Examining the Benefits and Drawbacks of Fluoride Usage: A Review of Literature

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Abstract:

Fluoride is a mineral naturally found in nature that has been utilized as a source of caries prevention. Its inclusion in dental offices, toothpaste, and the water supply in cities across the United States has been a means of caries (dental decay/cavity) prevention, yet its inclusion in these settings has raised concerns and lead to controversy. The purpose of this literature review is to explore research to understand both the benefits as well as the concerns that the use of fluoride in water supply and dental settings presents. The majority of the research indicates that fluoride is beneficial within a certain limit. Having high concentrations of fluoride leads to toxicity, also known as fluorosis. Dental fluorosis, which has cosmetic impacts as it causes opaque white spots on teeth in mild cases, and pits and dark brown streaks on teeth in more severe cases. On the other hand, skeletal fluorosis results in joint pain and difficulty of movement. Excess fluoride also has a rare chance of leading to neurotoxicity if a fetus or a very young infant is exposed to high amounts of it. Despite that, fluoride has presented more benefits than drawbacks as it has been significantly useful in preventing dental decay which many people suffer from worldwide. Most of the research concludes that the benefits of fluoride cannot be dismissed, and it should continue to be incorporated into people's daily lives if the amount of fluoride intake for the public is moderated to decrease the prevalence of fluorosis.

Introduction:

Fluoride has been used in dental settings since its discovery as a treatment for caries (dental decay) in the mid-1900s. Fluoride was not researched until it was found to be the cause of dental fluorosis due to the mineral's abundance in the water supply in the states of Colorado and Idaho. Based on that finding, fluoride was later developed as an agent used in dental settings to strengthen and protect enamel (National Institution of Dental and Craniofacial Research, 2024). Due to its history of causing dental fluorosis, the presence of fluoride in tap water as well as their use on dental patients has caused controversy as to whether fluoride usage poses a potential risk factor for public health.

Fluoride is the ionic form of the element of fluorine. It is a naturally occurring mineral that can be found in rocks, plants, soil, and water. Its initial presence in the water supply of Colorado Springs, Colorado, is due to the mineral being washed into the water supply from the Pikes Peak region which has a naturally high fluoride presence. Presently, the water supply in Colorado Springs gets diluted to decrease the concentration of fluoride in water (McCrimmon, 2024). Yet during the time of its initial discovery, inquiries began to be made about fluoride due to the way it changed the appearance of newly developing teeth whilst decreasing the likelihood of dental decay.

a) History of Fluoride

In 1901, Frederick McKay was the first dentist to discover signs of dental fluorosis as he arrived at Colorado Springs, Colorado to practice dentistry. The signs of fluorosis that McKay observed included permanent brown streaks on teeth, sometimes causing the entire tooth to be discolored. In 1909, Dr. G.V. Black helped McKay look further into finding out what was

causing the discoloration of teeth in 90 percent of the children in Colorado Springs. It was later established by McKay that the brown streaks, also known as mottled enamel, were caused only on developing teeth so fully calcified adult teeth would not display a brown appearance. McKay also discovered similar cases of mottled teeth in Oakley, Idaho soon after a new water line was installed. Upon advising residents not to get water from that water supply, the next years showed that children's teeth were no longer showing signs of mottling. This finally led to the discovery of the high amounts of fluoride in the water that was causing children's teeth to change in appearance.

Although the negative impact of the fluoride was the discoloration of teeth, the mottled teeth proved to display decreased rates of decay in comparison with children who did not experience fluorosis. This observation led a researcher, Dr. H Trendley Dean, to discover that putting fluoride that reached levels of 1.0 parts per million (ppm) in water can lead to the strengthening of enamel, therefore significantly decreasing rates of dental decay, without signs of dental fluorosis. Experimentation in Grand Rapids, Michigan over the span of 11 years proved those theories true as the caries rate in children dropped by 60% (National Institution of Dental and Craniofacial Research, 2024).

b) Overview

Most literature and research indicate that fluoride benefits enamel. However, there is still public uncertainty pertaining to the possibility of fluorosis, especially as it mainly impacts young children whose teeth are still growing and going through the process of development. Despite the concerns, community water fluoridation was introduced and implemented 75 years ago due to evidence proving its effectiveness in preventing dental decay after successful experimentation by Dr. H Trendley Dean. Since then, it has been greatly endorsed by public health, dental, and

medical organizations as an optimal way to prevent tooth decay for the public (Till & Green, 2023). Yet medicine is an eternally developing field with consistent new findings which can make it difficult for the public to accept implementations based on prior research. That is why it is crucial to continue to support the advancement of research in the dental field, specifically involving how fluoride impacts different populations, not just pertaining to children, whilst acknowledging the benefits that fluoride has brought to dental settings and continuing to utilize it to promote dental health.

Usage of Fluoride in Dental Settings

The regulated use of fluoride in dental settings has become a common practice to prevent the development of caries disease, especially in young children with developing teeth who are more susceptible to caries. Fluoride is also a key component of many toothpastes to increase effectiveness for cavity prevention. Fluoride functions as an anti-cariogenic agent when administered topically through three mechanisms including inhibiting tooth demineralization, promoting remineralization, and inhibiting buildup of plaque bacteria (Nassar & Brizuela, 2023). The composition of the tooth enamel consists mainly of the mineral calcium hydroxyapatite (HAP) in a crystal structure. Reducing demineralization of tooth enamel is done through the process of exchanging hydroxyl ions (OH^-) for fluoride ions (F^-). This forms fluorohydroxyapatite which has a tightly packed crystal structure due to the increased attraction of oppositely charged ions which is much more resistant to acid dissolution and damage to the enamel due to its decreased solubility. Fluoride promotes remineralization by enhancing and accelerating the growth of fluorapatite crystals. The fluoride also enters the demineralized

surface of the tooth and increases the attraction of calcium ions, which decreases the solubility of teeth to plaque acids (Simmer et al., 2020).

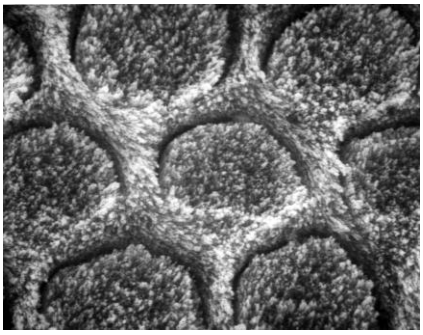

Figure 1. Acid etched tooth enamel surface showing hydroxyapatite crystals (Anatomicum, 2022).

a) Fluoride in Toothpaste

Although the usage of fluoride in dental care is proven to prevent dental caries, the risk of dental fluorosis still raises concern for people who are exposed to fluoride through different systems including water supply, application at the dentist's office, as well as in toothpaste. The acceptable range of fluoride in toothpaste is 500 ppm which prevents dental caries whereas around 1,000 ppm led to the fluorosis of permanent teeth. The accidental ingestion of toothpaste when brushing teeth can lead to excess fluoride exposure, thus causing fluorosis. A study was conducted on 80 individuals in Pakistan with healthy, non-decaying teeth, ranging from the age of 11 to 16 years of age to determine the correlation between the ingestion of toothpaste and the presence of fluorosis in permanent teeth. The results showed that 29 out of the 80 participants ingested their toothpaste when brushing whereas 51 of the participants did not. Out of those participants, the results indicated that 52 participants had very mild fluorosis that appears as white opaque areas covering less than 50% of a tooth. Only three participants had severe

fluorosis whereas 10 had none. The high number of participants that are present with very mild fluorosis are likely present with the condition due to factors other than the ingestion of toothpaste. This may include drinking high concentrations of fluoridated water or the general use of highly fluoridated toothpaste even without ingestion. The fluoride concentration in Pakistan is present in 500-1450 ppm where the higher end of the range is enough to cause fluorosis. Despite the results of this study, other research that was conducted indicated that 76-86% of children ingest toothpaste whereas this study only had a report of 36.3% ingesting toothpaste. This could be due to improper surveying of participants, or participants inaccurately disclosing their rate of ingestion due to how easy it may be to swallow small amounts of toothpaste without noticing. Despite that, the overall conclusion of the study in combination with other research and data indicated that people who ingested toothpaste during their childhood are more likely to develop fluorosis (Rehman et al., 2024).

This study provides context to the importance of proper oral care through the use of fluoridated toothpaste whilst moderating how children brush their teeth. Fluoride is proven to be beneficial in terms of preventing dental caries, although the development of fluorosis from excess amounts of fluoride could be avoided through supervision of children brushing their teeth to ensure that they are not swallowing the toothpaste. It is also recommended that a small “pea-sized” amount of toothpaste is used when brushing teeth, and that the concentrations of fluoride in toothpaste is moderated as to not exceed the recommended levels, to avoid fluorosis whilst preventing the likelihood of developing dental caries. This can also be reflected in how fluoride is used in dental settings when applied to teeth. If dental patients are warned not to swallow the fluoride applied to their teeth and it is applied in moderate concentrations, then it is more likely to provide the benefit of preventing tooth decay whilst avoiding developing dental fluorosis.

b) Fluoride Application at Dental Clinics

The impacts of dental caries can be very detrimental as it can lead to severe pain and the loss of permanent teeth if it progresses too far. That is why the progression of dental care has incorporated fluoride into regular care to prevent the progression of caries. It has become a regular practice to apply fluoride to teeth every other regular visit to the dentist, especially for children whose teeth are developing. Not only is fluoride proven to prevent the development of caries, but research was also conducted to investigate whether fluoride application can disrupt plaque microecology and remineralize tooth enamel.

The microecological bacteria of plaque leads to colonization on the surfaces of teeth thus leading to increased pathogenicity and the development of dental caries. A study titled "Application of fluoride disturbs plaque microecology and promotes remineralization of enamel initial caries," was conducted on a group of 52, 3-year-old children with permission from their guardian to apply fluoride to the surfaces of all their teeth at baseline and 6 months. At baseline, 3, 6, and 12 months, researchers used the International Caries Detection and Assessment System II (ICDASII), a visual and evidence-based diagnostic framework for detecting caries, to test the subjects' teeth. The ICDASII diagnosis ranges from code 0-6 with code 0 indicating no signs of caries whereas code 6 indicates the most severe signs of caries. The supragingival (area of the tooth above the gumline) plaque samples of 12 subjects were collected to perform 16s rRNA sequencing to test for and compare the bacteria in the plaque samples. Each of the measurements of the surfaces of the teeth at initial application of fluoride, and 3, 6, and 12 months indicated the majority of the subjects had a significantly higher proportion of code 0 in comparison to codes 1-6 on all surfaces of the teeth. The surfaces of the teeth that had the higher number of code 6 indications at 12 months were the occlusal surfaces (chewing surfaces found on molars) of teeth.

Despite that, the data remains consistent with the conclusion that the fluoride was effective in maintaining the code 0 ICDASII range for all surfaces of the teeth (Zhang et al., 2022)

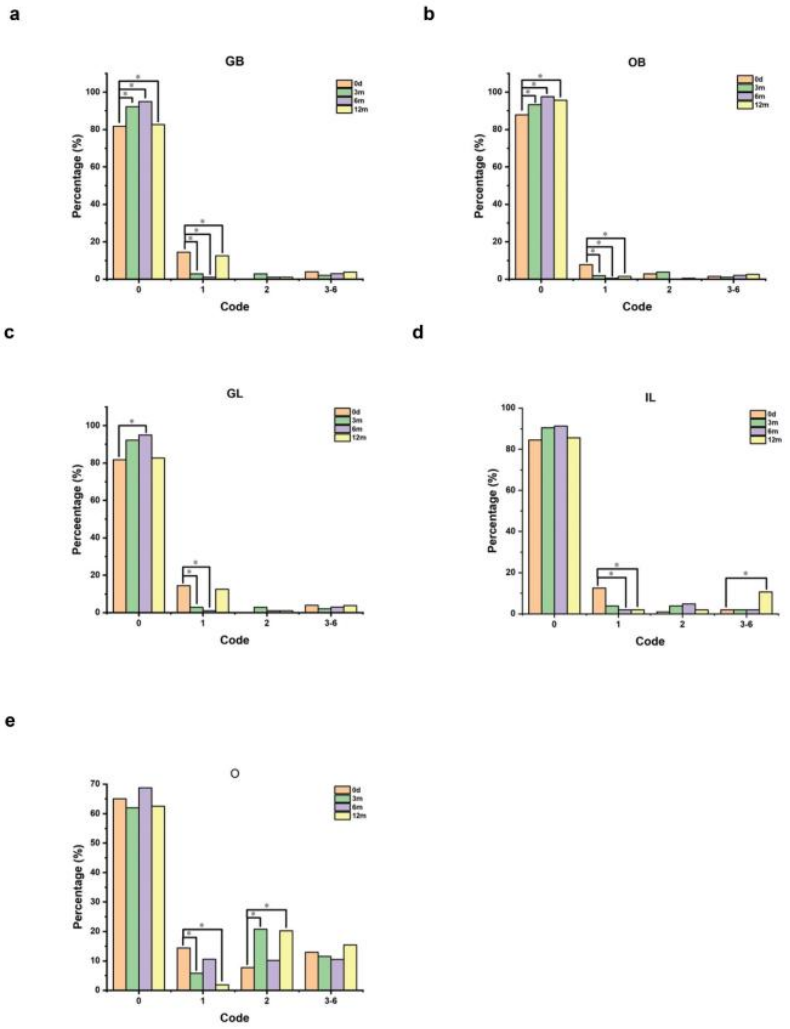

Figure 2. Charts of all ICDASII levels of the gingival 1/3 of the buccal surface (a), occlusal 2/3 of the buccal surface (b), gingival 1/3 of the labial surface (c), incisal 2/3 of the labial surface (d), and occlusal surface (c) at 0 days, 3, 6, and 12 months (Zhang et al., 2022).

The overall results of the experiment indicated that the application of topical fluoride to teeth impacted bacteria species diversity as well as disrupted microbial communities for a week after fluoride application until the bacteria microbiome recovered through interdependency around a week after the application of fluoride. Although, it did increase the abundancy of

cyanobacteria which is proven to have antimicrobial potential in an oral setting. That indicates that fluoride may have benefits in terms of promoting the growth of the beneficial bacteria naturally found in the oral cavity. The application of fluoride was also proven to significantly increase the remineralization of the enamel that was demineralized by caries and decrease overall demineralization due to the introduction of new minerals in the demineralized areas. This means despite the impacts of fluoride on the plaque microbiome; it still provides enforcement for the teeth that protects it from the caries producing acids from the plaque bacteria. Despite that, fluoride was proven to be less effective on non-smooth surfaces of the tooth than the incisal anterior surfaces of teeth which encourages looking for different application methods of fluoride to be more effective on those surfaces (Zhang et al., 2022).

The results of this research indicated that the decrease in bacteria species, metabolic functions and colonization after initial application of fluoride results in disturbed plaque microecology. An additional benefit of fluoride was its capability of reversing the effects of early caries demineralization of enamel due to its remineralizing qualities through the formation of fluorhydroxyapatite (Zhang et al. 2022). This continues to support the evidence that has promoted the use of fluoride in dental settings. The research indicates that fluoride serves the purpose of being a preventative measure for caries, especially for developing teeth. A drawback of this research conducted to test plaque microecology was that different amounts of fluoride were not tested which does not give a clear picture on whether increasing the amount of fluoride administered would increase the disruption of plaque-building-bacteria without causing fluorosis. Overall, the evidence presented by the research supports the regular usage of fluoride in dental settings.

c) Overview of Fluoride Use in Dental Settings

The usage of fluoridated toothpaste as well as the topical administration of fluoride at regular dentists' visits have been greatly regulated and encouraged. The evidence of the benefits of fluoride in topical dental usage is clear as it has been proven to promote the remineralization of enamel and decrease demineralization, thus even leading to the reversal of early caries development (Zhang et al. 2022). Despite that, it is important to be cautious of the potential risks of the development of dental fluorosis if the amount of fluoride being applied is not monitored, or if it is being ingested by young children whose teeth are still going through developmental stages. High concentrations of ingested or topically applied fluoride can result in the development of fluorosis, which is irreversible. Most toothpastes sold in the United States contain 1,000-1,100 mg/L of fluoride in the form of sodium fluoride or monofluorophosphate which in turn results in 1.3mg of fluoride in around a quarter of a teaspoon of toothpaste, although the amount of toothpaste ingested is much lower. Yet, 1.3mg is above the recommended daily amount of fluoride for children ages 8 and younger (National Institutes of Health, 2025). This poses the importance of close monitoring of children to ensure that they are not ingesting excess amounts of the toothpaste whilst brushing their teeth. Despite that, the overwhelming majority of research indicates that dental fluoride use in moderate amounts is highly beneficial for the prevention of caries.

Possible Drawbacks of Fluoride Usage

Due to the known adverse effects that fluoride is known to possibly cause, there has been increased research conducted on the potential dangers of fluoride, especially on children who are still going through development. Some of the concerns associated with excess fluoride are dental fluorosis, skeletal fluorosis, and even neurological issues. In fact, a 2024 report from the

National Toxicology Program (NTP) concluded that fluoride levels exceeding the 1.5mg/L limit of fluoride in water that is recommended by the World Health Organization are associated with an IQ deficit in children (Hu & Birnbaum, 2025). These concerns have made the use of fluoride in both dental settings and water supplies very controversial, although it takes about 10-20 years for any clinical symptoms of fluorosis to manifest (Almakadma et al., 2021). Yet, the research being conducted on the possible implications of excess fluoride provides more context for how some of these risk factors may be avoided whilst benefiting from the anti-caries effects of fluoride.

a) Impacts of Fluoride on Developing Brains

It was not until 2006 that the National Research Council (NRC) analyzed the fluoride standards set by the Environmental Protection Agency (EPA) and concluded that fluoride above the EPA's Maximum Contaminant Level Goal (MCLG) for fluoride of 4.0 mg/L would result in significant risks of the development of detrimental skeletal fluorosis and neurotoxicity in developing brains. Further research that was conducted also indicated that excess fluoride was proven to decrease the intelligence quotient (IQ) of children in school. This is likely due to the lack of development in their blood-brain barrier that prevents the fluoride from crossing into the brain through the cerebrospinal fluid. Concern due to fluoride arises as the rates of fluorosis surpass the estimate of less than 10% of children presenting with fluorosis predicted by the U.S. health authorities, (Grandjean, 2019). Most studies done on the impact of fluoride on the IQ of children that were analyzed in this study were done in locations in China with elevated levels of fluoride. A coverage of 27 cross-sectional studies conducted by Chinese fluoride experts indicated that the IQ of children who lived in areas with high fluoride exposure was lower than that of children who had less natural exposure to fluoride. Twelve more research papers that

were released after the year of 2012 that tested the range of fluoride exposure in water and/or urine samples of populations in China, India, Sudan, or Egypt reported an association between high fluoride exposure and lower intelligence. The research incorporated Raven-based intelligence scales as well as neuropsychological tests to further solidify the link between fluoride and intelligence. Four studies reported a clear negative correlation between dental fluorosis and IQ. Eighteen other studies were covered in a meta-analysis that indicated that a clear decrease in IQ was observed in people who were exposed to 1 mg/L or above of water-fluoride (Grandjean, 2019) This is above the amount of 0.7 mg/L of fluoride that is currently added to drinking water in the United States (National Institution of Health, 2025) This decreases the cause for concern for U.S. residents since the regulated amount of fluoride in drinking water does not reach the concentration that was indicated to have caused a decrease in IQ.

The overall results of the cumulation of studies about the possible impacts of fluoride on the Intelligence quotient of young children indicate that there is a risk of fluoride decreasing IQ due to the lack of development of the blood-brain barrier in developing brains. Despite that, it is important to do more research to indicate whether other factors may have contributed to decreases in IQ. A different study that was analyzed from New Zealand had contradicting results that indicated that the children in fluoridated areas were proven to have an IQ advantage over the children in non-fluoridated areas. Although, the review of the article acknowledges that it was not specified whether the subjects may have been receiving fluoride from external means other than drinking water (Grandjean, 2019). It is also important to note that the children being compared from certain areas with highly fluoridated water in previous studies may not have the same access to education as the children in areas with lower water fluoridation which may also be a factor that impacted the IQ comparisons. Despite the majority of the reviewed research

indicating a correlation between low IQ and high fluoridated water consumption, it is important to conduct more research with standardized intakes of fluoride in various areas of the world to get more conclusive results on the impacts that fluoride may have on intelligence.

b) The Risk of Skeletal Fluorosis

A common risk of excess fluoride intake is not only dental fluorosis, which can lead to the compromise of tooth structure aside from the cosmetic changes from the brown staining of teeth, but also skeletal fluorosis. Fluorosis is characterized by the increase in bone formation and may present similarly to osteoporosis. A case study was presented on a 70-year-old patient in Riyadh, Saudia Arabia who complained of generalized bone pain and fatigue. Upon checking her blood fluoride levels, it was indicated that she had 7.9 μmol/L of fluoride when the normal value is 0-4μmol/L. It was revealed that she had been drinking water from an untreated well. Later, the bone mineral density (BMD) of the patient's lumbar spine and neck of the femur were tested, and X-ray absorptiometry scans were also done on the areas. The result of her initial BMD of the lumbar spine was 2.609 g/cm² which has a T-score of +11.7 which indicated that it is greatly above normal and a sign of high bone density. On the other hand, the BMD of 1.400 g/cm² in her femur was also much higher than the normal range. After these initial scans, the patient was advised to find a new source of water and discontinue drinking water from the well with untreated water as it is likely the source of the excess fluoride in her body which led to the increased bone density indicated by the her BMD (Almakadma et al., 2021).

Nine years after advising the patient to find a new water source, final bone mineral density tests were conducted, as well as finalized X-rays of the patient's lumbar spine and radius instead of her femur due to an injury during the 9-year timeframe. The test results showed her lumbar BMD was 2.720 g/cm^2 and the radius had a BMD of 0.982 g/cm². Although the radius'

BMD cannot quite be compared to the femur BMD that was previously taken, the new lumbar spine BMD indicated an increase in bone density rather than the expected decrease from decreasing fluoride intake. Later, it was revealed upon questioning that the patient had not taken the advice of finding a new water source and continued to drink the fluoridated well water. Had the patient avoided the fluoridated water, her bone mineral density would have likely decreased, leading to alleviation of the bone pain she was experiencing (Almakadma et al., 2021).

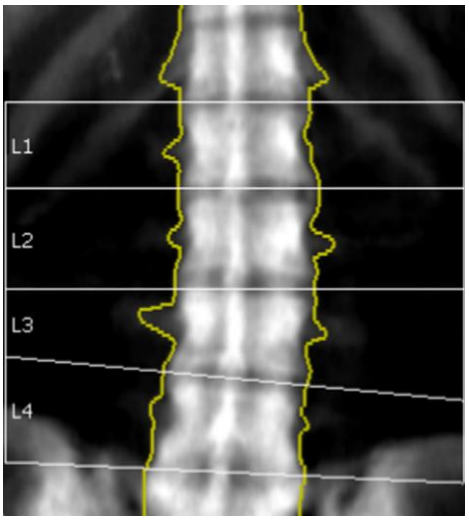

Figure 3. Initial X-ray absorptiometry image of patient's lumbar spine (Almakadma et al., 2021).

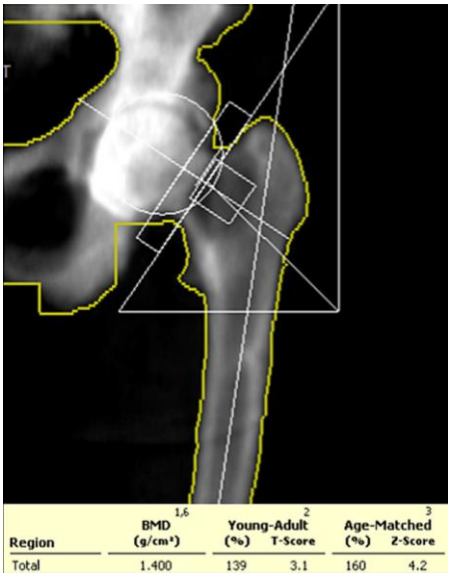

Figure 4. Initial X-ray absorptiometry image of patient's femur (Almakadma et al., 2021).

The conclusion raised by the increased BMD and bone pain that she was experiencing is that the patient likely presented with fluorosis-induced osteoporosis. According to the research presented by the case, osteoporosis and skeletal fluorosis are characterized by an increase in bone mass. The only distinction between the two is that osteoporosis occurs due to increased bone resorption whereas fluorosis is a result of osteoblast stimulator which results in increased bone formation. Although the increased bone formation promoted by fluoride may play a therapeutic role in treating osteoporosis by treating the low bone density that osteoporosis presents. Although the increased intake of fluoride may actually result in the opposite effect and present similarly to osteoporosis or even induce it by causing a deterioration of bone structure by increasing the brittleness which causes damage to the bone building and repair mechanism thus leading to osteoporosis (Almakadma et al., 2021). This reinforces the idea that fluoride is beneficial in moderate amounts yet may cause damage when taken in excess without supervision.

c) Overview of Drawbacks of Fluoride Use

As research is presented on the possible negative implications of fluoride usage, there has been increased concern regarding the incorporation of fluoride in dental settings as well as its inclusion in water supply. Despite the concern, it is important to note that a majority of the research presented about the negative impacts of fluoride only apply when fluoride is taken in excess amounts. Yet fluorosis is found in 23% of the population in the United States and is endemic in several parts of Asia and Africa. Dental fluorosis is present as discoloration in teeth and can be extremely mild, making it seemingly unnoticeable. Yet, skeletal fluorosis, which is much rarer, presents symptoms like abdominal pain, joint pain, back pain, and muscle weakness (Cleveland Clinic, 2024). To prevent the possibilities of both fluorosis and cognitive deficits in

children, it is important to maintain higher standards of fluoride exposure. It may also be beneficial to do more research on the healthy ranges of both topical and ingested fluoride in several age ranges to ensure increased safety with fluoride exposure. It is also important to provide more education to the public about the possible risks of fluoride, as well as the many benefits that it provides.

Fluoridation of Water Supply

The first time that fluoride was discovered was due to its presence in water in Colorado Springs being the cause of fluorosis. Despite that, fluoride is now incorporated into water supplies in many cities across the United States, although it is also diluted in areas that present with highly fluoridated water. Colorado Springs, Colorado is an example of this as its water supply has high amounts of fluoride due to the minerals from the mountains washing into the water supply. Although the majority consensus, as well as the information provided by the Center of Disease Control and Prevention (CDC), determined that water fluoridation is both healthy and cost effective. This is because it has been proven to help prevent tooth decay and boost oral health, which proves to be especially beneficial for impoverished communities who do not have access to dental care and need a way to further prevent tooth decay which may lead to a decreased quality of life (McCrimmon, 2024). Despite the benefits that water fluoridation presents, it still seems to be at the center of controversy due to the widespread fear of fluorosis.

a) Fluoride-Water Concentrations

Although water fluoridation has become a widespread practice, a crucial aspect of fluoridating water is knowing the optimal concentration of fluoride to add to water to ensure

community safety whilst maintaining oral health. A study was conducted in Chile to test for the appropriate concentration of fluoride to be added to water to maintain oral health. In the United States, there is currently 0.7 mg/L of fluoride being added to water (Grandjean, 2019), although this concentration is not internationally adhered to which requires studies to be conducted in different regions of the world. The study titled, "Estimation of optima concentration of fluoride in drinking water under conditions prevailing in Chile," was conducted in 5 urban cities with differing water-fluoride concentrations. This includes Rancagua (0.07 mg/L fluoride), Santiago (0.21 mg/L), La Serena (0.55 mg/L), San Felipe (0.93 mg/L), and Iquique (1.10 mg/L). A sample size of 2431 children aged 7, 12 and 15 were collected from the cities listed and were tested on the impacts of their water fluoridation concentrations in comparison to the DMFT index (decayed, missing, and filled teeth), with a lower DMFT indicating better conditions in regard to oral care. Data was collected from the schoolchildren by having examiners do oral clinical examinations on the students to look for signs of old and newly developed caries as well as fluorosis on fully erupted permanent teeth. This led to the collection of data that indicated the impacts of water fluoride concentrations on both caries prevention and fluorosis (Villa et al., 1998).

The results of the study indicated that overall, the students from Iquique from all age groups generally had lower DMFTs as well as higher percentages of students with DMFTs equal to zero, meaning they had completely avoided the development of caries or dental decay in any of their teeth at any point of having their adult teeth. In fact, as the water-fluoride concentrations correlated with each city increased, the DMFTs generally decreased except for some exceptions, and the percentage of students with DMFTs equaling zero also increased. This indicates a strong correspondence between increased water fluoride concentrations as decreased risk and rates of

dental caries leading to decaying, missing, or filled teeth. It is also indicated that as the age range increased, so did the DMFT for each city, likely due to having longer time for dental decay to develop over time. As for the rates of fluorosis, the results indicated that the prevalence of fluorosis increased as fluoride-water concentrations did for each age group, meaning the students living in Iquique had the highest percentage of fluorosis prevalence. In comparison, students in Rancagua, the city with the lowest water-fluoride concentration, had around 40-50% less prevalence of fluorosis than students in Iquique in each age group (Villa et al., 1998).

Table 1. Caries experience in 7-year-old children

	Primary dentition				
City	Water F conc. (mg/L)	*N*	dmft	Standard deviation	dmft=0 %
Rancagua	0.07	158	3.67	3.54	25.8
Santiago	0.21	205	3.39	2.96	29.0
La Serena	0.55	162	2.38	2.80	41.1
San Felipe	0.93	129	1.72	2.33	55.2
Iquique	1.10	158	1.56	1.90	59.2
	Permanent dentition				
	DMFT				
Rancagua	0.07	158	0.52	1.15	
Santiago	0.21	205	0.26	0.67	
La Serena	0.55	162	0.21	0.61	
San Felipe	0.93	129	0.16	0.43	
Iquique	1.10	158	0.19	0.38	

Table 2. Caries experience in 12-year-old children

City	Water F conc. (mg/L)	*N*	DMFT	Standard deviation	DMFT=0 %
Rancagua	0.07	155	3.10	2.65	22.9
Santiago	0.21	197	2.42	2.74	33.6
La Serena	0.55	160	1.51	1.68	41.0
San Felipe	0.93	152	1.28	1.65	52.0
Iquique	1.10	157	1.32	1.23	41.9

Table 3. Caries experience in 15-year-old children

City	Water F conc. (mg/L)	*N*	DMFT	Standard deviation	DMFT=0 %
Rancagua	0.07	150	5.06	3.94	15.3
Santiago	0.21	203	4.12	3.29	18.8
La Serena	0.55	158	3.55	2.94	19.1
San Felipe	0.93	155	3.33	2.91	15.5
Iquique	1.10	132	2.60	2.65	31.8

Figure 5. Tables of dental examination DMFT results for each age group corresponding with cities in Chile (Villa et al., 1998).

Overall, this study indicates an inverse relationship between the development of caries and concentrations of water fluoride. This means that fluoridation of water results in decreased risks of developing caries and therefore maintaining the integrity of the teeth. This was proven by the decreased rates of decaying, missing, and filled teeth in students who grew up in areas with higher concentrations of fluoride in their water. Yet, the increased fluoride concentrations had a direct relationship with increased rates of fluorosis in those students. In comparison to the

data presented by this study, it appears that the concentration of 0.7 mg/L that is maintained in the water supply in the United States is appropriate as it is significantly lower than the 1.10 mg/L in Iquique that presented with a high prevalence of fluorosis, yet higher than the concentration of 0.55 mg/L in La Serena which presented with higher DMFT rates. Although people may still present with mild fluorosis levels, it will only result in slight cosmetic changes like opaque white spots in teeth yet maintain the integrity of the teeth whilst preventing dental caries.

b) Overview of Water Fluoridation

After the implementation of water fluoridation in the United States in 1945, other countries followed, especially after the encouragement from the World Health Organization (WHO) to encourage the use of fluoride for improved public health and quality of life through avoiding dental decay. Water fluoridation of 1 ppm is proven to be effective in decreasing tooth decay in up to 50% in children. Additionally, water fluoridation also reduces the number of decaying, missing, or filled teeth in over two teeth per child on average. The main concern regarding water fluoridation is that the consumption of fluoridated water along with the use of fluoridated toothpaste as well as consuming foods that have naturally occurring fluoride may result in dental fluorosis (Moore, 2009). This concern is valid since 75-90% of ingested fluoride gets absorbed into the bloodstream and distributed through the body where 99% of the fluoride gets bound to calcium-rich tissue such as bone and teeth. This further emphasizes the importance of maintaining water fluoride levels at a consistent concentration that does not surpass the amount recommended by the WHO. Overall, it may be beneficial to continue to do research on the impacts of water fluoridation on populations such as children, and pregnant women as fluoride may also cross the placenta which reaches the fetus through amniotic fluid. Children also retain 80-90% of absorbed fluoride in comparison to the 50-60% retained by adults

(Grandjean, 2019). This means that water fluoride may have a greater impact on younger populations, therefore making it a worthwhile concept to research. Doing research on how the current concentration of 0.7 mg/L is impacting children versus adults would provide more scientific backing on whether water-fluoride concentrations should remain as they are or be altered to reduce the risk of fluorosis and cognitive impacts on children. Despite that, research has proven that water fluoridation has presented more benefits than drawbacks as it has significantly reduced the rate of dental decay, thus promoting improved quality of life.

Conclusion

Although fluoride has become a controversial agent, its usage has been promoted in dental settings, and it has been incorporated into the water supply as a means to enhance dental care. Fluoride is added or diluted from the water supply across the United States, as well as other countries globally, to maintain an adequate concentration to decrease the risk of dental decay whilst not amplifying the risk of developing dental fluorosis. Although there are other risk factors associated with excess fluoride like neurocognitive declines in children and skeletal fluorosis, those risks are rare and present in cases when abnormally high amounts of fluoride are ingested. This poses the importance of conducting more research to investigate whether water-fluoride concentrations should be adjusted based on how fluoride concentrations impact different age groups, especially in the context of developing children. Research can also be conducted on whether another mineral or agent can be added with fluoride to maintain healthy fluorohydroxy apatite crystal amounts to prevent the stimulation of osteoblasts which can counteract dental fluorosis, thus eliminating the concern of the development of fluorosis.

All the research that was reviewed for this paper acknowledged the importance and benefits of fluoride for adequate dental care, as well as its efficiency in decreasing the risk of the development of caries. Caries can be detrimental to a person's quality of life as it may lead to nerve damage if it progresses over time. This amplifies the importance of including fluoride in day-to-day life as well as dental settings as it greatly reduces the rate of caries by preventing tooth demineralization, promoting remineralization, and inhibiting the metabolism of sugars by bacteria which leads to acid release which damages enamel (Moore, 2009). Educating dental patients and the general public about both the benefits and the risks of fluoride usage may be the most beneficial method of destigmatizing fluoride whilst bringing awareness to how to prevent the possibility of developing fluorosis. It is important to maintain the addition of fluoride in dental practices as well as water supplies to continue to prevent caries in the general public, whilst maintaining awareness about how much fluoride is being added in toothpaste, topical fluoride, and water supply.

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