Community water fluoridation: Additional information on recent publications

The purpose of this document

This document has been prepared to supplement the existing 2024 evidence brief completed by the Ministry of Health | Manatū Hauora. It addresses information regarding community water fluoridation (CWF) published since the evidence brief was completed. The developments include;

- The final publication of the US National Toxicology Program Monograph on the State of the Science Concerning Fluoride Exposure and Neurodevelopment and Cognition: A Systematic Review [1], published in August 2024 (the NTP report).
- The Cochrane review of the evidence related to the prevention of dental decay by community water fluoridation, published in October 2024. [2]
- Issues raised from the October 2024 ruling from the US District Court for the Northern District of California relating to CWF in the US. [3]

Overall conclusion

These recent developments do not alter the conclusions reached regarding the health benefits and safety aspects of CWF in New Zealand.

There is clear and convincing evidence of the effectiveness of CWF to reduce the incidence and severity of dental caries. The evidence remains robust even in the presence of fluoridated oral health products.

There is a possible association between concentrations of fluoride in drinking water above the upper limit used for CWF and mild neurodevelopmental delay. However, there is no evidence of causation and no demonstrated pathophysiological mechanism. The studies reporting an association between neurodevelopmental harm and fluoride are heavily biased by reliance on a small number of datasets which have been mined for negative associations between fluoride and health. Therefore, at the current time there is no evidence that CWF causes neurodevelopmental delay.

Overview of the Ministry of Health's 2024 CWF evidence brief

A systematic review of the safety and effectiveness of CWF for the prevention of dental caries was undertaken by the Ministry of Health in 2024 (the 2024 MoH Review). The review supplemented information already available from the 2014 and 2021 reviews of CWF undertaken by the Royal Society of New Zealand [4] and the Office of the Prime Minister's Chief Science Advisor (OPMCSA) [5]. The protocol of the 2024 MoH Review is fully explained in the document and follows accepted best practice. The inclusion and exclusion criteria for the 2024 MoH Review are also discussed below. In addition, the 2024 MoH Review was externally peer reviewed and considered by the reviewers to be of a high standard.

The 2024 MoH Review was undertaken as a systematic review to ensure that the best quality evidence was used to inform the Director-General of Health's Bill of Rights analysis. The primary advantage of a systematic review is that individual studies are identified for quality and relevance and then amalgamated and placed in context. The context in this case being the safety and effectiveness of CWF. A systematic review avoids the issues associated with recency bias,[1] and the attribution of disproportionate weight to individual studies which correspond to a particular predetermined position.

All relevant publications regarding the risks and benefits of CWF were identified through a thorough search of the literature which was conducted by a qualified and experienced research librarian alongside the authors of the 2024 MoH Review. The time-period of the search was extended backwards to ensure all publications published since the OPMCSA 2021 report were identified.

Monitoring of the evidence regarding CWF and related issues of fluoride in drinking water is an ongoing function of the Ministry of Health. A monthly review of all relevant literature regarding fluoride in drinking water is undertaken by the Ministry of Health. The majority of articles identified by the monthly search are not relevant to CWF but provide important context for the authors of the 2024 MoH Review and others within the Ministry of Health who monitor evidence pertaining to fluoride in drinking water.

Rationale for inclusion/exclusion criteria in the evidence brief

Collating published studies from systematic reviews and regularly supplementing this information with newly published data from original studies using robust search criteria provides an effective mechanism for ensuring inclusion of relevant studies. In addition, the use of systematic reviews is a robust approach to identifying and synthesising a body of evidence, that is, it looks at the overall evidence, identifies sources of potential bias and draws conclusions about that body of evidence as a whole. In this situation, it is very unlikely, at least in the context of such a large, established body of evidence, that a single study would alter the overall conclusions, although we always approach new evidence with an open mind, judging each publication on its merits.

[1] Recency bias occurs when undue weight is given to the most recent publication.

The initial search was undertaken to identify systematic reviews of the benefits and risks of CWF published between January 2019 and April 2024. The aim was to identify new evidence since the publication of the OPMSCA 2021 report on the risks and benefits of CWF. The search period was extended to 2019 to ensure all relevant material was identified. Published individual studies were also searched for, to ensure that we identified all relevant evidence published since 2021. Individual studies already included in the systematic reviews identified were excluded to avoid double counting.

Publications were excluded if they had not been peer-reviewed. Therefore, editorials, letters, opinion pieces and review articles which did not use a systematic methodology (that is, narrative reviews) were not incorporated into the 2024 MoH Review. Studies which were referenced in the OPMCSA report were excluded from the evidence brief as they already informed the existing evidence base. Non-English language publications were also excluded. These inclusion and exclusion criteria were to ensure that only the most relevant, applicable and appropriate studies were included in our evidence brief.

Scientific protocol requires that for an intervention study to be valid, it must compare groups of people who are clearly defined by their exposure to the intervention. Therefore, to assess the risks and benefits of CWF, a treatment group, who receive CWF, must be compared to a group of people who received little or no fluoride in their drinking water. In the 2024 MoH Review, weight was given to studies comparing CWF with sources of drinking water containing fluoride levels well below that used in CWF. This was to ensure that the study presents an accurate reflection of the effects of CWF in a New Zealand context.

Topic One: US National Toxicology Program Monograph

The US National Toxicology Program (NTP) published the final version of its Monograph on the State of the Science Concerning Fluoride Exposure and Neurodevelopment and Cognition: A Systematic Review in August 2024. [1] The initial NTP literature review covered the period up to May 2020 and all of the relevant information in the initial literature review was covered in the report from the OPMCSA in 2021. [5] The final NTP report included a supplement to the draft versions to include studies on neurodevelopmental delay published from May 2020 to October 2023. This period of time matches the period of time covered by the 2024 MoH Review and all relevant studies included in the NTP supplement are included in the 2024 MoH Review.

The NTP review was designed to evaluate total fluoride exposure from all sources and was not designed to evaluate the health effects of fluoridated drinking water alone. However, it is important to note that there were **"insufficient data to determine if the low fluoride level of 0.7 mg/L currently recommended for U.S. community water supplies has a negative effect on children's IQ."** [bold is our emphasis]

In the main body of the NTP review document, an analysis of 19 studies[2] reporting the impact of fluoride exposure during pregnancy on IQ in the child was undertaken. In the supplement, an analysis of 12[3] studies was undertaken. The main NTP document assessed the 19 studies as being of high quality. However, only three were prospective cohort studies,[4] which seriously limits the ability to infer any causality and is inconsistent with the GRADE levels of evidence which would rate randomised trials initially as being high quality and retrospective observational studies (which formed the majority of studies) initially as low-quality evidence[5]. The 19 studies were carried out in countries with high naturally occurring water fluoride levels (i.e., they were not carried out in places with CWF) and with very different methodologies. The range of study designs and high levels of naturally occurring fluoride seriously limits the generalisability and applicability to CWF in places like New Zealand and the USA.

Of the 12 studies identified in the supplement, seven were cross-sectional and assessed outcomes in children. These studies were not included in the 2024 MoH Review as they were not studies of CWF. Five were prospective cohort studies of maternal fluoride exposure. [6-10] All of these, except one, [9] were identified in the 2024 MoH Review.

[2] From 72 studies identified.

[3] From 28 studies identified.

[4] A prospective study design enables the development of a high-quality study methodology, as opposed to using data collected for routine clinical purposes or other studies. This approach decreases the risk of both confounders and bias and improves the quality of the study and the reliability of the result.

[5] https://bestpractice.bmj.com/info/us/toolkit/learn-ebm/what-is-grade/#:~:text=GRADE%20has%20four%20levels%20of,data%20starts%20at%20low%20quality.

Of the five prospective cohort studies, the study by Dewey [6] was included in the 2024 MoH Review, although major deficiencies in the methodology were identified and discussed in the 2024 MoH Review.

Of the other four cohort studies, one was excluded due to not meeting the outcome criteria [10] and two were found to be included in 2 and 3 of the systematic reviews in the 2024 MoH Review. [7, 8]

The final cohort study was not identified by the search strategy of the 2024 MoH Review. However, having evaluated the study, it would have been excluded because it did not meet the exposure criteria i.e., it used spot maternal urinary fluoride concentration as a measure of exposure. [9]

For completeness we discuss the four studies further here.

The study by Farmus [7] includes the MIREC data which is the same population as Green [11] and Till [12] and the results are included in three of the systematic reviews assessed in the 2024 MoH Review. The study also uses maternal spot urine measurements to assess long term maternal fluoride exposure. As discussed below, spot maternal urine assessment is an unsuitable measurement of fetal fluoride exposure.

The two studies by Goodman [8, 9] were excluded. One study, which is based on the ELEMENT dataset, is not an assessment of CWF and uses maternal spot urine tests to assess fluoride exposure. [8] The results of this study are also included in two of the systematic reviews assessed in the 2024 MoH Review. The second study is based on the MIREC dataset (which is discussed below) and was designed to assess whether there is an interaction between maternal urinary fluoride concentration, maternal urinary iodine concentration and IQ in children. [9]

The study by Grandjean reports results from the Odense Child Cohort, in which no association between maternal urinary fluoride and IQ in the children was identified. [10] This data was also combined with data from two previously reported studies derived from the MIREC and ELEMENT datasets to produce a benchmark dose analysis, which is not relevant to CWF as it includes information from non-CWF studies. It was excluded from the 2024 MoH Review because the outcome (benchmark dose analysis) did not meet the inclusion criteria and used maternal urinary fluoride concentration as a measure of long-term fluoride exposure and fetal fluoride exposure (benchmark dose studies and maternal urinary fluoride concentrations are discussed further below).

The NTP report concludes that **"higher levels of fluoride exposure, such as drinking water containing more than 1.5 milligrams of fluoride per litre, are associated with lower IQ in children. More studies are needed to fully understand the potential for lower fluoride exposure to affect children's IQ."** [bold is our emphasis]

The NTP review authors' expressly state that "This Monograph and Addendum do not address whether the sole exposure to fluoride added to drinking water in some countries (i.e., fluoridation, at 0.7 mg/L in the United States and Canada) is associated with a measurable effect on IQ." Further, the NTP review authors state that "This Monograph and

Addendum do not assess benefits of the use of fluorides in oral health or provide a risk/benefit analysis."

To summarise, the NTP review indicates that there may be an **association** between exposure to high fluoride levels (>1.5 mg/l) in drinking water with lower IQ in children. This level is greater than that used for CWF in New Zealand. In evaluating the review, it is important to also note that there is no biological mechanism of harm identified, no supporting evidence of harm from animal models and no evidence of causality. There has been substantial criticism of the methodology adopted including inconsistent application of risk of bias criteria, inadequate statistical rigour and selective reporting of non-significant study results. [13-18]

Methodological issues in NTP studies

Including studies that use maternal urinary fluoride levels as a measure of exposure

A group of authors have, in an attempt to avoid the difficulties inherent in estimating long-term fluoride exposure from cross-sectional studies[6], published several articles derived from a single dataset, which was designed to test for the impact of known environmental neurotoxins, such as lead, to perform a secondary analysis for the effects of fluoride in pregnancy. [7, 10-12, 19] It is this group of articles which have formed the basis of most of the evidence suggesting an association between CWF and neurodevelopmental delay. The data set, called MIREC, used single maternal urine sample (a spot urine sample) during each trimester of pregnancy to measure the concentration of known neurotoxins. However, while this approach may be reasonable for some compounds such as lead in which a spot urine sample can reflect long-term exposure, a spot urine sample only measures the consumption of fluoride over the previous few hours and does not assess long-term exposure to fluoride. For example, a woman who had recently consumed fluoridated water or brushed their teeth with fluoride toothpaste would have an elevated level of fluoride in their spot sample.

Therefore, studies that used urinary fluoride levels were excluded from the 2024 MoH Review as spot samples are not considered to be a valid measure of chronic exposure due to their high variability over the day and from day-to-day. A detailed discussion of the underlying flaws of using the MIREC data is presented in a review by Guichon et al. [20] The key points are that: spot urine samples are unable to determine long-term fluoride exposure; the correlation between maternal urine levels and maternal blood levels are poor or absent [21]; the relationship between maternal serum fluoride levels and fetal fluoride levels is variable [22]; and the metabolism within the different compartments of the fetal circulation[7] has not been determined. [23]

[6] A cross-sectional study uses a single time frame to compare two groups with (purportedly) different exposure to an intervention.

[7] The three relevant compartments are fetal, placental and amniotic.

The application of GRADE criteria

There are also concerns about the application of the GRADE[8] approach to rating the quality of the body of evidence within the NTP review. The review authors do not start with assessing the study design for rating the quality of evidence (randomised trials start as 'high' and observational studies start as 'moderate') as required using this approach[9] but rather start with key features of study design.[10] Considering the number of cross-sectional studies, studies with high risk of bias, lack of adjustment for confounders, and the number of non-significant results, it is not clear why the confidence in the conclusions of the body of evidence has not been downgraded from 'moderate' to 'low' or even 'very low'.

The assessment of neurodevelopmental delay

The MIREC data includes IQ measurements which were undertaken in each of the cities participating in the research. Measuring IQ is known to be difficult, even when using recognised testing methods. The MIREC study used different examiners in each city, which is a clear source of bias. In addition, the level of competence of the examiners is not explained, and importantly, there is no difference in the IQ of the total cohort of children in cities with or without CWF, which varied by 4-8 IQ points in the cities irrespective of the fluoridation status. Therefore, an observed difference of a 4 IQ point difference in the sample of mother-child dyads who lived in cities with or without CWF[11] is based on inadequate measurements of the relevant variable (fetal fluoride exposure) and is of doubtful clinical significance because of major concerns regarding the assessment of the outcome (IQ) which is less than the baseline variability in IQ reported between the cities.

In summary, the NTP review concludes that there is "**insufficient data to determine if the low fluoride level of 0.7 mg/L currently recommended for U.S. community water supplies has a negative effect on children's IQ**."[1] While this review raises important questions about fluoride exposure above 1.5mg/L, there is no reliable, robust evidence that this applies to levels of fluoride exposure used in community water fluoridation.

[8] Grading of Recommendations, Assessment, Development and Evaluation Link
[9] 5.1 Factors determining the quality of evidence
https://gdt.gradepro.org/app/handbook/handbook.html#h.trgki08omk7z
[10] Figure 1. Page 18 of the NTP review.
[11] The analysis of IQ related to fluoride exposure was only a subset of the total number of children who were tested for IQ.

Topic Two: 2024 Cochrane Review

Overview

Two Cochrane reviews [2, 24] have been undertaken to determine if CWF is better than water without added fluoride at:

- reducing the number of teeth, or tooth surfaces, with signs of decay.
- increasing the number of people who have no tooth decay.

The latest Cochrane review was published in October 2024, and updated a 2015 Cochrane review on CWF.

The Cochrane review remains a good source of evidence in relation to the efficacy of CWF. The review only included prospective studies with a concurrent control, comparing at least two populations, one receiving fluoridated water and the other non-fluoridated water, with at least two points in time evaluated. Groups had to be comparable in terms of the concentration of fluoride in drinking water prior to the introduction of CWF[12]. The purpose of the study design was to obtain a measure of change in caries experience in the fluoridated community from before implementation of fluoridation to sometime afterwards, and to compare this change with any change in the control (or reference) community over the same time period. Considering that the majority of studies were undertaken prior to 1975, during a period of time when fluoridated toothpaste was not widely available, the results of the Cochrane review are robust, good-quality evidence that CWF decreases the incidence of caries experience and tooth decay.

Due to the inclusion criteria, the 2015 Cochrane review was unable to demonstrate a statistically significant improvement in dental caries as only two publications published since 1975 fulfilled the criteria.

2024 Cochrane Update

The 2024 Cochrane review concluded that:

- studies conducted after 1975 showed that adding fluoride to water may lead to slightly less tooth decay in children's baby teeth. There was uncertainty about whether adding fluoride to water reduced tooth decay in children's permanent teeth or decay on the surfaces of permanent teeth.
- adding fluoride to water may slightly increase the number of children who have no tooth decay in either their baby teeth or permanent teeth. However, these results also included the possibility of little or no difference in tooth decay.
- studies conducted in 1975 or earlier showed a clear and important effect on prevention of tooth decay in children. However, due to the increased availability of fluoride in toothpaste since 1975, it is unlikely that we will see this effect across all populations today.

[12] With a single study of before and after cessation of CWF.

There were very few additional studies identified in the 2024 update that conformed to the selection criteria, which remained the same as the 2015 inclusion criteria. Because of the lack of available studies, sensitivity analyses were undertaken, including seeing if the removal of studies deemed to be at critical risk of bias and which required imputation of standard deviation[13] changed the effect estimate to any major degree. [2]

To fully understand the conclusions of the 2024 review, it is necessary to understand that the Cochrane review reported 12 outcomes related to dental caries as described in Appendix 1. All of the measures used to identify dental caries were associated with an improvement in oral health with CWF. For measures of DMFT/dmft, a positive effect size indicates a greater decrease in the number of decayed, missing or filled teeth for individuals exposed to the intervention (CWF) compared to those not exposed to CWF. For changes in the proportion of caries free individuals, a negative number indicates a greater number of individuals exposed to CWF remain caries free compared to those not exposed.

Not all of the improvements were statistically significant at the conventionally accepted 95% confidence interval.[14] For this reason the authors were cautious about their conclusions despite all indices being consistent with a beneficial effect of CWF.

Therefore, the restrictive requirements for inclusion of studies into the 2015 and 2024 Cochrane review of CWF which was undertaken to ensure that only studies of a particular design (with an innate low risk of bias) were included in the analysis has again resulted in insufficient information being available to provide a clear answer to the effectiveness of CWF. It does not imply that CWF is ineffective in a modern setting, only that few studies using the required study design have been performed.

Although the Cochrane review provides good quality evidence, there are many other studies with a range of designs which have found strong associations between CWF and improvements in oral health and very few studies which do not support the benefits of CWF. While individually these studies may provide lower quality evidence on the basis of their design, they constitute a large body of evidence that CWF remains effective in the modern environment. A detailed analysis of the evidence supporting the efficacy of CWF in the modern era is provided in the peer-reviewed 2024 MoH Review, which builds upon the previous reviews in 2014 and 2021 by the Royal Society and OPMCSA.

[13] These statistical processes are used to assess the effect of including low quality studies and studies that need imputation.

[14] A 95% confidence interval implies that the relevant statistic, in this case the difference in oral health between CWF and non-CWF areas, is 95% likely to be correct.

Topic Three: US District Court for the Northern District of California

Overview

On 24 September 2024 the US District Court for the Northern District of California released a ruling relating to community water fluoridation. [3] The Court was considering, under the Toxic Substances Control Act, whether the evidence suggests that fluoridation of drinking water at levels typical in the United States "poses an unreasonable risk of injury to health."

The Court found that fluoridation of water at 0.7 milligrams per litre – the level presently considered "optimal" in the United States – poses an unreasonable risk of reduced IQ in children. The Court noted that this finding does not conclude with certainty that fluoridated water is injurious to public health, rather there is an unreasonable risk of such injury.

The Court ruled that the U.S. Environmental Protection Agency (EPA) must take regulatory action in response to the ruling. While the EPA is required to take action, the ruling did not prescribe what that response should be. The Court did not direct the cessation of fluoridation of public drinking water supplies or direct fluoridation at a particular level.

The issues considered from that ruling include (i) a discussion of benchmark studies; (ii) the issue of safety margins for chemicals in water; and (iii) "additive effects". (Issues relating to the NTP monograph, which was also considered in the US judgment, have already been discussed above).

Comment

Benchmark Dose studies

Attempts have been made to calculate a benchmark dose[15] (BMD) [25] for fluoride toxicity in humans. [26] Such studies were relied on in the reasoning of the September US Court judgment.

The BMD approach involves determining a critical effect (e.g., IQ) and the benchmark response (this is a predetermined change in the response rate which, by default, is either a decrease in IQ of 5% or 10%). Once these parameters have been determined, different mathematical models are applied to fit the dose-response data to estimate the BMD. The dose response data are derived from published studies looking at fluoride and IQ.

Based on the available data, there are some legitimate concerns about whether it is appropriate to attempt to calculate a BMD and the validity and accuracy of the BMDs that have been calculated. The validity of the results of the BMD studies depends on the quality and applicability of the study (or studies) from which the input data is derived. There are several reasons why the BMDs calculated [10, 27] may be problematic:

[15] A benchmark dose (BMD) is a dose or concentration that produces a predetermined change in the response rate of an adverse effect. This predetermined change in response is called the benchmark response (BMR).

- The quality and selection of the input data i.e., it is unclear why some studies were selected e.g., Bashash, Thomas [28], Goodman, Bashash [8],Green, Lanphear [11] and others were not e.g., Broadbent, Thomson [29]
- There are limitations such as a small sample size and lack of control of other neurotoxins e.g., Green, Lanphear [11]
- The high variability of the IQ data used (see Fig 3A from Green, Lanphear [11])
- There is considerable debate about any dose-response curve especially at low exposure of fluoride (see dose-repose curves from Veneri, Vinceti [30] in the 2024 MoH Review)
- Animal and in vitro studies have not been considered.
- Assessment of exposure: as noted above, maternal urinary/blood fluoride levels, are not a reliable measure of chronic exposure.
- Assessment of outcome: measuring IQ in a standardised, reliable way in younger children is challenging; it should ideally be assessed by the same person, in the same way and using a valid instrument – this is not often undertaken.

In summary, the BMD is a model which is derived from original research. Therefore, the relevance of the model is dependent on the accuracy of the original data. Insufficient consideration of possible confounders, reliance on a small number of studies, concerns about both exposure and outcome measurement, and rejection of studies that show no effect on IQ, brings considerable doubt as to the appropriateness of conducting at BMD analysis and of the accuracy and robustness of the BMD results.

Safety margins

Regarding safety margins for fluoride, the current recommended level of fluoride in CWF is based on the risk of severe dental fluorosis, which is a proven complication of ingesting high concentrations of fluoride and for which there is a considerable safety margin. Currently, there is no evidence of a causal relationship between fluoride and neurodevelopmental delay, nor is there a proven mechanism by which this could occur. Therefore, the issue of a margin of error in the context of CWF does not arise.

Additive effects – Dietary sources of fluoride in NZ

New Zealand has low levels of naturally occurring fluoride in its environment which results in a low level of fluoride in water. [31] The major sources of fluoride in New Zealand are from CWF and fluoridated dental products such as fluoridated toothpaste. [32-36] (Appendix 2). A review of the amount of fluoride ingested for different population groups has been undertaken and discussed in the 2021 review of CWF by the OPMCSA. Recent data is also available from unpublished theses. [37, 38]

In New Zealand, where CWF is implemented, fluoride is added to water to a concentration of about 0.7 mg/L. Studies of actual levels indicate that few samples are over the recommended level of 1.0 mg/L and very few over the Maximum Allowable Value (MAV) of 1.5 mg/L. When this does occur, it is usually for a very short period of time. [31]

Regarding fluoride intake in children, fluoride concentrations in breast milk are substantially lower than that observed in maternal plasma and are relatively insensitive to changes in the fluoride concentration of drinking water. Therefore, exclusively breastfed children receive little fluoride in their diet. [39] Fluoride concentrations in infant formula in Australia and New Zealand are low. For babies who are bottle fed, the recommended volume of formula (as recommended by the Ministry of Health) for infants from birth to six months of age is 700ml per day of total fluid, which would result in ingestion of less than 0.5 mg/day of fluoride and is well within the recommended guidelines. [40]

The Australian and New Zealand governments jointly set nutrient reference values for a range of nutrients. [41] These values include recommended adequate intake and upper limit values for fluoride intake, which vary based on age and gender. The evidence above demonstrates that the total fluoride intake from all dietary sources remains below the recommended adequate intake for all age groups and that the risks of long-term overdosage from additive effects in any age range is minimal.

Appendix 1: Studies published after 1975 reporting dental caries associated with CWF from the 2024 Cochrane review

Group	Analysis	No. of studies	No of participants	Statistical Method	Effect size
1.1.1	Change in the number of decayed, missing or filled primary teeth (dmft)	2	2908	Mean Difference (95% CI)	0.24 [-0.03, 0.52]
1.2.1	Change in the number of decayed, missing or filled permanent teeth (DMFT)	4	2856	Mean Difference (95% CI)	0.27 [-0.11, 0.66]
1.3.1	Change in the number of decayed, missing or filled permanent surfaces (DMFS)	1	343	Mean Difference (95% CI)	2.46 [1.11 – 3.81]
1.4.1	Change in the proportion of caries free participants (primary teeth)	2	2908	Mean Difference (95% CI)	-0.04 [-0.09, 0.01]
1.5.1	Change in the proportion of caries free participants (permanent teeth)	2	2348	Mean Difference (95% CI)	-0.03 [-0.07, 0.01]
1.6.1	Sensitivity analysis - all included studies: change in the number of decayed, missing or filled primary teeth (dmft)	3	6622	Mean Difference (95% CI)	1.08 [-0.53, 2.70]
1.7.1	Sensitivity analysis - all included studies: change in the number of decayed, missing or filled permanent teeth (DMFT)	6	12906	Mean Difference (95% CI)	0.53 [0.00, 1.06]
1.8.1	Sensitivity analysis - all included studies: change in the proportion of caries free participants (primary teeth)	4	9608	Mean Difference (95% CI)	-0.10 [-0.19, -0.01]
1.9.1	Sensitivity analysis - all included studies: change in the proportion of caries free participants (permanent teeth)	3	10502	Mean Difference (95% CI)	-0.12 [-0.33, 0.09]
1.10.1	Sensitivity analysis - change in analytical approach: change in the number of decayed, missing or filled primary teeth (dmft)	2	2825	Mean Difference (95% CI)	0.28 [0.12, 0.43]
1.11.1	Sensitivity analysis - excluding studies with imputed standard deviations: change in the number of decayed, missing or filled primary teeth (dmft)	2	2908	Mean Difference (95% CI)	0.24 [-0.03, 0.52]
1.12.1	Sensitivity analysis - excluding studies with imputed standard deviations: change in the number of decayed, missing or filled permanent teeth (DMFT)	2	1535	Mean Difference (95% CI)	0.53 [-0.45, 1.51]

The analyses in red indicate a statistically significant benefit observed in cohorts living in locations with CWF. Other indices indicate CWF is beneficial, but confidence intervals include a zero-mean difference, so are not statistically significant at the 95% confidence level.

Appendix 2: Studies of dietary fluoride in NZ[16]

Author, country, year	Population group	Study method (*Dietary, biochemical, clinical, analysis*)	Fluoride intake males	Fluoride intake females	Main fluoride sources
Chowdhury N. Brown R. Shepherd M. *NZ, 1990* (46)	n = 60 11-13 m	Method: Comparison of F (0.8-0.9 mg/L) and NF (0.09-0.1 mg/L) regions. ***Dietary***: 3-day duplicate method. ***Analysis***: ion-specific electrode.	Dietary intake only (mean ± SD, mg/day): F area = 0.26 ± 0.13 ↓ NF area = 0.08 ± 0.05 ↓ Intake from diet, toothpaste and tablets (mean ± SD, mg/day): F area = 0.31 ± 0.23 ↓ NF area = 0.20 ± 0.17 ↓		Water Infant formula Soy-milk formulae Fluoridated toothpastes and tablets
Chowdhury N. Drummond B. Smillie A. *NZ, 1996* (40)	n = 66 3-4 y	Method: Longitudinal study comparing F (0.9-1.0 mg/L) and NF (0.2-0.3 mg/L) regions. ***Dietary***: 3 separate duplicate diets. ***Biochemical***: ingestion of toothpaste and supplements. ***Analysis***: ion-specific electrode.	Dietary intake only (mean ± SD, mg/day): F area = 0.36 ± 0.17 ↓ NF area = 0.15 ± 0.06 ↓ Intake from diet, toothpaste and supplements (mean ± SD, mg/day): F area = 0.68 ± 0.27 ↓ NF area = 0.49 + 0.25 ↓		Water Toothpaste (especially in the NF areas)
Cressey P. Gaw S. Love J. *NZ, 2010* (10)	14–18 y	Method: Estimated dietary fluoride intake based on NF water supply (0.1 mg/L), and F water supply (1.0 mg/L). ***Dietary***: simulated diets or using national 24-hour dietary recall surveys.	Mean estimated dietary intake (mg/day): F area = 1.89 ↓ NF area = 0.86 ↓ Mean estimated intake from toothpaste = 0.20 mg/day	Mean estimated dietary intake (mg/day): F area = 1.68 ↓ NF area = 0.73 ↓ Mean estimated intake from toothpaste = 0.20 mg/day	Water Bread Tea Carbonated beverages
NZ Total Diet Study (Ministry of Primary Industries) *NZ, 2016* (6)	11-14 y	Method: National study sampling 132 foods predominantly representing the most commonly consumed foods. ***Dietary***: 57% of sample analysed for fluoride, including water.	Range of intake = 0.20-0.70 mg/day ↓ 25% of AI (2.0mg)/day 5% of UL (10.0mg)/day	Range of intake = 0.20-0.60 mg/day ↓ 20% of AI (2.0mg)/day 4% of UL (10.0mg)/day	Water Tea
The Fluoride in Schoolchildren Study (FLOSS) *NZ, 2018* (39)	n = 64 9-11 y	Method: Cross-sectional study comparing F and NF regions. ***Dietary***: 24hr weighed diet records. ***Clinical***: 24hr urine samples. ***Analysis***: deionised water samples collected to calculate fluoride ingested from toothpaste.	Dietary intake only (mg/day) F area = 0.73 ± 0.37 ↓ NF area = 0.29 ± 0.28 ↓ Intake from diet and toothpaste (mg/day): F = 1.55 ± 0.95 ↓ NF = 1.04 ± 0.85 ↓		Water Toothpaste (52-67% total fluoride intake)

F = area with fluoridated water; NF = area with non-fluoridated water; m = months; y = years; AI = adequate intake; UL = Upper Level; SD = standard deviation;
↓ = Mean is below MOH adequate intake recommendations for selected age group; ↑ = Mean is above MOH adequate intake recommendations for selected age group

Additional research

Dietary fluoride in older children and adolescents has been calculated using robust methodologies. The studies both demonstrate that CWF did not result in dietary intakes above the upper acceptable limit in these groups. These results are consistent with evidence from previous studies outlined in the OPMCSA evidence review.

Table 2. Total fluoride intake in subsets of NZ population

Age	Adequate intake mg/day	Upper limit mg/day	Intake CWF Breast mg/day (SD)	Intake CWF-Bottle mg/day
9-13 years [38]	2.0	10.0	1.04 (0.87) [38]	1.55 (0.96)
14-18 years female [37]	3.0	10.0	0.56 (0.32) [37]	2.37 (1.04)
14-18 years male [37]	3.0	10.0	0.50 (0.21)[4]	1.63 (0.66)

[16] Source: Shahin, A. (2021). The fluoride intake from diet, water and toothpaste of New Zealand adolescents. University of Otago.

References

1. National Toxicology Program, *NTP Monograph on the State of the Science Concerning Fluoride Exposure and Neurodevelopment and Cognition:A Systematic Review,*. 2024, National Toxicology Program: North Carolina, USA.
2. Iheozor-Ejiofor, Z., et al., *Water fluoridation for the prevention of dental caries.* Cochrane Database of Systematic Reviews, 2024(10).
3. Chen, E., *Food and Water Watch et al. v. United States Environmental Protection Agency et al.*, in *17-cv-02162-EMC*, U.S.D. Court, Editor. 2024, Northern District of California.
4. The Royal Society of New Zealand, *Health effects of water fluoridation: A review of the scientific evidence*. 2014: Wellington, New Zealand.
5. Gerrard, J. *Fluoridation: an update on evidence*. 2021; Available from: https://www.pmcsa.ac.nz/topics/fluoridation-an-update-on-evidence/.
6. Dewey, D., et al., *Fluoride exposure during pregnancy from a community water supply is associated with executive function in preschool children: A prospective ecological cohort study.* Sci Total Environ, 2023. **891**: p. 164322.
7. Farmus, L., et al., *Critical windows of fluoride neurotoxicity in Canadian children.* Environmental Research, 2021. **200**: p. 111315.
8. Goodman, C.V., et al., *Domain-specific effects of prenatal fluoride exposure on child IQ at 4, 5, and 6-12 years in the ELEMENT cohort.* Environmental Research, 2022. **211**: p. 112993.
9. Goodman, C.V., et al., *Iodine Status Modifies the Association between Fluoride Exposure in Pregnancy and Preschool Boys' Intelligence.* Nutrients, 2022. **14**(14): p. 16.
10. Grandjean, P., et al., *Dose dependence of prenatal fluoride exposure associations with cognitive performance at school age in three prospective studies.* Eur J Public Health, 2024. **34**(1): p. 143-149.
11. Green, R., et al., *Association Between Maternal Fluoride Exposure During Pregnancy and IQ Scores in Offspring in Canada.* JAMA Pediatr, 2019. **173**(10): p. 940-948.
12. Till, C., et al., *Fluoride exposure from infant formula and child IQ in a Canadian birth cohort.* Environment International, 2020. **134**: p. 105315.
13. Steir, J., *The truth behind that viral study on fluoride and IQ*, in *Stat*. 2024.
14. Anderson, O. *National Toxicology Program releases fluoride exposure monograph. ADA reaffirms support for community water fluoridation*. 2024 [cited 2024; Available from: ADA reaffirms support for community water fluoridation.
15. National Academies of Sciences, E. and Medicine, *Review of the Revised NTP Monograph on the Systematic Review of Fluoride Exposure and Neurodevelopmental and Cognitive Health Effects: A Letter Report*. 2021, Washington, DC: The National Academies Press. 28.
16. Society, A.F. *Fluoride Report Walks Back Its Original Findings* 2024; Available from: https://americanfluoridationsociety.org/wp-content/uploads/2024/08/AFS-Release_NTP-Report_8.26.2024.pdf.
17. Fitch, J. *NTP report: Higher fluoride levels linked to lower IQ in children*. 2024; Available from: https://www.contemporarypediatrics.com/view/ntp-report-higher-fluoride-levels-linked-lower-iq-in-children.
18. Shepley, G., Cohlmia, Raymond.,, *Re: NTP Monograph on the State of the Science Concerning Fluoride Exposure and Neurodevelopmental and Cognitive Health Effects: A Systematic Review* 2023, American Dental Association.
19. Hall, M., et al., *Fluoride exposure and hypothyroidism in a Canadian pregnancy cohort.* Science of the Total Environment, 2023. **869**: p. 161149.
20. Guichon, J.R., et al., *Flawed MIREC fluoride and intelligence quotient publications: A failed attempt to undermine community water fluoridation.* Community Dentistry and Oral Epidemiology, 2024. **52**(4): p. 365-374.
21. Thomas, D.B., et al., *Urinary and plasma fluoride levels in pregnant women from Mexico City.* Environmental Research, 2016. **150**: p. 489-495.

22. Caldera, R., et al., *Maternal-fetal transfer of fluoride in pregnant women.* Biology of the Neonate, 1988. **54**(5): p. 263-9.
23. Shimonovitz, S., et al., *Umbilical cord fluoride serum levels may not reflect fetal fluoride status.* Journal of Perinatal Medicine, 1995. **23**(4): p. 279-82.
24. Iheozor-Ejiofor, Z., et al., *Water fluoridation for the prevention of dental caries.* Cochrane Database of Systematic Reviews, 2015(6).
25. Anonymous. *What Is Benchmark Dose (BMD) and How to Calculate BMDL*. 2021 [cited 2024; Available from: https://www.chemsafetypro.com/Topics/CRA/What_Is_Benchmark_Dose_(BMD)_and_How_to_Calculate_BMDL.html.
26. Grandjean, P., *Developmental fluoride neurotoxicity: an updated review.* Environ Health, 2019. **18**(1): p. 110.
27. Grandjean, P., et al., *A Benchmark Dose Analysis for Maternal Pregnancy Urine-Fluoride and IQ in Children.* Risk Analysis, 2022. **42**(3): p. 439-449.
28. Bashash, M., et al., *Prenatal Fluoride Exposure and Cognitive Outcomes in Children at 4 and 6-12 Years of Age in Mexico.* Environmental Health Perspectives, 2017. **125**(9): p. 097017.
29. Broadbent, J.M., et al., *Community Water Fluoridation and Intelligence: Prospective Study in New Zealand.* Am J Public Health, 2015. **105**(1): p. 72-76.
30. Veneri, F., S.R. Vinceti, and T. Filippini, *Fluoride and caries prevention: a scoping review of public health policies.* Annali di Igiene : Medicina Preventiva e Di Comunita, 2024. **36**(3): p. 270-280.
31. Chambers, T., M. Hobbs, and J.M. Broadbent, *An assessment of compliance with optimal fluoride levels for oral health benefit by New Zealand drinking water suppliers.* Journal of Public Health Dentistry, 2023. **83**(2): p. 217-221.
32. Chowdhury, N.G., R.H. Brown, and M.G. Shepherd, *Fluoride intake of infants in New Zealand.* J Dent Res, 1990. **69**(12): p. 1828-33.
33. Guha-Chowdhury, N., B.K. Drummond, and A.C. Smillie, *Total Fluoride Intake in Children Aged 3 to 4 Years—A Longitudinal Study.* Journal of Dental Research, 1996. **75**(7): p. 1451-1457.
34. Cressey, P., S. Gaw, and J. Love, *Estimated dietary fluoride intake for New Zealanders.* J Public Health Dent, 2010. **70**(4): p. 327-36.
35. Pearson, A., et al., *2016 New Zealand Total Food Survey*. 2016, Ministry for Primary Industries.
36. Lo, C., *The Fluoride in Schoolchildren Study [FLOSS]*, S. Skeaff, Editor. 2019, University of Otago.
37. Shahin, A., *The fluoride intake from diet, water and toothpaste of New Zealand adolescents*, S. Skeaff, Editor. 2021, University of Otago.
38. Rogers, T., *Fluoride intakes of nine to eleven year-old children living in fluoridated and non-fluoridated areas of the lower South Island of New Zealand*, S. Skeaff, Editor. 2019, University of Otago.
39. Esala, S., E. Vuori, and A. Helle, *Effect of maternal fluorine intake on breast milk fluorine content.* British Journal of Nutrition, 1982. **48**(2): p. 201-4.
40. Anonymous. *Bottle-feeding*. Available from: https://www.plunket.org.nz/caring-for-your-child/feeding/bottle-feeding/#how-much-do-bottle-feeding-babies-drink.
41. Anonymous. *Nutrient Reference Values: Australia and New Zealand*. 2015; Available from: https://www.eatforhealth.gov.au/nutrient-reference-values.