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The relationship between fluoride concentration in drinking water and dental fluorosis in children aged 6-15 Years

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Abstract

Background: Dental fluorosis occurs due to excess fluoride intake during tooth formation. This excess fluoride intake is usually obtained from fluorine content in water sources, either naturally or added from other sources. Fluorosis that occurs can cause tooth discoloration which is characterized by the presence of brown stains or yellow spots that spread imperfectly on the surface of the teeth so that it interferes with dental aesthetics.

Purpose: To determine the relationship between fluorine concentration in drinking water consumed and the occurrence of dental fluorosis in children aged 6-15 years.

Methods: This study was conducted by searching for articles within the last 12 years related to the theme on online platforms such as PubMed and Google Scholar.

Results: Ten studies were identified. The weaknesses of the study design/behavior were the low response rate and the identification and treatment of confounding factors. The collection of statistical data was imprecise due to substantial heterogeneity, partly due to variations in sample sizes, water fluoridation concentrations, indices used, and target populations. Ten studies presented dental fluorosis at any level.

Conclusion: There is an increase in the incidence of dental fluorosis along with an increase in fluorine levels in drinking water. Fluorine levels in good drinking water are 0,6-1 ppm.

Keywords: Dental fluorosis; Drinking water; Children; Fluoride concentration

1. Introduction

Fluoride as the ionic form of fluorine, plays a role in inhibiting the onset and progression of dental caries and in promoting new bone formation. When fluoride is ingested orally, approximately 80% or more is absorbed by the digestive tract. In adults, around 50% of this absorbed fluoride is retained in the body, while the remaining 50% is excreted through urine. Bones and teeth store about 99% of the body's total fluoride. In young children, up to 80% of absorbed fluoride is retained, as a larger proportion is absorbed by their developing bones and teeth compared to adults [1]. Although fluoride is not essential for human growth and development, it is a naturally occurring substance added to drinking water, dental hygiene products, and food supplements to help prevent dental caries [2].

However, excessive fluoride intake can lead to dental fluorosis, a defect in enamel structure that occurs due to excessive fluoride intake during the tooth formation period [3]. Clinically, this results in hypocalcification which is distributed

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evenly across the enamel surface. Hypocalcification manifests in various grades depending on the total amount of fluoride consumed, exposure time, age, body weight of the subject, and nutritional status [4]. Dental fluorosis can result in tooth discoloration, causing teeth to appear less white than normal healthy teeth, often marked by brown stains or yellow spots scattered across imperfect tooth surfaces. This condition usually affects a person's appearance and can potentially lead to significant self-esteem issues [3].

Fluorosis serves as an indicator of excessive fluoride intake during the critical period of tooth development in early childhood. Unerupted permanent teeth are particularly vulnerable to fluorosis during this developmental phase, with maxillary central incisors being most sensitive between the ages of 2 to 3 years, and posterior teeth between 6 to 8 years. During this time, dietary sources of fluoride include infant formula, weaning foods, and water, while toothpaste is the primary non-dietary source. Among the various factors that can affect the normal appearance of teeth, fluoride is one of the most common contributors. Although fluoride use has been recognized as one of the most successful public health interventions, excessive fluoride intake can have multiple adverse effects on human health [5].

The human body can absorb fluoride from various sources, including drinking water, food, toothpaste, mouthwash products, and air. In most communities, drinking water serves as the main source of fluoride intake [6]. Recommendations for water fluoridation are widely accepted because the benefits of reducing caries outweigh the risks of dental fluorosis. However, the increasing prevalence of dental fluorosis worldwide has led to a loss of aesthetic appeal in children's teeth, which can have psychological and behavioral impacts on the individual [7]. Based on the Indonesian Ministry of Health Regulation No. 492/2010 on drinking water quality requirements, fluoride is an inorganic chemical directly related to health, and the permitted threshold value is 1.5 mg/L. Fluoride will have a detrimental effect on teeth if present in concentrations above 1.5 mg/L.

Literature reveals the importance of determining fluoride concentrations in drinking water and comparing them to acceptable levels to prevent dental fluorosis. This study is one of the few conducted to evaluate fluoride content in drinking water. The current research aims to evaluate the fluoride levels in drinking water and the occurrence of dental fluorosis in children aged 6-15 years.

2. Material and methods

Information was gathered from articles published between 2012 and 2024 through platforms such as Medline, PubMed, Google Scholar, and Elsevier using the following keywords: "dental fluorosis" AND "water intake" AND "children aged xx years" AND "fluoride concentration". The reference lists of the selected articles were also manually searched for additional relevant publications that may have been missed during the database search. All original articles in English and review articles were retrieved as full texts, and the bibliographies were manually cross-checked for additional relevant articles. Full-text references that could not be retrieved as well as other irrelevant study types such as commentaries, editorials, case reports, case series, books and general informational materials were excluded.

3. Results and discussion

This study is a systematic review to review the relationship between fluoride levels in drinking water and the occurrence of dental fluorosis in children aged 6-15 years old by conducting reviews of 10 journals obtained through database. The results obtained from this study are the higher concentration of fluoride in drinking water is directly related to the higher degree of fluorosis.

Table 1 Reviews on relationship between fluoride levels in drinking water and the occurrence of dental fluorosis in children aged 6-15 years

Author	Year	Subject	Methods	Result
James, P., Harding, M., Beecher, T. M., Browne, D., Cronin, M. T. D., Guiney, H., O'Mullane, D., & Whelton, H. [8]	2020	Children aged 8 years old in Dublin and Cork-Kerry	A cohort study design was conducted to compare caries and fluorosis in a random sample of 8-year-old children from Dublin and Cork-Kerry in 2017 with a similar group of 8-year-olds from Dublin and Cork-Kerry in 2002.	Caries severity was lower in 2017 compared to 2002 among children without community water fluoridation (CWF). Reducing CWF levels from 0.8–1.0 ppm to 0.6–0.8 ppm is seen as an effective strategy for

				preventing caries without causing fluorosis.
Mohd Nor, N. A., Chadwick, B. L., Farnell, D. J. J., & Chestnutt, I. G. [5]	2021	Malaysian children aged 9 and 12 years old	A cross-sectional study was conducted to compare lifelong residents (n = 1,155) aged 9 and 12 years living in fluoridated and non-fluoridated areas. The 12-year-old children in Malaysia were born when the public water supply had a fluoride concentration of 0.7 ppm, whereas the 9-year-olds were born after the fluoride level was reduced to 0.5 ppm.	The prevalence of fluorosis was lower in the younger children born after the fluoride concentration was reduced to 0.5 ppm, at 31.9%, compared to 38.4% in the older cohort who were born when fluoride levels were 0.7 ppm.
Thilakarathne BKG, Ekanayake L. [9]	2022	1,040 children aged 15 years, from 42 schools who have lived in the Kurunegala district since birth	A cross-sectional study was conducted. Dentist examined all participants for dental fluorosis using the Thylstrup and Fejerskov index. Water samples from the participants' drinking water sources were also analyzed for fluoride content.	Dental fluorosis occurs with a prevalence of 71.5%. In areas where fluoride levels are suboptimal, the prevalence is 39.7%, while it reaches 100% in areas with high fluoride levels. Fluoride concentrations in drinking water ranged from 0.0 to 1.9 mg/L, with higher fluoride levels in the water correlating with an increased prevalence of dental fluorosis.
Shekar C, Cheluvaiah MB, Namile D. [10]	2012	Children 12 and 15 years old in Andhra Pradesh	A cross-sectional study was conducted to evaluate the prevalence and severity of dental fluorosis and dental caries in children aged 12 to 15, in relation to the fluoride concentration in their drinking water.	Among children, the prevalence of dental caries was 56.3%, with the highest rate observed in areas with below-optimal fluoride levels (71.3%) and the lowest rate in areas with optimal fluoride levels (24.3%). The prevalence and severity of dental fluorosis rose with increasing fluoride concentrations. Additionally, boys experienced more caries than girls.
Mercado S., Mercado J., Mercado L., Mercado G., [11]	2023	504 students aged 12-15 years from different regions	A cross-sectional study was conducted. Water samples were then evaluated and subjected to laboratory analysis to determine the fluoride concentration in mg/L	The higher concentration of fluoride in drinking water is directly related to the higher degree of fluorosis.
Moimaz SAS, Saliba O, Marques LB, Garbin CAS, Saliba NA. [12]	2015	496 children aged 12 years old	Using a cross-sectional study to compare two groups; those who had always lived in an area with excessive fluoride (1.2 mgF/l) and those who had always lived in an area with ideal fluoride levels (0.7 mgF/l) in the water supply.	The distribution of dental fluorosis indicated that excessive fluoride concentrations in the public water supply were linked to dental fluorosis in 41.5% of the children examined.

Prasad, U. V., Vastrad, P., N, C., Barvaliya, M. J., Kirte, R., R, S., Ray, S. K., B, R., Chakma, T., Murhekar, M. V., & Roy, S. [13]	2023	Children aged between 6-12 years from 17 villages in Manvi and Devadurga in the Raichur district	A cross-sectional study was conducted to estimate the prevalence of dental fluorosis among children aged 6–12 years in 17 villages of Manvi and Devadurga taluks in Raichur district	As participants' age increased, the odds of developing dental fluorosis were found to rise by 2 to 4 times. The likelihood of having dental fluorosis was significantly higher with water fluoride levels of 3 to 5 ppm compared to levels below 1 ppm.
Irigoyen-Camacho ME, Perez-Perez N, Zepeda-Zepeda MA, Velazquez-Alva MC, Castaño-Seiquer A, Barbero-Navarro I, Sanchez-Perez L. [14]	2023	585 schoolchildren aged 8–12	A cross-sectional study was carried out with 585 schoolchildren aged 8–12 years in communities within a southern state of Mexico, where groundwater fluoride levels exceeded 0.7 parts per million (ppm).	The average fluoride concentration in tap water was 1.39 ppm (SD 0.66), while in bottled water it was 0.32 ppm (SD 0.23). About 14.39% of children had a BMI Z-score of ≤ −1 SD. Over half (56.1%) of the children exhibited dental fluorosis in TFI categories ≥ 4. Children living in areas with higher fluoride concentrations in both tap and bottled water were more likely to have severe dental fluorosis (TFI ≥ 4). The BMI Z-score was associated with an increased likelihood of severe dental fluorosis (TFI ≥ 4; OR 2.11, $p < 0.001$), with an effect size of 29.3%.
Meena C., Rathore S., Dwivedi S., Gonmei Z., Toteja, Bala, Mohanty [17]	2017	150 children aged 6-14 years old was surveyed	A cross-sectional study to compare fluoride level in two blocks (a) Jamwa Ramgarh block in; Heerawala, Palera, Nayabas, Saipur and Birasana, (b) Amber block in; Jugalpura, Chitanukalan, Sunder ka bas, Peelwa and Sirsali of Jaipur district, Rajasthan, India of the study villages.	There is a positive relation of fluorosis to high fluoride levels in drinking water sources.
Molina-Frechero N, Gaona E, Angulo M, Sánchez Pérez L, González González R, Nevarez Rascón M, Bologna-Molina R. [25]	2015	Students between 10 and 12 years living in Mexico City	A cross-sectional study was conducted to determine the prevalence and severity of dental fluorosis	The frequency and severity of the lesion increase as the ingestion of fluoride in the water increases above 0.7 ppm

The study conducted by James et al. in 2020 [8] revealed that the majority of fluorosis cases were relatively moderate, with no statistically significant difference between 2017 and 2002. The reduction in community water fluoridation from 0.8-1.0 ppm to 0.6-0.8 ppm was an effective caries prevention treatment that did not result in fluorosis. This study used 8-year-old individuals from Dublin and Cork-Kerry. The study used a before-and-after design, comparing caries and fluorosis in a random sample of 8-year-olds in Dublin (n = 707) and Cork-Kerry (n = 1,148) in 2017 to 8-year-olds in Dublin (n = 679) and Cork-Kerry (n = 565) in 2002.

Another study of children aged 9 and 12 living in fluoridated and non-fluoridated districts of Malaysia found that the incidence of fluorosis was reduced among children born after the fluoride content in water was adjusted. Fluoridated water has remained a significant risk factor for fluorosis. This cross-sectional study included 1,155 children aged 9 to 12 years old. Malaysian children aged 12 were born at a fluoride level of 0.7 ppm in the public water supply, whereas

those aged 9 were born after the amount was dropped to 0.5 ppm. Dean's criteria were used to assess fluorosis on standardized images of the maxillary central incisors [5].

Thilakarathne BKG and Ekanayake L. [9] found that greater fluoride levels in drinking water enhanced the prevalence of dental fluorosis. A cross-sectional design was used in the study, and all individuals were tested for dental fluorosis using the Thylstrup and Ferjeskov indexes. Fluoride levels were measured in water samples collected from participants' drinking water sources. This study comprised 1,040 15-year-old children from 42 schools who had lived in the Kurunegala district since birth.

In areas with suboptimal fluoride concentrations, the incidence of dental fluorosis was lower compared to areas with high fluoride concentrations [10]. This study's sample consisted of children aged 12 and 15 years in Andhra Pradesh, selected using simple random sampling from 5 of Nalgonda's 59 districts. Three schools from each of the specified areas were then picked at random. All eligible students in grades 6 and 9 were considered for the final analysis. Using a standardized questionnaire, three skilled dentists gathered demographic and other relevant information. Dean's fluorosis index was used to assess treatment needs and fluorosis.

Given that fluoride levels in drinking water sources have a high correlation with caries experience and the prevalence of dental fluorosis, the optimal fluoride concentration for drinking is 0.7 ppm in tropical regions and 1.2 ppm in cold regions [15].

Figure 1 Dental fluorosis with Dean's grading, (a) normal (Grade 0), (b) questionable (Grade 1), (c) very mild (Grade 2), (d) mild (Grade 3), (e) moderate (Grade 4) and (f) severe (Grade 5). Source: Meena, 2017 [18]

Another study involving 496 children aged 12 years as subjects to verify the prevalence of dental fluorosis in 12-year-old children [12]. To assess the prevalence of fluorosis, clinical examinations were conducted, and instruments were used to evaluate self-perception as well as the water supply sources in the areas where the children lived as research criteria. Another study used demographic information and oral hygiene practices from 307 children from the villages of Mankulam, Anavilundan, and Sinnasippikulam, which were recorded by interviewing the children and their mothers. The assessment of dental fluorosis was carried out according to the codes and criteria of Dean's Index. The results of the study showed that nearly 73% of the children had clinically detected dental fluorosis, and this high prevalence was clearly due to the high fluoride content in the groundwater and dug wells used for drinking and cooking [16].

Dental fluorosis was found to be 46% common in 1,614 children aged 6 to 12 from 17 villages in the Manvi and Devadurga districts of the Raichur district. Of children, 37.9% had mild dental fluorosis, 7.8% had moderate dental fluorosis, and 0.3% had severe dental fluorosis. The study used sample urine from the children, semi-structured questionnaires in ODK software, and cross-sectional data analysis. Measurements of weight and height, clinical tests, drinking water sources, and demographic information were also carried out. Samples of water and urine were taken in order to calculate the fluoride levels. Logistic regression analysis was used to evaluate the association between dental

fluorosis and variables such as gender, ages, diet type, drinking water sources, height for age, BMI for ages, water fluoride levels, and urine fluoride levels. The findings indicated that the chance of dental fluorosis rise 2-4 times as the participant's age increased. Elevations of water fluoride between 3 and 5 ppm and urine fluoride below 4 ppm significantly enhanced the risk of dental fluorosis [13]. This review aims to assess studies measuring the prevalence of dental fluorosis in children aged 6-15 years. According to the Institute of Medicine (US) Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, the adequate daily fluoride intake is as follows [1]:

Table 2 Adequate daily fluoride intake according to the Institute of Medicine (US) Standing Committee on the Scientific Evaluation of Dietary Reference Intakes

Age	**Male**	**Female**
Newborn to 6 months	0,01 mg	0,01 mg
7-12 months	0,5 mg	0,5 mg
1-3 years	0,7 mg	0,7 mg
4-8 years	1 mg	1 mg
9-13 years	2 mg	2 mg
14-18 years	3 mg	3 mg
Over 19 years	4 mg	3 mg
During pregnancy or breastfeeding	-	3 mg

Two indices are frequently used to characterize the degree and severity of dental fluorosis: the Thylstrup and Fejerskov Index (TFI) and Dean's Index. Dental fluorosis is categorized into six groups by both indices: normal, questionable, very mild, mild, moderate, and severe. The differences between the two indices are that the TFI utilizes a ten-point scale that takes into consideration all tooth surfaces, including buccal, lingual, and occlusal, and Dean's Index uses a five-point scale (ranging from 0 to 5). There are additional indices as well, such as the Tooth Surface Index of Fluorosis (TSIF) and the Developmental Defects of Enamel Index (DDE) [18].

The presence of fluorosis on tooth surfaces, particularly in more severe cases when the color darkens, is regarded as an aesthetic concern. However, the influence of dental fluorosis extends beyond aesthetics, as some argue that fluorosis is an increased risk associated with dental caries [18]. According to one study, taking too much fluoride causes "mottling" of the enamel, that leads to caries and fluorosis [19].

This theory is confirmed by a study conducted in Brazil, which revealed that dental fluorosis weakens teeth and makes them more likely to develop dental caries. They found that teeth identified with level 3 dental fluorosis on the TFI were weaker than healthy teeth [20]. Several journals with subjects from rural areas have reported significant results showing that these children experience dental fluorosis [9, 10, 13, 16]. The reasons cited in these journals include the influence of drinking water sources that originate from groundwater and contain high fluoride levels. Another study found that water fluoridation has been widely used worldwide for several decades, and evidence suggests that it reduces the occurrence of dental caries [24].

The duration of fluoride exposure is associated with dental fluorosis. The critical period of fluoride exposure leading to fluorosis in males is between 15 and 24 months, while in females, it is between 21 and 30 months [18]. This period extends to 8 years, as some teeth form later, leading to aesthetic problems [20]. Another study finding indicate that the sixth year of life is the most crucial period for the development of dental fluorosis in late-erupting permanent teeth, but the teeth remain vulnerable from approximately age 2 to 8 years [21]. Fluoride is central to the development of fluorosis in teeth, but the duration of fluoride exposure during amelogenesis will lead to dental fluorosis in children [18.]

The study discovered that more than half of the individuals having dental fluorosis were classified as having dental fluorosis on an aesthetic level. The majority of children did not believe that fluorosis harm their quality of life, although at some levels, fluorosis may have an impact on a child's quality of life. A study conducted in Mexico revealed that children with level 4 or higher fluorosis level on the TFI had some social issues [22]. Future research should investigate how dental fluorosis impacts children aged 6 to 15 years.

Nearly all included studies argue that the main cause of dental fluorosis is water fluoridation. However, none of the studies considered the socioeconomic status of the participants, as some participants might consume bottled water rather than well water. The safe amount of water fluoridation to prevent dental caries and avoid dental fluorosis depends on the target population's socioeconomic status, oral health practices, and the use of other fluoride sources such as fluoride toothpaste. As a result, the safe amount of water fluoridation should consider other fluoride sources to achieve a balance between preventing dental caries and avoiding dental fluorosis [23]. A survey should be conducted to determine the percentage of children aged 6-15 years using fluoride toothpaste and how frequently. Overall, most of the included studies cannot be categorized as good studies because they did not consider confounding factors.

4. Conclusion

Based on the collected data, it can be concluded that water with high fluoride levels is a strong risk factor for the occurrence of dental fluorosis in children. The water consumed by these children comes from groundwater or dug wells located near their homes in rural areas. A fluoride dose of less than 1.5 ppm does not affect the incidence of dental fluorosis, and the safe dose to avoid fluorosis is around 0.6 - 1 ppm.

Compliance with ethical standards

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Disclosure of conflict of interest

All the authors declare that there is not any conflict of interest with this document's release.

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