

Fluoride benefits and risks: Lessons from 70 years of water fluoridation in Singapore

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ABSTRACT

Fluoride is well-proven to prevent caries. In controlled amounts, its benefits outweigh its risks. A recent systematic review and meta-analysis investigating fluoride exposure and children's intelligence quotient (IQ) scores found limited data and uncertainty in the dose-response association between fluoride exposure and children's IQ at water concentrations <1.5 ppm. Notably, 1.5 ppm is the World Health Organization's threshold for water fluoridation, which is 3 times higher than Singapore's current level of 0.5 ppm. The study's methodology, interpretations and limitations have been questioned. It reignited the debate surrounding fluoride use, particularly in community water fluoridation.

The main adverse effects of excessive fluoride exposure are dental and skeletal fluorosis. Skeletal fluorosis is associated with chronic exposures typically from high fluoride levels in drinking water, often in communities dependent on groundwater. This does not apply to Singapore where its sole water agency regulates and fluoridates the water supply.

Fluoride use in children must be supervised by parents to maximise benefits and minimise risks. This commentary revisits the history of fluoride uses in Singapore, and presents a balanced view and risk-benefit analysis of fluoride use. Physicians and nurses are often the first healthcare professionals that parents consult regarding concerns on their child's health and intelligence. Therefore, interprofessional education can help empower them to educate, identify, and refer persons in need early. Future studies could investigate the benefits and risks of water fluoridation in contemporary Singapore, a developed country with one of the world's highest average IQ and widespread access to fluoride toothpastes.

Keywords: dental caries, fluoride, IQ, oral health, paediatrics, public health, water fluoridation

INTRODUCTION

On 6 January 2025, Taylor et al. published a systematic review and meta-analysis investigating fluoride exposure and children's intelligence quotient (IQ) in the *Journal of the American Medical Association*

Pediatrics (JAMA Pediatrics).¹ They concluded that there were "inverse associations and a dose-response association between fluoride measurements in urine and drinking water and children's IQ" and "limited data and uncertainty in the dose-response association between fluoride exposure and children's IQ when fluoride exposure was estimated by drinking water alone at concentrations less than 1.5 mg/L [ppm]."¹ Within hours, many internet and news sources reported on the controversial article published by the researchers from the Division of Translational Toxicology, National Institute of Environmental Health Sciences, US National Institutes of Health; and ICF International. This reignited the debate on the use of fluoride.

It is critical to evaluate the science behind the systematic review before determining if current practices should be adjusted. Further investigations are required as it may not be possible to determine if the current World Health Organization (WHO)'s threshold of 1.5 ppm is unsafe based on this study alone, given the high heterogeneity in data. Therefore, this commentary is not meant to refute or confirm the study's findings but to contextualise them in a real-world context, particularly that of Singapore where the level of fluoride is lower (0.5 ppm). Furthermore, this commentary examines the different aspects of fluoridation and topical fluoride use, including its effectiveness in preventing dental caries and its risks.

Critical appraisal of systematic review on fluoride exposure and children's IQ

Taylor et al. included a total of 64 cross-sectional studies and 10 prospective cohort studies (Table 1). The majority of the studies were carried out in China and India; none from the US, where the systematic review originates. The main critique is that most studies were carried out in areas where fluoride levels in the water are endemically high (>1.5 ppm). This is 3 times that of the current water fluoride levels in Singapore (0.5 ppm). There was a stark lack of studies from countries with long histories of community fluoridation,

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Accepted: 10 May 2025

Published Online First: 16 June 2025

possibly due to the dearth of published data from these countries. In Asia alone, a high percentage of people in Malaysia (75.5%), Hong Kong (100%), Brunei (95%) and Singapore (100%) receive optimally fluoridated water.²

Table 1. Characteristics of studies included in the systematic review and meta-analysis by Taylor et al. 2025.¹

Countries where the studies were performed (no. of studies)	China (n=45) India (n=12) Iran (n=4) Mexico (n=4) Canada (n=3) Pakistan (n=2) Denmark (n=1) New Zealand (n=1) Spain (n=1) Taiwan (n=1)
Risk of bias of the studies (no. of studies)	High risk of bias (n=52) Low risk of bias (n=22) • Low risk of bias across all 7 risk-of-bias domains (n=13) • Low risk of bias in 6 domains and probably high risk of bias in ≤ 1 domain (n=9)

The meta-analysis included studies with both higher and lower risk of bias, of which the majority (47 out of 59) were evaluated to be at higher risk of bias. Even for the sub-analysis that included studies with lower risk of bias, there was evidence of substantial heterogeneity in the combined data (high I^2 values). There was also insufficient justification for the selection or omission of studies, and for the calculated individual effect sizes presented in the main analysis. In an editorial published in the same issue,³ Levy highlighted that the studies with lower risk of bias actually showed negligible or negative effect, and the lack of discussion of important recent studies including those from nonendemic fluorosis areas. He also underscored that the meta-analysis had not included more recent primary studies.^{4,5}

In another editorial also published in the same issue, Lanphear et al. argued that the urinary fluoride level is a better biological measure and highlighted Taylor et al.'s findings that urinary fluoride concentrations <1.5 ppm were significantly associated with decreased IQ.⁶ However, the urinary sample collection approaches utilised in all included studies (i.e. spot urinary fluoride or a few 24-hour samples, often not adjusted for dilution) is not a reliably valid measure of long-term fluoride exposure in individuals. There may be variations between days or even within the same day, which can also be affected by the usage of topical fluorides.³

It is concerning that confounding factors were not well controlled. Caution should be exercised when evaluating cross-sectional studies on the associations

between fluoride and intelligence due to the presence of potential confounding factors, such as socioeconomic status, place of residence, maternal intelligence and exposure to other neurotoxic chemicals.⁷ In fact, the measurement of IQ itself with standard IQ tests is fraught with complexities and may not be generalisable across different sociocultural settings, especially in non-Western societies where non-academic skills may be valued more.⁸

These confounders reduce confidence in substantivity and therefore generalisability of the paper. Indeed, based on the data available and methodology, the paper concluded by acknowledging the “uncertainty in the dose-response association between fluoride exposure and children’s IQ when fluoride exposure was estimated by drinking water alone at concentrations less than 1.5 mg/L” (equivalent to the WHO’s current threshold). Furthermore, it is not known how much lower water fluoridation levels should be adjusted to be considered safe for community consumption. The current water fluoridation level in Singapore is 0.5 ppm,⁹ far below the threshold of 1.5 ppm reported in the study by Taylor et al.¹

Benefits of fluoride and community water fluoridation

Fluoride’s benefits are well documented. A 2021 Cochrane review reported high-certainty evidence that toothpastes containing 1000 to 1250 ppm fluoride are more effective than non-fluoride toothpaste in caries prevention, with a positive dose-response effect observed in children and adolescents with decayed, missing and filled surfaces.¹⁰ Consequently, professional dental bodies around the world recommend the use of toothpastes containing at least 1000 ppm fluoride in both children and adults.^{11–16} Other Cochrane reviews have also found a preventive effect of topical fluoride in other forms such as mouthrinses, gels or varnishes.¹⁷

In Singapore, water fluoridation introduced in 1956 effectively reduced dental caries. In a 10-year water fluoridation study, about 300 schoolchildren aged 7 to 9 years selected from 34 schools were examined almost every year between 1957 and 1968. That study reported a 30.8% reduction in primary tooth caries among the children in Singapore where water was fluoridated, while there was no corresponding decline in the control group of the children in Malacca where water was not fluoridated then. The reduction of caries prevalence in permanent teeth was 31.0% and 52.3% in 7- to 9-year-old Malay and Chinese children in Singapore, respectively.¹⁸

In 2018, water fluoridation (≥ 0.7 ppm) in England was associated with a 59% reduction in hospital admissions for dental extractions among young people

aged 0 to 19 years.¹⁹ There is concern that water fluoridation's benefits may be relatively muted with the widespread use of fluoride toothpastes, topical fluoride varnishes and dental sealants from the mid to late 1970s.²⁰ Published data from communities that removed water fluoridation, such as those in Calgary, Canada²¹ and Israel,²² showed an increase in caries, especially in vulnerable populations. Therefore, for vulnerable groups that carry the heaviest disease burden and lowest access to fluoride toothpastes and other forms of prevention, community water fluoridation may remain a passive vehicle to reduce oral health inequalities.²³

Singapore's schoolchildren now have relatively low levels of caries based on WHO standards; this is attributed to factors including Singapore's water fluoridation, School Dental Service (introduced in 1948), improvements in general living conditions, parental education levels and socio-economic conditions over the past decades. Notwithstanding, almost half of Singapore's preschoolers are still affected by early childhood caries. The most common chronic childhood disease may be difficult to overcome, partially due to the plateau effect of water fluoridation, where further increase beyond optimal water fluoride levels would yield diminishing returns in its population caries-prevention benefit.^{24,25} Notably, 16% of preschoolers bear 78% of the burden of disease and 16.5% suffered from rampant caries. These children comprise the smaller but significant percentage of children who often are vulnerable members of lower socioeconomic groups and the indigenous population.²⁴ Therefore, there is a high risk that cessation of water fluoridation in Singapore may further widen oral health inequalities, particularly regarding dental caries in young children from different socioeconomic strata.

Concerns around fluoride toxicity

A side effect of chronic excessive fluoride ingestion is dental fluorosis. Excessive fluoride exposure during enamel formation results in enamel hypomineralisation.²⁶ Depending on the levels of fluoride exposure, the defects can range from faint white speckles to severe brown mottling defects. Various epidemiological dental fluorosis indices have been used across studies, including the Dean's Index (Table 2).²⁷⁻³⁰ A 2024 Cochrane review on dental fluorosis concluded that most studies found mild fluorosis to be a possible side effect of topical fluoride use early in life. However, this conclusion was stated to be at low certainty, due to inconclusive evidence.²⁷

A literature search was conducted on PubMed and MEDLINE, supplemented with Google Scholar, to identify major studies or narratives on water fluoridation and its effects in the Singapore context.^{9,11,18,24,25,31-37} The natural water fluoride content in Singapore was found to be 0.2 ppm. Water fluoridation in Singapore raised it to 0.7 ppm in 1956.¹⁸ The classic 10-year study on water fluoridation by Wong et al. reported the prevalence of dental fluorosis in permanent teeth to be <5% in 7- to 9-year-old children from 1966 to 1968.¹⁸ In 1986, a survey of 1739 Singaporean children aged 9, 12 and 16 years found 42.6% with very mild to mild, 26.3% with moderate and 9.2% with severe dental fluorosis using the Dean's Index.³²

While the authors speculated that the increase in prevalence and severity of dental fluorosis in 1986 was greater than that reported by Wong et al. earlier, they suggested that different methods of clinical examination and indices used may have been a confounding factor. A 1989 survey by the Dental Division of the Ministry of Health, Singapore found that in a cohort of 11- to 13-year-old children where

Table 2. Dean's Index.²⁸⁻³⁰

Score	Criteria
Normal	The enamel represents the usual translucent semi-vitriform type of structure; surface is smooth, glassy, pale, creamy-white translucent.
Questionable	The enamel discloses slight aberrations from the translucency of normal enamel, ranging from a few white flecks or occasional white spots.
Very mild	Small opaque paper-white area scattered irregularly over the tooth covering less than 25% of tooth surface. Premolars/second molars not showing more than 1–2 mm of white opacity at the tip of summit of cusps are also frequently involved in this classification.
Mild	Opaque white area in the enamel of the tooth covering less than 50% of the tooth surface.
Moderate	All enamel tooth surfaces are affected and surfaces subject to attrition show marked wear. Brown stain may be present.
Severe	All enamel surfaces are affected, hypoplastic brown stains are widespread and teeth often present as corroded appearance. The major diagnostic sign of this classification is the discrete or confluent pitting.

83.3% had a history of fluoride toothpaste use before age 6, 61.9% had no/questionable fluorosis, 26.6% had very mild fluorosis and 10.5% had mild fluorosis.^{9,35} Such mild dental fluorosis usually only produces minimal aesthetic challenges with no additional detriment to oral health. The water fluoridation level was subsequently reduced to 0.6 ppm in 1992, and again to 0.5 ppm in 2008.⁹ A follow-up study in 2017 found that only 15.4% (41,651 out of 270,630) of Singaporean students had dental fluorosis (unpublished data from official source: School Dental Services, Health Promotion Board).¹¹

Another chronic side effect is skeletal fluorosis with an increased risk of bony fractures. According to the European Food Safety Authority (EFSA), skeletal fluorosis develops after many years of excessive fluoride intake of 10–20 mg/day.²⁶ Such chronic exposures are typically from residing in areas with high fluoride concentrations in drinking water, usually in communities dependent on ground water.²⁶ This situation does not apply to Singapore where the Public Utilities Board is the nation's sole water agency that fluoridates and regulates water supply.⁹ A typical Singapore resident's approximate daily fluoride intake is estimated to be just 1 mg/day, based on the average recommended water intake of 2 L (equivalent to at least 8 glasses of water—dependent on individual physical needs as well as climate changes³⁸) at 0.5 ppm of fluoride (Table 3). This amount is at least 10 times below the safety threshold of 10–20 mg/day as recommended by the EFSA.²⁶

Other than the aforementioned risks, there is very limited evidence of any other adverse events associated with chronic exposure to fluoride in water at regulated levels.³⁹ Renal or liver injuries are reported to be of concern only at water fluoride levels of 2 ppm or above.⁴⁰ This is irrelevant to the Singapore's context with much lower fluoride levels in water. An FDI World Dental Federation policy also states that there is no evidence of risks to children with renal diseases from water fluoridation and other fluoride sources within the recommended dosages and with precautions of use.⁴¹

Maximising benefit and minimising risks

Over-the-counter (OTC) analgesic/antipyretic paracetamol is efficacious within therapeutic dosages, but overdose can lead to liver toxicity.⁴² Likewise, no other topical agent is likely as cost-effective and well-proven to prevent caries as fluoride. The estimated net cost savings from the US community water fluoridation programme in 2013 were USD 6469 million in 2013, with savings of USD 20 related to caries prevented for every USD 1 spent on water fluoridation.⁴³

Nonetheless, inappropriate use and overdose of fluoride can lead to side effects and toxicity. To mitigate its risks and maximise its benefit, excessive ingestion must be minimised. Parents are responsible for dispensing and supervise its use, teach their children to spit out the toothpaste when they reach an appropriate age, and keep both prescription, and OTC fluoride products (e.g. toothpastes and mouthrinses) out of reach of children to prevent accidental consumption and associated adverse effects. Jointly, regulatory bodies should ensure appropriate labelling of fluoride toothpastes by manufacturers so that informed choices can be made.

The risk of dental fluorosis from over-ingestion affects the aesthetic zone (permanent incisors) predominantly in the first 3 years of life during its calcification/maturation stage, as crown calcification completes by 30 months. Beyond that, the aesthetic risk of dental fluorosis decreases and disappears after 6 years of age, especially after children have learnt to spit.¹² In view of this, a smear (approximately rice grain-sized amount) of toothpaste is recommended for children below 3 years old, and a pea-sized amount is recommended for those aged 3 years and above (Fig. 1).¹¹

For even greater prudence, the Society for Paediatric Dentistry Singapore (SPDS) considered the nation's water fluoridation programme in its recommendations for toothpaste use in children. The SPDS supports the use of toothpaste with at least 1000 ppm fluoride but advises that for children below 2 years of age with low caries risk, parents should discuss with the

Table 3. Estimated consumption of fluoride from public water intake per day in an individual consuming 2 L of water.

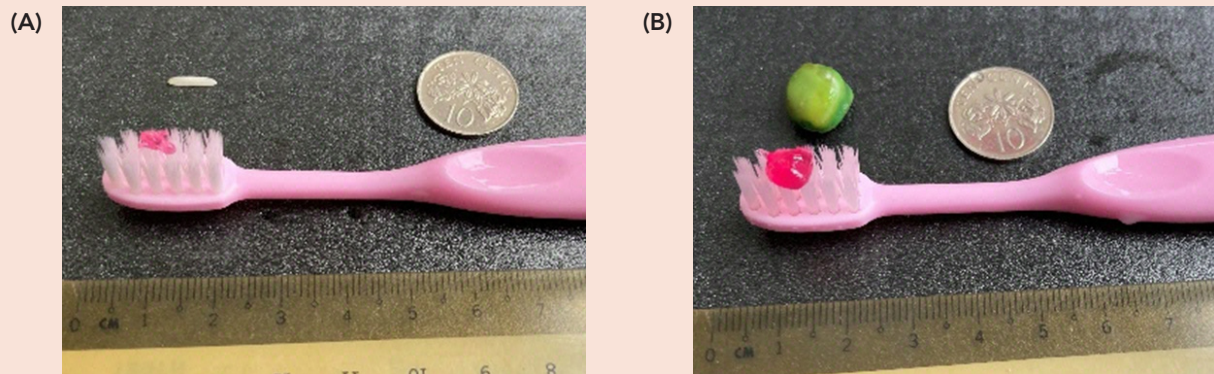
Step-by-step calculation for the total amount of fluoride in 2 L of water when the concentration is 0.5 ppm

Convert concentration from ppm to mg:

- 1 ppm = 1 mg of fluoride per L of water (1 mg/L).
- If the concentration is 0.5 ppm, this means there are 0.5 mg of fluoride per L of water.
- Therefore, in 2 L of water: Total amount of fluoride = 0.5mg/L × 2 L = 1 mg.

Conclusion: The total amount of fluoride in 2 L of water with a concentration of 0.5 ppm fluoride is 1 milligram (mg) of fluoride.

Fig. 1. (A) A smear of toothpaste and (B) a pea-sized amount of toothpaste, placed next to a rice grain and green pea respectively, together with a Singapore 10-cent coin and ruler.



child's dentist when choosing a toothpaste.¹¹ This targeted advice is notable, in contrast to the blanket recommendations in many other countries.¹²⁻¹⁶ This discussion must start at the child's first dental visit, which should occur before age 1 for caries risk assessment and anticipatory guidance, including the appropriate selection and use of toothpaste.¹³

Concluding thoughts: What does this mean for healthcare professionals?

Despite the potential association between high fluoride levels in water and IQ suggested by Taylor et al., the concentrations at which this is a concern are well above levels recommended for water fluoridation (0.7–1.5 ppm). This should not be a concern for Singapore with a water fluoridation level of 0.5 ppm. Singapore ranked third in average IQ in 2019,⁴⁴ and its 70-year history of 100% water fluoridation may provide an invaluable natural experiment for assessing both the efficacy and safety of water fluoridation, especially with a strong central water management system. Nonetheless, future studies could investigate the benefits and risks of water fluoridation in contemporary Singapore, amid the backdrop of improved access to fluoride toothpastes and other preventive measures. These studies should include analysis of vulnerable subpopulations to better understand the impact of community water fluoridation on oral health disparities.

In terms of regulations, it is important that policy-makers re-examine local data periodically, especially in the wake of new controversies, and avoid making abrupt policy shifts without robust, contextual evidence.

Physicians and medical nurses are trusted healthcare professionals whom parents and patients frequently consult and should therefore be well-versed in the science and evidence supporting the use of fluoride. Interprofessional education may empower medical

colleagues who are well-positioned to help identify and refer those in need early, as well as emphasise the importance of the first dental check by age 1 and a healthy mouth as integral components of overall health.

Ethics statement

Not applicable.

Declaration

The authors declare no affiliations or financial involvement with any commercial organisation with a direct financial interest in the subject or materials discussed in the manuscript.

Acknowledgements

The authors acknowledge A/Prof Hu Shijia for his contributions in vetting and citation management of the first manuscript draft, and Dr Eunice Ho for her help in sourcing for some of the archived articles available only in print.

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