQ scores at ages 7-13 years and 38 years between those exposed to water fluoridation and those not.

^{ae} *Insufficient evidence to draw any conclusion* – this wording was used when the Fluoride Reference Group was not convinced that there was enough valid evidence to draw any conclusion about the relationship between water fluoridation and the health outcome. While it may be highly unlikely, the Fluoride Reference Group was unable to definitively rule out the possibility of these health outcomes.

The remaining studies were of low quality or at a high risk of bias and all were of limited applicability to Australia. All studies included groups with water fluoride levels above the level used in Australia for water fluoridation. Only two studies adjusted for potential confounding, one of which showed no significant differences in the adjusted analysis¹²⁸ and the other of which remained confounded by exposure to arsenic.¹³⁵

Evidence Statement

The evidence shows that there is no association^{af} between the IQ or cognitive function of children or adults, and water fluoridation at current Australian levels.

Kidney stones

Introduction

The kidneys filter blood and remove waste and water from the body. Kidney stones are crystals which can form from salts in the kidney, sometimes causing severe pain and requiring treatment.

Description of the evidence

The 2000 York review did not include any studies that assessed the association between water fluoridation and kidney stones.

The 2007 NHMRC review identified one poor quality cross-sectional study that reported an increased prevalence of kidney stones in an area with fluoride concentrations higher than that would be observed with water fluoridation in Australia.¹³⁹

The 2016 NHMRC Evidence Evaluation included one additional acceptable quality ecological study that reported a significantly lower prevalence of kidney stones in areas with water fluoridation.⁴²

Evidence Statement

There is insufficient evidence^{ag} to reach a conclusion about any association between kidney stones and water fluoridation at current Australian levels.

Low birth weight

Introduction

Low birth weight babies are those born weighing less than 2.5 kg. This is usually due to the baby being born early (prematurely) or due to the baby not growing well in the womb.

^{af} *The evidence shows no association of a health outcome* – this wording was used when the Fluoride Reference Group was confident that the body of evidence was valid, applicable to the Australian context and consistently demonstrated that there was no association between water fluoridation and the health outcome.

^{ag} *Insufficient evidence to draw any conclusion* – this wording was used when the Fluoride Reference Group was not convinced that there was enough valid evidence to draw any conclusion about the relationship between water fluoridation and the health outcome. While it may be highly unlikely, the Fluoride Reference Group was unable to definitively rule out the possibility of these health outcomes.

Description of the evidence

There were no studies that investigated the association between the prevalence of low birth weight and water fluoride levels included in the 2000 York review or the 2007 NHMRC review.

The 2016 NHMRC Evidence Evaluation identified one low quality case-control study that reported an increased risk of having a low birth weight baby at fluoride levels almost five times greater than that used for water fluoridation in Australia.⁴

Evidence Statement

There is insufficient evidence^{ah} to reach a conclusion about any association between low birth weight and water fluoridation at current Australian levels.

Mortality

Introduction

Death from any cause is measured by all-cause mortality. This is a broad measure which may show an association but is also likely to be at risk of confounding as many social, economic and environmental factors can affect mortality.

Description of the evidence

Five studies were identified in the 2000 York review that assessed the association between water fluoride levels and all-cause mortality.¹⁴⁰⁻¹⁴⁴ Three studies found an increase in mortality associated with water fluoridation, one found a decrease in mortality and one found no association. No measures of the statistical significance of these associations were provided. However, for two of the studies that found an increase in mortality, the adjusted rate-ratio was 1.01, and the review authors considered these results unlikely to have reflected a statistically significant effect. The review concluded that because of the small number of studies, the study designs used and the low quality of studies that there was insufficient evidence to reach a conclusion. The 2007 NHMRC review included the same five studies and did not identify any additional studies. This review reiterated the findings of the 2000 York review that these studies provided insufficient evidence to reach a conclusion.

The 2016 NHMRC Evidence Evaluation included a single ecological study of acceptable quality that assessed overall mortality and exposure to water fluoridation.⁴² This study found that mortality in the areas supplied with fluoridated water was slightly less than that in the non-fluoridated areas after taking into consideration age, gender, deprivation and ethnicity. The study concluded that the effect was so small that this was likely to have occurred as a result of chance, or possibly confounding.

Evidence Statement

The evidence shows that there is no association^{ai} between all-cause mortality and water fluoridation at current Australian levels.

ah *Insufficient evidence to draw any conclusion* – this wording was used when the Fluoride Reference Group was not convinced that there was enough valid evidence to draw any conclusion about the relationship between water fluoridation and the health outcome. While it may be highly unlikely, the Fluoride Reference Group was unable to definitively rule out the possibility of these health outcomes.

ai *The evidence shows no association of a health outcome* – this wording was used when the Fluoride Reference Group was confident that the body of evidence was valid, applicable to the Australian context and consistently demonstrated that there was no association between water fluoridation and the health outcome.

Muscle and skeletal effects

Introduction

Consuming large amounts of fluoride over a long period of time can cause the disease of skeletal fluorosis, which, at its most severe it can cause deformities, pain and serious disability.^{145,146} It is found in parts of China, Ethiopia, India, South Africa, and Tanzania where water contains very high levels of naturally occurring fluoride.

Osteoporosis, which is when bones become fragile, is one of the most common diseases affecting bones. There are many known risk factors for osteoporosis such as age, sex and dietary factors. Osteoporosis is often diagnosed following a bone fracture so measuring bone fractures is a means of looking for any association between fluoride and osteoporosis.

Musculoskeletal pain is not a specific disease but a self-reported health outcome in which pain is reported in joints or muscles. Self-reported outcomes, particularly those which are poorly defined, are often not very accurate which results in the studies being at high risk of bias.

Description of the evidence

One study was included in the 2000 York review that assessed skeletal fluorosis. This study found that skeletal fluorosis was more common at higher fluoride levels.¹⁴⁷ The 2007 NHMRC review did not locate any more studies on this topic.

The 2016 NHMRC Evidence Evaluation identified two low quality ecological studies that assessed how common skeletal fluorosis is in areas with different levels of fluoride in drinking water.^{5,8} Both studies were from areas of India where skeletal fluorosis is found and where the levels of fluoride in the drinking water are much higher than the levels used for water fluoridation in Australia (>5.0 ppm in one study and up to 3.7 ppm in the other). The results did not show any clear increase in the occurrence of skeletal fluorosis with increasing fluoride levels.

There were no studies that investigated the association between osteoporosis and water fluoridation included in the 2000 York review or the 2007 NHMRC review.

The 2000 York review²⁰ included 18 studies with 30 analyses undertaken^{ai} that investigated the relationship between water fluoridation and the occurrence of hip fracture.¹⁴⁸⁻¹⁶⁵ Most of the studies had a high risk of bias or did not account for confounders. Twenty-one of the analyses did not find an association between hip fractures and water fluoridation. Five suggested that water fluoridation was associated with fewer hip fractures and four with increased hip fractures. The review authors concluded that, overall, there was no clear association between water fluoridation and hip fracture.

The 2007 NHMRC review³ located one additional study that found no increased risk of hip fracture at fluoride levels similar to that used for water fluoridation in Australia.¹⁶⁰ Two systematic reviews were also identified and both concluded that water fluoridation at levels used to prevent tooth decay has no effect on hip fracture risk.^{166,167}

The 2016 NHMRC Evidence Evaluation included two studies that investigated the number of hip fractures in areas with and without fluoridated water.^{42,168} Both studies involved large numbers of people and also looked at other factors known to be associated with hip fractures including sex and age. The results found no difference in the occurrence of hip fracture at levels of water fluoridation used in Australia.

The 2016 NHMRC Evidence Evaluation identified one study that assessed osteoporosis and fluoride levels in water.¹⁶⁹ The results of this study suggested there was no association between osteoporosis and fluoride levels in water. However, as one of the fluoride levels considered was well above that used in Australia, the results of this study are unlikely to be relevant to water fluoridation in Australia. Further, this study assessed osteoporosis using a plain x-ray of the shin and forearm, which would not commonly be used for diagnosing osteoporosis in Australia as it may be inaccurate. In Australia, osteoporosis is usually diagnosed using a bone density test.

There were no studies that investigated the association between musculoskeletal pain and water fluoridation included in the 2000 York review and the 2007 NHMRC review.

The 2016 NHMRC Evidence Evaluation included two studies that looked at the association between self-reported musculoskeletal pain and water fluoridation.^{170,171} One study from Thailand reported higher rates of joint pain with high levels of fluoride (>1.5 ppm).¹⁷¹ However these results could be explained by other known causes of joint pain. In addition, the levels of fluoride were higher than levels used for water fluoridation in Australia.

The other study from India reported an association between lower back pain with higher levels of water fluoride (>0.7 ppm).¹⁷⁰ Knee pain and leg pain were not associated with fluoride water levels. No important risk factors for lower back pain (such as lack of exercise, smoking, and excessive weight) were considered. The Fluoride Reference Group considered that it was very likely that these other factors could explain the study's findings.

Evidence Statement

There is insufficient evidence^{aj} to reach a conclusion about any association between skeletal fluorosis and water fluoridation at current Australian levels.

There is insufficient evidence^{aj} to reach a conclusion about any association between osteoporosis and water fluoridation at current Australian levels.

The evidence shows that there is no association^{ak} between incidence of hip fracture and water fluoridation at current Australian levels.

There is insufficient evidence^{aj} to reach a conclusion about any association between musculoskeletal pain and water fluoridation at current Australian levels.

Thyroid function

Introduction

The thyroid gland is in the neck and releases hormones to regulate growth and energy expenditure.

Description of the evidence

The 2000 York and 2007 NHMRC reviews did not include any studies that assessed the association of water fluoride concentrations and thyroid function.

^{aj} *Insufficient evidence to draw any conclusion* – this wording was used when the Fluoride Reference Group was not convinced that there was enough valid evidence to draw any conclusion about the relationship between water fluoridation and the health outcome. While it may be highly unlikely, the Fluoride Reference Group was unable to definitively rule out the possibility of these health outcomes.

^{ak} *The evidence shows no association of a health outcome* – this wording was used when the Fluoride Reference Group was confident that the body of evidence was valid, applicable to the Australian context and consistently demonstrated that there was no association between water fluoridation and the health outcome.

The 2016 NHMRC Evidence Evaluation included two low quality studies (one ecological and one cross-sectional) that investigated thyroid function in children.^{82;172} Both studies reported an increase in thyroid stimulating hormone (TSH) associated with levels of fluoride above that used in the Australian context. However, all TSH levels were within the normal range. There was no difference in the other thyroid function tests.

Evidence Statement

There is insufficient evidence^{al} to reach a conclusion about any association between thyroid function and water fluoridation at current Australian levels.

Self-reported health outcomes

Introduction

Self-reported health outcomes are assessed by asking someone whether they have experienced them. Hence, they are less reliable than an outcome which can be measured such as number of decayed teeth. The self-reported outcomes included here are not associated with any specific disease and are complaints which most people would be likely to experience from time to time.

Description of the evidence

The 2000 York and 2007 NHMRC reviews did not include any studies that assessed the association of water fluoridation and gastric discomfort, headache or insomnia.

Two low quality ecological studies were identified in the 2016 NHMRC Evidence Evaluation.^{171;173} Both studies reported that the prevalence of gastric discomfort/problems was higher in villages with higher water fluoride levels. No statistical analysis was conducted and no other factors that could explain the symptoms were elicited. Therefore it is possible that the reported findings may be due to chance or these other, unmeasured confounding factors.

The 2016 NHMRC Evidence Evaluation identified two low quality ecological studies that investigated the association between water fluoride levels and headache.^{171;173} Both studies found that people in the villages with the higher water fluoride levels recalled having headaches more often. Again, no statistical analysis was reported and possible confounding factors were not considered.

Two low quality ecological studies were identified in the 2016 NHMRC Evidence Evaluation that assessed the association between fluoride water levels and the prevalence of insomnia.^{171;174} Both studies reported a higher prevalence of insomnia in villages with water fluoride levels >1.5 ppm although in one study¹⁷¹ this was only seen in adults. There was no statistical analysis and no possible confounding factors were considered.

^{al} *Insufficient evidence to draw any conclusion* – this wording was used when the Fluoride Reference Group was not convinced that there was enough valid evidence to draw any conclusion about the relationship between water fluoridation and the health outcome. While it may be highly unlikely, the Fluoride Reference Group was unable to definitively rule out the possibility of these health outcomes.

Evidence Statement

There is insufficient evidence^{am} to reach a conclusion about any association between gastric discomfort and water fluoridation at current Australian levels.

There is insufficient evidence^{am} to reach a conclusion about any association between headache and water fluoridation at current Australian levels.

There is insufficient evidence^{am} to reach a conclusion about any association between insomnia and water fluoridation at current Australian levels.

Health outcomes in earlier reviews with insufficient evidence

Some studies included in the 2000 York and 2007 NHMRC reviews assessed the association of water fluoridation and health outcomes for which no additional evidence was identified in the 2016 NHMRC Evidence Evaluation. Interpreting the results for these studies was difficult due to the small number of studies, the study designs, lack of control for possible confounding factors, and the low quality of the studies. Therefore, there was insufficient evidence to reach any conclusions for the following health outcomes:

- age of menarche
- Alzheimer's disease
- anaemia during pregnancy
- birth rates
- childhood behavioural problems
- congenital malformations
- coronary heart disease mortality
- foetal and perinatal mortality
- fractures (other than hip fractures)
- goitre
- otosclerosis
- primary degenerative dementia
- slipped epiphysis
- sudden infant death syndrome
- thyroid cancer.

^{am} *Insufficient evidence to draw any conclusion* – this wording was used when the Fluoride Reference Group was not convinced that there was enough valid evidence to draw any conclusion about the relationship between water fluoridation and the health outcome. While it may be highly unlikely, the Fluoride Reference Group was unable to definitively rule out the possibility of these health outcomes.

Resource use and cost-effectiveness

Providing fluoridated water to a population requires an investment. But the costs involved in establishing and maintaining a fluoridated water supply have been shown to be significantly lower than the savings made in reduced dental treatments. That is, water fluoridation is found to be cost-effective.

Evidence on the cost-effectiveness of water fluoridation was systematically reviewed in 2015. This study found:

- The annual cost of providing water fluoridation ranged from \$0.11 to \$4.92 per person for communities with at least 1,000 population.
- The annual savings ranged from \$5.49 to \$93.19 per person in avoided costs such as health care savings and avoided days off work.¹⁷⁵

A 2015 cost-effectiveness analysis of water fluoridation in New Zealand found:

- The total cost per person was between NZ\$0.37 to NZ\$5.63 per year depending on the size of the community (the cost per head was higher in smaller communities).
- Water fluoridation resulted in a cost saving for the total population and children in all communities of over 5,000 people.
- Water fluoridation with dental treatment was more cost-effective than treatment alone.¹⁷⁷

Specific Australian studies on the cost-effectiveness of water fluoridation have found:

- That for every dollar spent on fluoridation, between \$7 and \$18 is saved due to avoided treatment costs.¹⁷⁷⁻¹⁷⁹
- Over 25 years, water fluoridation had saved the state of Victoria about \$1 billion through avoided dental costs, days away from work or school and other costs.¹⁸⁰

Ethical considerations

Ethics is about doing the right thing, which can involve weighing up benefits and harms. For a public health intervention like adding fluoride to drinking water, it is important to consider the good effects, such as improved oral health versus any disadvantages, such as reducing people's choices about the water they drink.

Ethical justifications for water fluoridation

The 2016 NHMRC Evidence Evaluation confirmed that water fluoridation provides a benefit to health by reducing occurrence and severity of tooth decay in children, adolescents and adults. The main ethical justification for fluoridating water is that individuals place high importance in their health and maintaining good health is seen to provide a benefit to society. As water fluoridation reduces tooth decay, it also helps to reduce infection, pain, avoidable treatment (including hospitalisation) and other consequences of tooth decay. Better oral health also provides a cost saving as less money has to be spent on tooth restoration.

The main ethical justification for fluoridating water is that it provides an important dental health benefit to society. Water fluoridation reduces dental caries^{20;21;41-47;49-55}, which in turn reduces infection, pain, avoidable treatment (including hospitalisation^{42;74;75}) and other consequences of tooth decay. This is an important benefit for children and adults. Better oral health also provides a cost saving as less money has to be spent on tooth restoration.^{175;178;179}

Water fluoridation may help to reduce health inequalities by providing a benefit to all members of society. Water fluoridation may benefit most those at greater risk of tooth decay, including those who might be less likely to adopt preventive dental behaviours and who struggle to pay for dental care.^{42;48;57;63-67;69;71} This is important in Australia where there are differences in dental health between different sectors of the community.^{14;33;38;180}

Another reason for recommending water fluoridation is that it demonstrates community solidarity, it is an action taken by the government to look after the dental health of all citizens. We tend to think that governments should act to support good health, through ensuring things like clean air and safe foods and many people see water fluoridation in the same way.

Ethical concerns about water fluoridation

Even if water fluoridation provides benefits, it might not be justified if it causes serious harms. We know that water fluoridation is associated with mild to very mild dental fluorosis (changing the appearance of the teeth) within the population. Generally children and parents are not concerned by the appearance of teeth with very mild or mild dental fluorosis. There is no evidence that water fluoridation at Australian levels is associated with any other health effects.

Some people are concerned that fluoride is a poison, medication or drug, which should not be added to the drinking water. Regulatory bodies (like the Therapeutic Goods Administration) do not consider fluoridated drinking water to be a therapeutic good or medicine.¹⁸¹

The most common ethical argument put forward against water fluoridation is that fluoridating an area's water may impose on people's right to choose to drink water which is not fluoridated.^{182,183} Although, it should be noted that water supplies may naturally contain some level of fluoride. Water fluoridation certainly reduces choices about drinking fluoridated water in areas where naturally occurring levels are lower than intentionally fluoridated water. It is possible to avoid drinking fluoridated water by using rain water, bottled water or a reverse osmosis filter, but these measures can be expensive so may not be available to everyone.

Other government actions to improve public health raise similar ethical issues, such as the chlorination of water or the addition of folic acid to bread.¹⁸⁴ Even though these measures may not improve the health of all members of the community, there is a view that it is reasonable to accept a restriction on some choices, so that other members of the community may be protected from potentially serious health problems.

In order to reach a decision about whether it is ethical to provide water fluoridation to the community, the following issues were considered:

1. ***Is there a need for water fluoridation?*** As tooth decay is a significant health problem in Australia, we do need strategies to improve and safeguard dental health.
2. ***Is water fluoridation at Australian levels effective in reducing caries?*** The 2016 NHMRC Evidence Evaluation found that water fluoridation is effective in reducing tooth decay by between 26-44%.
3. ***Is water fluoridation at Australian levels harmful?*** No. Water fluoridation in Australia is associated with mostly very mild or mild dental fluorosis which is unlikely to be of concern to people. There is no evidence that water fluoridation at Australian levels causes any health problems.
4. ***Does water fluoridation lead to unacceptable restrictions in individual choice?*** Water fluoridation does limit individual choices to drink non-fluoridated water. It may be difficult and/or expensive for people to avoid fluoridated water in areas with water fluoridation programs. Again it should be noted that 'non-fluoridated' water may naturally contain some level of fluoride.
5. ***Are the values of equity and solidarity important in the Australian community?*** These values are important. Water fluoridation can reduce health inequalities as it provides dental benefits to people who may find it difficult to adopt preventive dental behaviours and may not be able to afford dental care. Is water fluoridation a proportionate response to the problem of tooth decay? The answer to this question depends on the value placed on preventing tooth decay versus the value placed on people's right to choose about fluoride in their tap water. The Fluoride Reference Group considered that the benefits of water fluoridation outweigh any concerns, including that water fluoridation does restrict people's choices about water. But this is a matter that people may disagree over. Of note, the large majority of the Australian public support water fluoridation.^{185,186}
6. ***Finally, the Fluoride Reference Group considered what would happen if we stopped providing water fluoridation.*** People would have more choice about whether or not to consume fluoride, but this would come at the cost of higher rates of tooth decay in children and adults. Children and adults with tooth decay may feel pain, be less satisfied with their dental appearance, require costly dental treatment and may suffer other health effects. Stopping water fluoridation would have the most impact on people who struggle financially, as they would be least likely or able to afford dental care such as fluoride treatments. Differences in health between well off and disadvantaged groups might increase, as would the costs of dental and other health care. Given the government has limited funding to dedicate to health care, increased costs in the treatment of preventable tooth decay and other associated diseases may reduce the resources that could otherwise be used for other health care measures. Moreover, water fluoridation is cost-effective and can save individuals and communities money by reducing the need for dental treatment.

Overall conclusion

Water fluoridation within the current recommended range in Australia (0.6 to 1.1 mg/L) is effective in reducing the occurrence and severity of tooth decay in children, adolescents and adults. In Australia, water fluoridation within this range can be associated with an increase in dental fluorosis. This is often not readily visible and it has no effect on the function of teeth. There is no evidence that water fluoridation within the current Australian range is associated with any adverse health effects.

Appendices

A Membership and terms of reference of the Fluoride Reference Group

Membership

Members	Job title and other relevant roles
Emeritus Professor Judith Whitworth AC FTSE (Chair)	Emeritus Professor, John Curtin School of Medical Research, Australian National University
Professor Vicki Anderson	Director, Clinical Sciences Research, Murdoch Childrens Research Institute Director, Psychology, The Royal Children's Hospital Professorial Fellow, School of Psychological Sciences, University of Melbourne
Doctor Meenakshi Arora	Lecturer in Environmental Engineering, Melbourne School of Engineering, University of Melbourne
Associate Professor Stephen Corbett	Director, Centre for Population Health, Western Sydney Local Health District Conjoint Associate Professor, School of Public Health, University of Sydney and Western Clinical School, Westmead
Professor Dallas English	Professor of Epidemiology and Biostatistics, Centre for Epidemiology and Biostatistics, Melbourne School of Population and Global Health, University of Melbourne Research Fellow, Cancer Epidemiology Centre, Cancer Council Victoria
Professor Matthew Gillespie	Professor, Faculty of Medicine, Nursing and Health Sciences, Monash University
Professor Sharon Goldfeld	Paediatrician, Centre for Community Child Health, Royal Children's Hospital Co-Group Leader, Policy Equity and Translation, Murdoch Childrens Research Institute Professor, Department of Paediatrics, Faculty of Medicine, Dentistry and Health Sciences, University of Melbourne
Professor Alison Jones	Executive Dean; Faculty of Science, Medicine and Health, University of Wollongong Clinical Toxicologist, Blacktown Hospital
Associate Professor Frederic Leusch	Associate Professor and Head of Discipline, Soil Water and Energy, School of Environment, Griffith University
Professor Mike Morgan ^{an}	Head of School, Melbourne Dental School, Faculty of Medicine, Dentistry and Health Sciences, University of Melbourne
Ms Debra Petrys	Member, Consumers Health Forum Australia
Adjunct Professor Kaye Roberts-Thomson	School of Dentistry, University of Adelaide
Professor Wendy Rogers	Professor of Clinical Ethics, Department of Clinical Medicine and Department of Philosophy, Macquarie University
Emeritus Professor A. John Spencer	Emeritus Professor, Australian Research Centre for Population Oral Health, School of Dentistry, University of Adelaide
Professor Clive Wright	Associate Director (Oral Health) and Clinical Professor, Centre for Research and Education on Ageing, Concord Clinical School, the University of Sydney and Concord Repatriation General Hospital, Sydney Local Health District

^{an} Resigned on 25 July 2016 due to other work commitments.

Terms of reference

1. The Fluoride Reference Group will guide the development of an evaluation of the evidence on the health effects of water fluoridation, focusing on studies published since 2006.
2. The Fluoride Reference Group will consider the outcomes of this evaluation, and use these findings to:
 - a) inform the development of an evidence evaluation report that synthesises the evidence and identifies critical gaps in the current evidence base
 - b) guide the identification of key issues to be considered by the Council and CEO of NHMRC as the Office of NHMRC translates the 2016 NHMRC Evidence Evaluation into an Information Paper on the artificial fluoridation of drinking water.
3. The Fluoride Reference Group will consider comments received during consultation on the draft Information Paper.
4. The Fluoride Reference Group will report to the Council of NHMRC.

B Quality assurance processes

Rigorous quality assurance processes support the development of all NHMRC health advice. The quality assurance processes used to support the quality of the 2016 NHMRC Evidence Evaluation and the Information Paper are outlined below.

- **Declaration of interests** — As part of their formal appointment to the Fluoride Reference Group, each member and observer was required to disclose any factors that may cause, or be perceived to cause, a conflict of interest with their duties as members of the Fluoride Reference Group. The declared interests of all Fluoride Reference Group members are published on NHMRC's website. Under the *Public Governance, Performance and Accountability Act 2013*, members have a responsibility to declare any interests to the whole committee and members have a joint responsibility to decide on the management of any perceived or real conflict. No unmanageable conflicts were identified by the Fluoride Reference Group or NHMRC. Meetings of the Fluoride Reference Group involved a quorum of members and decision-making was consensus-based.
- **Independent evidence evaluation** — The 2016 NHMRC Evidence Evaluation was conducted by independent evidence reviewers with expertise in systematic review methodology. The evidence reviewers were selected from NHMRC's Health Evidence Panel through a competitive tender process. The 2016 NHMRC Evidence Evaluation team completed a declaration of interest process before being appointed by NHMRC and no conflicts of interest were identified.
- **Methodological review** — Independent reviewers examined the methodological quality of the report of the evidence review to ensure that the review followed the systematic and rigorous approach documented in the review protocol. The methodological reviewers were appropriately qualified in systematic review processes and methodology. The methodological review team completed a declaration of interest process before being appointed by NHMRC and no conflicts of interest were identified.
- **Public consultation** — The draft Information Paper will be released for public consultation. The public consultation process will allow members of the public to make submissions about the document, comment on the evidence-based approach that was undertaken and provide any relevant additional evidence for consideration. The draft Information Paper will be revised in light of the submissions received during public consultation.
- **Expert review** — The Information Paper will undergo expert review before being finalised to ensure that the evidence was appropriately interpreted and synthesised.
- **Consideration by the Council of NHMRC** — The consultation draft was, and final Information Paper will be considered by the Council of NHMRC for its recommendation to the Chief Executive Officer that the documents be released. The Council has a broad range of experience and expertise in health and medical research. Council's final approval of NHMRC health advice documents ensures that the checks and balances at all stages of the process have been met and that any material issued by NHMRC is evidence-based, robust and meets international standards.

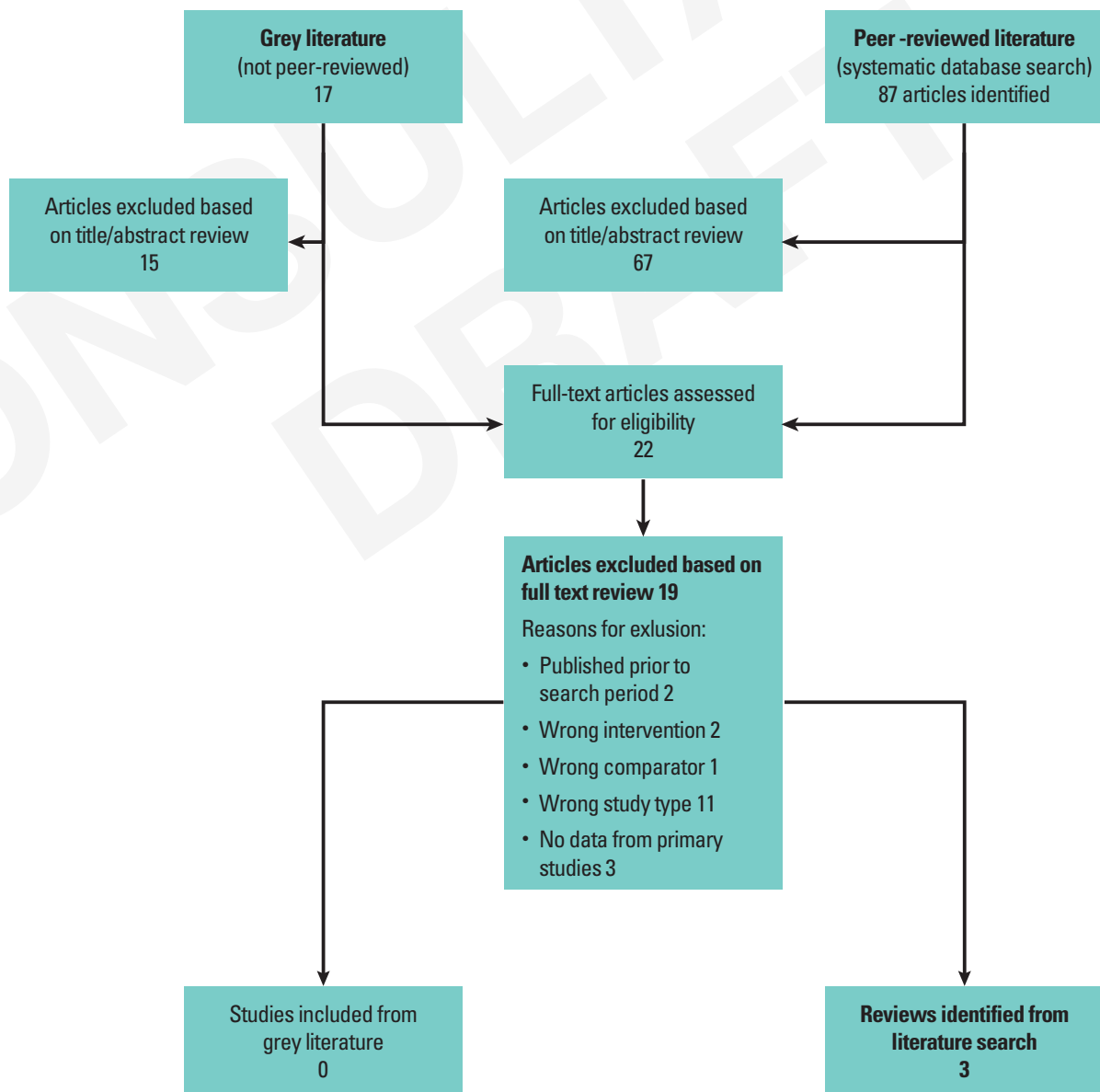
C Selection of literature

All literature searches in the 2016 NHMRC Evidence Evaluation were conducted from 2006 onwards to update the 2007 NHMRC review.

Existing reviews on the effect of water fluoridation on tooth decay

Search terms used to search electronic databases for the review of existing reviews which followed a systematic approach to evaluate studies on water fluoridation and tooth decay included: *fluoridation*, *water supply* and *systematic review*. This search was undertaken in November 2015 and the process for selecting existing reviews to be included in this component of the 2016 NHMRC Evidence Evaluation is provided in Figure 6.

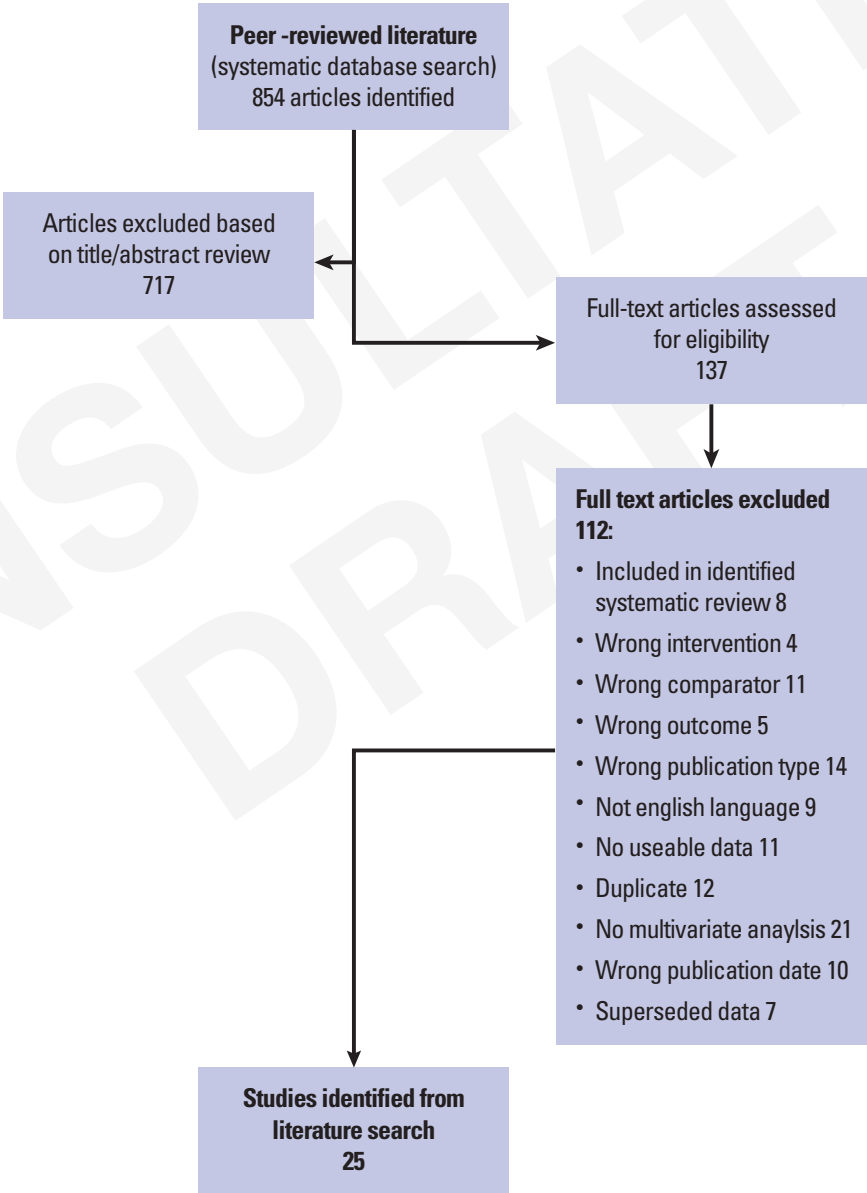
Figure 6 Process for selecting literature for inclusion in the NHMRC Evaluation of existing reviews on the effects of water fluoridation on tooth decay



Research studies on the effect of water fluoridation on tooth decay

Search terms used for the review of research studies on water fluoridation and tooth decay included: *fluoridation, water supply* and *dental caries, tooth demineralisation, decay, dmft* or *dmfs*. This search was undertaken in November 2015 and the process for selecting literature for inclusion in this component of the 2016 NHMRC Evidence Evaluation is provided in Figure 7.

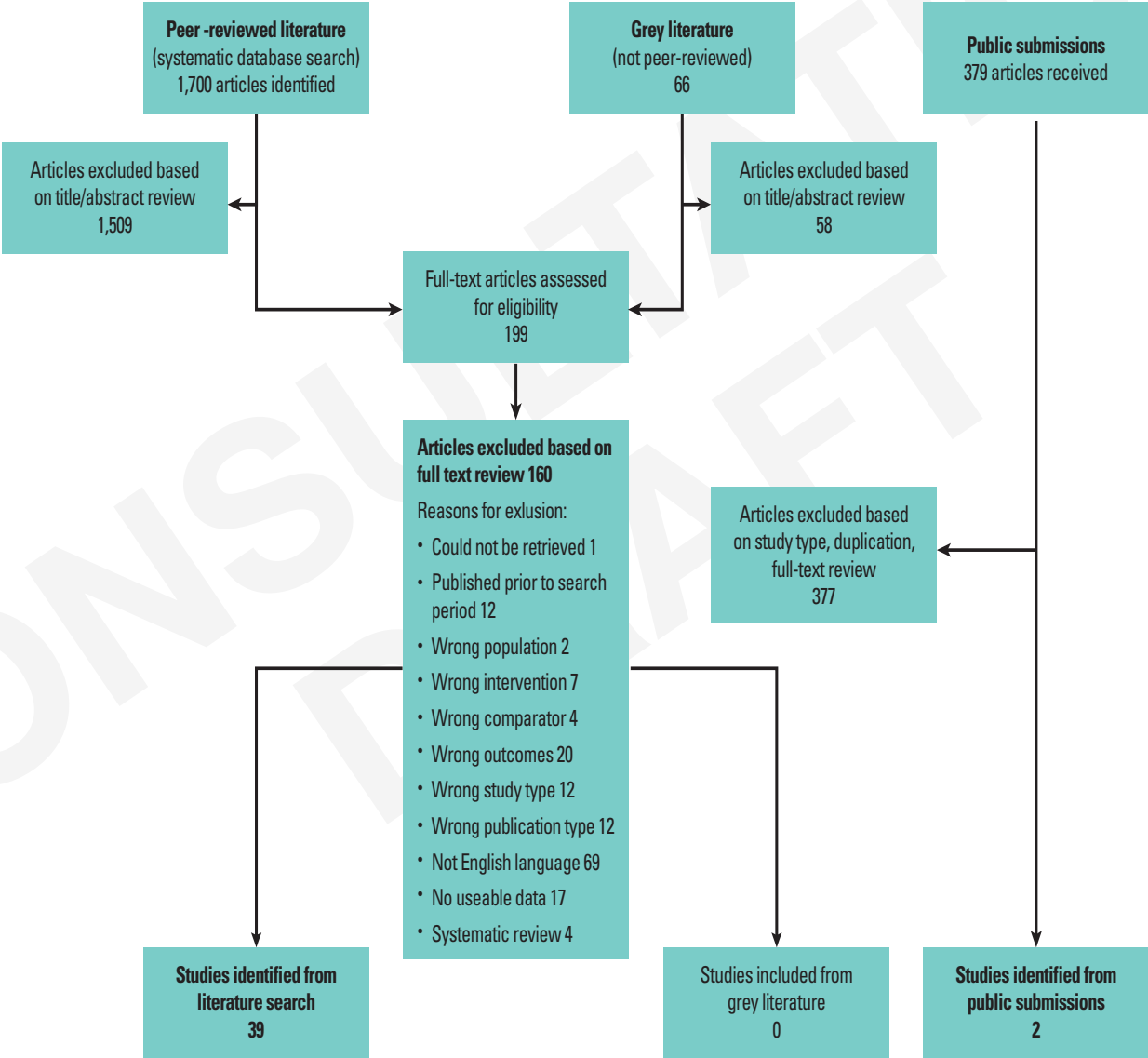
Figure 7 Process for selecting literature for inclusion in the NHMRC review of primary studies looking at tooth decay



Research studies on any other health effects of water fluoridation

Search terms used for the review of any other health effects of water fluoridation included: *fluoridation* and *water supply*. This search was undertaken in October 2014 and the process for selecting literature for inclusion in this component of the review is provided in Figure 8.

Figure 8 Process for selecting literature for the systematic review of the health effects of water fluoridation



D Current state and territory regulations

Table 5. State and territory fluoride legislation and regulations

<p>Australian Capital Territory</p>	<p><i>Licensed condition issued under the Public Health Act 1997</i> http://www.legislation.act.gov.au/a/1997-69/</p> <p><i>Clause 36 of the Utilities (Technical Regulation) Act 2014</i> http://www.legislation.act.gov.au/a/2014-60/</p>
<p>New South Wales</p>	<p><i>Fluoridation of Public Water Supplies Act 1957</i></p> <p><i>Fluoridation of Public Water Supplies Regulation 2012</i></p> <p><i>NSW Code of Practice for Fluoridation of Public Water Supplies</i> http://www.health.nsw.gov.au/environment/water/Pages/fluoridation.aspx</p>
<p>Northern Territory</p>	<p><i>The Use of Fluorides in the Northern Territory – position statement 2010</i> http://www.health.nt.gov.au/Oral_Health/Water_Fluoridation/index.aspx</p>
<p>Queensland</p>	<p><i>Water Fluoridation Act 2008 (current as at 1 November 2013)</i> https://www.legislation.qld.gov.au/LEGISLTN/CURRENT/W/WatrFluorA08.pdf</p> <p><i>Water Fluoridation Regulation 2008 (current as at 21 December 2012)</i> https://www.legislation.qld.gov.au/LEGISLTN/CURRENT/W/WatrFluorR08.pdf</p> <p><i>Water Fluoridation Code of Practice (revised September 2013)</i> https://www.health.qld.gov.au/public-health/industry-environment/environment-land-water/water/fluoridation/default.asp</p>
<p>South Australia</p>	<p><i>No legislation or regulations</i></p>
<p>Tasmania</p>	<p><i>Fluoridation Act 1968</i> http://www.thelaw.tas.gov.au/tocview/content.w3p;doc_id=87++1968+AT@EN+20111005000000;rec=0</p> <p><i>Fluoridation (Interim) Regulations 2009</i> http://www.thelaw.tas.gov.au/tocview/index.w3p;cond=ALL;doc_id=%2B14%2B2009%2BAT%40EN%2B20160817150000;histon=;pdfauthverid=;prompt=;rec=;rtfauthverid=;term=fluoride;webauthverid=</p>
<p>Victoria</p>	<p><i>Health (Fluoridation) Act 1973</i></p> <p><i>Code of practice for fluoridation of drinking water supplies 2009</i> https://www2.health.vic.gov.au/public-health/water/water-fluoridation/water-fluoridation-legislation</p>
<p>Western Australia</p>	<p><i>Fluoridation of Public Water Supplies Act 1966 Reprinted under the Reprints Act 1984 [as at 8 August 2014]</i> https://www.slp.wa.gov.au/legislation/statutes.nsf/main_mrtitle_348_homepage.html</p>

E Other government policy advice relating to fluoride

Safe drinking water

NHMRC's *Australian Drinking Water Guidelines 2011* (ADWG) provide guidance to Australia's state and territory governments, councils, and the water supply industry on what constitutes good quality drinking water and how it can be achieved and assured.¹⁸⁷ The guidelines are based on the best available scientific evidence and provide a framework for good management of drinking water supplies to ensure safety at the point of use.

The ADWGs are not mandatory standards. However, they are relied upon by agencies with responsibilities associated with the supply of drinking water, and are referred to in state and territory legislation on water quality.

Drinking water suppliers, water regulators and health authorities closely monitor the addition of fluoride to public water supplies. The ADWGs recommend that fluoride levels should not exceed 1.5 mg/L. This value is not a recommended value for fluoridation of water supplies. Rather, it is an upper limit that has been set to protect children from the risk of dental fluorosis. It is considered that this level would also protect against any other unwanted health effects which may occur at higher exposures and at different life stages.

The ADWGs contain fact sheets on the acceptable use of hydrofluorosilic acid, sodium fluoride, and sodium fluorosilicate to artificially fluoridate drinking water to the optimal level for dental health, including guidance on their use in controlled doses to ensure safe, good quality drinking water.

Fluoride in food and drinks

NHMRC's *Infant Feeding Guidelines: Information for health workers* (2012)¹⁸⁸ advise that boiled and cooled tap water should be used to reconstitute infant formula powder. This is based on the assumption that the tap water is fluoridated to approximately 1 mg/L. For children aged 6-24 months living in areas where water is not fluoridated, parents should seek the advice of a dentist.

Food Standards Australia New Zealand (FSANZ) is responsible for developing standards that regulate the use of ingredients, additives, vitamins and minerals. FSANZ is also responsible for some labelling requirements for packaged and unpackaged food, e.g. specific mandatory warnings or advisory labels.¹⁸⁹ The *Australia New Zealand Food Standards Code* covers the composition of some foods and recommends that the concentration of fluoride in infant formula powder should be low enough to allow for reconstitution with fluoridated water.⁸⁷ Under Standard 2.9.1 (Clause 23) of the code, infant formula products that exceed the limits of fluoride are required to contain a label indicating the potential risk of dental fluorosis and recommending discussion with a medical practitioner or other health professional before use.

For bottled or packaged drinking water, the *Australia New Zealand Food Standards Code* allows between 0.6 and 1.0 mg/L (including naturally occurring and added fluoride) to align with the NHMRC's 2007 Public Statement (Standard 2.6.2, Clause 4.c).¹⁹⁰

A 2009 FSANZ risk assessment found there is a history of safe use of fluoride in tap water at this level. Fluoridated bottled water (at the approved levels) is nutritionally equivalent to fluoridated tap water. Not all bottled water contains fluoride. However, all bottled water with fluoride added must be clearly labelled. FSANZ states that bottled water with added fluoride is safe for everyone and can be used to make up infant formula.¹⁹¹

The 2006 *Nutrient Reference Values for Australia and New Zealand* (NRVs) provide information on the amount of individual nutrients that are needed to ensure health and prevent chronic disease. This resource is used by health professionals developing nutritional advice for individuals, and by health policy areas. The NRVs include recommended Adequate Intake (AI) and Upper Levels (UL) of daily fluoride intake for different age groups, taking into account the sources of fluoride from food, beverages and toothpaste.¹⁹² The Australian Government Department of Health, in conjunction with the New Zealand Ministry of Health is currently reviewing the NRVs to ensure that they remain relevant, appropriate and useful. The NRVs for fluoride intake in infants and young children is being revised as part of this process. A draft report on the revised NRVs for fluoride was released for public consultation in October 2015 and is currently being finalised.¹⁹³

Fluoride is not a therapeutic good

The Therapeutic Goods Administration (TGA) is the Australian regulator responsible for making sure that therapeutic goods used to prevent or manage health conditions in Australia are safe and of good quality. Fluoridated drinking water is not considered to be a therapeutic good or medicine by the TGA.¹⁸¹

Glossary

Association: a statistical relationship in which two or more events, attributes or other variables occur together either more or less often than expected by chance.

Bias: any influence or action at any stage of a study that systematically distorts the findings.

Blinding: procedures intended to keep participants in a study from knowing some facts or observations that might bias or influence their actions or decisions regarding the study.

Case-control study: a study in which participants are selected by whether they have the outcome of interest (“cases”) or not (“controls”) and the exposure levels of each group is compared.

Cohort study: see Prospective cohort study.

Chance: the probability that an event will happen.

Chromosome: structures inside a cell nucleus that contain genetic material.

Confounding: a type of bias where a third factor distorts the relationship between the outcome and exposure of interest and can lead to untrue results.

Cross-sectional study: a study in which the outcome(s) of interest is measured in a two groups of participants (one exposed to, in this review, water fluoridation and the other not exposed) at one point in time.

Deciduous teeth (synonym: primary teeth): the first set of teeth which start to come through the gums at about the age of 6 months and is complete at about 2½ years; when complete it consists of 20 teeth; deciduous teeth are gradually replaced by the permanent teeth.

Dental caries: see Tooth decay.

Dose-response relationship: a change in dose is associated with a correlated change in effect.

Ecological studies: a study in which the exposure(s) and/or outcome(s) are measured on a population basis (in this review, fluoridated water is an exposure on a population basis).

Economic benefit: a benefit to a person, business or society that can be expressed numerically as an amount of money that will be saved or generated as the result of an action.

Epidemiology: the study of the occurrence and distribution of health and disease in populations, including the study of what influences them, and the application of this knowledge to control relevant health problems.

Equity: the absence of avoidable or remediable differences among groups of people.

Ethics: consideration the perceived risks and benefits of the technologies involved, and their impact on society; major principles on which ethical decision-making is based are: benevolence (doing good, acting in the best interests of an individual and of all, securing their well-being); non-maleficence (preventing harm); autonomy (acting in a way that maximizes freedom of choice for the individual); confidentiality (respecting privacy of information) and justice (treating all fairly, unless there are morally relevant differences between people).

Exposure: for this review, exposure relates to living in an area with a fluoridated water supply.

Fluoride: naturally occurring inorganic ion of fluorine, a non-metallic gaseous element.

Fluoridation: for this review, this indicates water fluoridation.

Grey literature: multiple document types and literature produced by government, academia, business and other organisations in electronic or print format; it is not always peer-reviewed and is not controlled by commercial publishing.

Health outcome: a defined disease, state of health or health related event that has been measured in a study.

Incidence: the number of new health related events in a defined population within a specified period of time.

Inequality: for this review, inequalities are differences in health status or in the distribution of health determinants between different population groups.

Ingestion: the taking of food, drugs, liquids, or other substances into the body by mouth.

Mean: the average (the sum of all the individual values in a set of measurements divided by the number of values in the set).

Median: the value on the scale that divides the number of observations into two equal parts.

Mortality: death rate (an estimate of the portion of a population that dies during a specified period).

Neurodevelopment: refers to the processes that generate, shape, and reshape the nervous system, from the earliest to the final years of life.

Observational study: a study where the investigator does not assign the participants to an intervention or exposure.

Outcome: see Health outcome.

Participants: people who have taken part in a trial or study or have responded to a survey questionnaire or interview.

Peer-reviewed literature: published literature that, before it was published, was reviewed critically by other people in the same field of research and revised in response to the critical review as a condition of publication.

Prevalence: a measure of occurrence or disease frequency that refers to the proportion of individuals in a population who have a disease or condition.

Prospective cohort study: a study in which a group of participants are followed over a period of time and the outcome(s) of interest in the participants exposed to water fluoridation are compared to the outcome(s) in the participants not exposed.

Randomised controlled trial: a study in which participants are randomly assigned to one of two or more treatment groups and the outcome(s) of interest of each treatment groups is compared.

Selection bias: distortions in outcomes of a study that result from the procedures used to select participants and from factors that influence participation in a study.

Self-report: information about a person's history or personal characteristic that a person themselves provides, generally from memory.

Socio-economic status: a descriptive term for a person's position in society, which may be expressed on a scale using such criteria as income, level of education attained, occupation, value of dwelling place.

Synthesis: For this review, combining the results of individual studies and systematic reviews together to make conclusions about the body of evidence.

Systematic review: a process that provides a transparent and reproducible means for gathering, synthesising and appraising the findings of studies on a particular topic or question with the aim to minimise the bias associated with the findings of single studies and non-systematic reviews.

Tooth decay: (synonym: dental caries): the breakdown of the outer layers of teeth caused by acid produced by bacteria in the mouth.

Toxicology: the science of the study of actual or potential hazards of chemicals on living organisms and ecosystems.

List of acronyms and abbreviations

dmft	number of decayed, missing and filled deciduous teeth
DMFT	number of decayed, missing and filled permanent teeth
dmfs	number of decayed, missing and filled surfaces in deciduous teeth
DMFS	number of decayed, missing and filled surfaces in permanent teeth
GRADE	Grading of Recommendations Assessment, Development and Evaluation
IQ	Intelligence quotient
mg/L	milligrams per litre (equivalent to ppm)
NHMRC	National Health and Medical Research Council
ppm	parts per million (equivalent to mg/L)
TF	Thylstrup-Fejerskov Index
TSH	thyroid stimulating hormone
UK	United Kingdom
USA	United States of America

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