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An Update on Fluorides and Fluorosis with Reference to Oral Health Status in the Gulf Region: Review

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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Review Article

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ABSTRACT

Fluoride (F) has exerted the most significant impact on practice of dentistry because of its effectiveness in preventing dental caries. Despite improvements in the oral health of populations, dental caries remains a public health problem worldwide affecting most schoolchildren and present costly burden to health care services. Water fluoridation remains the cornerstone of caries prevention programs. It is the most effective means of reducing caries, cost-effective, convenient, and reliable method of providing the benefits of F to the general population. Without a doubt, the most widely used method of applying F topically is by means of dentifrices. Additional F-modes should be targeting at high-risk populations. The decision to use F in caries prevention requires a balance between benefits and the risk of fluorosis. Fluoride treatment is systemic and local. Modes of systemic fluorides include water fluoridation, dietary F supplements, fluoridated table salt and milk. Topical fluorides are self-applied toothpastes, mouthrinses, gels or professionally-applied F solutions, gels, foams, and varnishes. Acidulated F gels (APF, 1.23% F) are the most potential hazardous F products currently used in pediatric dentistry due to the inadvertent ingestion of the gel during treatment. This article reviews F and fluorosis in relation to water, foods, and beverage's intake, dental products, and industrial emissions. Fluoride metabolism, safety and toxicity is discussing. The therapeutic effects and safety of F treatment can only be answered by understanding the mechanism of F metabolism. The incidence of fluorosis is increasing due to multiple sources of F. The severity of the dental fluorosis depends on the dose, duration, and timing of fluoride intake. Dental health of children in the Arabian Gulf region will be discussed in this review.

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1. INTRODUCTION

Fluorine is an element of the halogen family, including chlorine, bromine and iodine. Due to itsreactivity, fluorine exists almost as a fluoride. Fluoride (F) constitutes about 0.032% of theearth's crust and the 17th of elements abundance. The main F-containing mineral is fluorspar (fluorite), in which 48.8% F content in the form of calcium fluoride (CaF_2).Cryolite (Na_3AlF_6) is a relatively rare mineral used as a raw material inthe aluminum industry. Fluorapatite rock [$Ca_3(PO_4)_2F$] contain 3.8% F [1,2]. Fluorosilicic acid, sodium fluoride, and hexafluorosilicate are used in community water fluoridation. Although these F compounds are readily soluble in water, others like AlF_3, MgF_2, CaF_2, and MnF_2 compounds are sparingly soluble or insoluble. Because of the universal presence of F in the earth's crust, all waters contain varying concentrations of F, depending on the availability and solubility of F minerals in contact with waters. Fluoride concentrations in rivers and lakes are generally less than 0.5 ppm (mg/L). Seawater F levels range of 0.9 to 1.4 ppm (average 1.1 ppm). In some African countries, however, where the soil is F-rich, F content in drinking-water can be very high. For example, in Tanzania;during the dry season, the maximum F level in the Maki ya Chai river was 69 ppm [3]. The highest natural F concentration ever found in water was recorded in Lake Nakuru in the rift valley in Kenya (2800 ppm) where the soil at the lake shore contained 5600 mg F/kg, and the dust 150 mgF/L (150 µg F/m^3) [4]. In groundwaters, F concentrations vary greatly depending on the nature of the soil and rocks (acidity and porosity), the temperature, the F-bearing minerals, and the depth of wells. In different geologicalareas, F concentrations in groundwater/wells range from under 1 ppm to more than 35 ppm [2,4]. In India, the highest F level in groundwater was 48 ppm [5]. In some areas in Sudan, the averageF concentration was 1.37 ppm and the maximum 7 ppm [6]. The average F level in Algeria was 1.47 ppm and the maximum 2.61 ppm [6]. InJordan, the maximum F levels in wells was 2.15 ppm [7].

1.1 Airborne Fluoride

Airborne F in the form of hydrogen fluoride (HF, a colorless gas or mists) or hydrofluoric acid (a solution of HF in water) originates from mines, industrial emissions, coal burning, fertilizers, and pesticides.In non-industrial areas, the F content in air is low (0.05–1.90 µg/m^3), while in some industrial zone can reach a level of 1.4 mg F/m^3in the ambient air [8,9]. Fluoride in the air of aluminum plants accounts for about 10% of total industrial emissions [10]. Another major source of F in the air isfrom phosphate fertilizer plants.High levels of atmospheric F dust have been reported in phosphate fertilizer areas in Morocco [11] and Jordan [12]. The dust mayinhale by the workers and contaminate foodstuffs and vegetables. In some provinces of China, F content in indoor air is high due to the combustion of F-rich coal used for cooking food [4]. In exposure to airborne F; assuming a total respiratory rate of 10 m^3 during a working day, the daily amount of F inhaled could be 10–25 mg when the air concentration is at 1–2.5 mg/m^3. Hydrofluoric acid is also absorbed through the skin.Gaseous F attacks tissue much more strongly than F salt and can cause considerable damage to the skin and respiratory tract. In the United States, the permitted occupational level of HF is 2.5 mg /m^3 [9].

2. OCCURRENCE OF DENTAL AND SKELETAL FLUOROSIS

Fluorosis is one of the serious public health problems caused by high levels of F in the drinkingwater and F-polluted air. It places a heavy burden to health care servicesin developing countries. Belts of fluorosis extend from Turkey through Iraq, Syria, Jordan, Oman, Yemen, Egypt, Libya, Algeria, to Morocco and from Egypt through the Rift Valley to Sudan, Ethiopia, Uganda, Kenya, Tanzania to Zimbabwe and parts of South Africa. According to the World Health Organization (WHO), dental fluorosis (DF) is endemic in at least 25 countries across the world with about 200 million of people are affected, particularly in the tropical regions [13)]. In China and India alone, over 60 million people have DFand 3 to 6 million suffer from skeletal fluorosis disabilities due to the exposure of excessive F in ground/well's water [13,14]. A national epidemiologic study in China revealed he prevalence rates of DF were 40.8%, 55.1% and 67.2% in areas where F concentration in drinking water was 1.2–2, 2–4 and>4 mg/L respectively [15]. In India, about 25 million people have DF, and 6 million of them are disabled due to skeletal fluorosis [14]. The skeletal fluorosis was found in 54.5% of 71-years old and older living in Poldasht County(Iran), where the maximum F concentration in wells was 10.3 ppm [16]. People in Kenya, Tanzania, Pakistan, Thailand, and Sri Lanka also suffer from DF with several million exposed to high F concentrations in the water sources [4,9]. Children can develop DF even if the F content in drinking water is below the optimal level.In South Africa, examination of 282 children living in three areas of F levels in drinking water of 0.19 ppm, 0.48 ppm, and 3 ppm showed DF rate of 47 %, 50%, and 95%, respectively [17]. Examination of 917 Mexican schoolchildren living in area of drinking water contain 0.43 ppm showed 80% had DF with 41% of them have very mild fluorosis [18].

3. INDUSTRIAL FLUOROSIS

The main sources of industrial F emissions are aluminum production and phosphate fertilizer plants. Both emit gaseous hydrogen fluoride and F dust particles. Other industries releasing hydrogen fluoride are: chemical production; steel; magnesium; and brick and clay products [9,19].

3.1 Aluminum Industry

Aluminum, the most abundant metal in the earth's crust, is one of the largest industries in the world today. It has a multitude of uses including aircraft, utensils, scientific and domestic apparatus, pharmaceuticals, conductors, and automotive parts. In the aluminum industry, F is released in the form of gaseous HF, sodium and aluminum fluoride, and unused cryolite particles. In aluminum industries, workers exposed to F-contaminated air have various health problems including skeletal fluorosis, musculoskeletal malady, asthma, neurotoxicity [20]. The F content in the air of Iran's largest aluminum plant is 73.43 µg /m3 [21]. Exposure to high F levels in the working site significantly increase the blood and urine F concentrations of workers [20,21].

3.2 Phosphate Fertilizer

Phosphorus is one of the key nutrients that plants need. Morocco owns 70% of the world's phosphate rock. In phosphate fertilizer plants, fluorapatite rocks and soil are treated with sulfuric acid (H_2SO_4), producing volatile F dust and fumes contains HF and silicon fluoride (SiF_4). A study on workers at the phosphate fertilizer plant in Khouribga area, Morocco showed over 90% of the workers had DF with more than one-third had moderate fluorosis and 12% had severe fluorosis. The DMFT and DMFS in persons living near the fertilizer area were significantly lower ($P < 0.001$) than those residing outside [11]. A study on 10 villages in the vicinity of phosphate fertilizer near Udaipur, India, showed that although the F content in drinking water is below the optimal level, more than 48% of villagers have DF. The F content in ambient air of the fertilizer exceeds 2.0 µg/m^3, and the F content of crops and vegetables is 27.5 to 143.4 µg /g [22]. Another survey of villagers living near the phosphate fertilizer of Udaipur city showed that more than half of the villagers (55.5%) had mild to severe DF, and 18.0% had fluorosis [23]. In addition to DF, Jordanian phosphate workers have oral and general health problems, including 62.2% grade 2 and 3 tooth erosion, 78% sensitive teeth, 76% bleeding gums, 67% dry mouth, and 61% taste disorders. More than half (51–69%) of the workers complained of abdominal discomfort, burning and itching of the skin and eyes, and headaches [12]. In China, endemic fluorosis reported in areas where coal and mud contain more than 10,000 mg F/kg are used to make bricks and tiles. After combustion, the gases and fumes of HF and SiF4 are released in the workplace [24]. The F released into the atmosphere by industry contaminate not only soil, air and water, but also vegetation, crops and many other staff on which humans and animals depend [22,23].

4. FLUORIDE IN FOOD AND BEVERAGES

4.1 Fluoride in Plants

Vegetables and fruits normally have low levels of F (0.1–0.4 mg/kg) and thus contribute littleto daily F intake [1,9]. The F levels of food depend on the nature of soil and water used for irrigation. Foods grown in endemic F areas have high levels of F. The F contents of cereals and vegetables vary from 0.45 to 5.98 µg/g where irrigation water contains 1.5 to 11.82 ppm F and 4.25 to 29.15 µg/g grown in soil contain 8.5 to 135.5 mg F/kg [5]. A simple wash with water will remove most of the F deposited in the food. Since F is dissolved from minerals, plants growing in acidic soils (such as tea) accumulate more F. Tea plant is rich in F, and its F content depends on the type/brand of tea and its source. The F content of 26 Chinese and Indian brands of dry tea leaves (bulk and bagged)from the Hong Kong market is between82 and 371 µg F/g [25]. Preparation of tea infusion by adding 1 g of the tea leaf (contain an average of 225 µg F/g)to 100 mL deionized water preheated to 85°Cresulted in an average of 1.5 ppm F. Tea leaves brewing for 15 minutes significantly released more F than 5-minutes brewing [25]. The intake of 250 mL (~1 tea cup) of tea leaves infused in tap water contains 0.7 ppm will expose the body to 0.55 mg F.A tea bag that contains 1.5 g tea leaves have an average of 338µgF/g. The F concentration in herb teas is negligible. In some provinces in China, people ingest large amounts of F (14 mg/day) of brick tea made from older leaves containing as much as 590 to 708 µg F/g dry weight [26]. In F endemic areas, tea trees will accumulate more F, which release during the brewing process. Boiled tea leaves increase the concentration of F. The addition of milk will reduce the concentration of F [5,25].

4.2 Fluoride in Animal Products

Meat and poultry have a low F content of 0.04–1.7 µg/g, but may be higher due to their F accumulation in bone and cartilage [1,2]. Fluoride content in varieties of fishes in Canada ranged from 0.21 to 4.57 µg/g [27]. In South East Asia, the F content (µg/g) of dried sea foods was: top shells 33.6–292, anchovies and sardines 7.8–63.3, shrimps 5.4–44.1, oysters and mussels 2.9–5.1, octopus and squids 1.4–1.7 [1,28]. The F content of cow's milk was 0.01 mg/L [29]. In endemic fluorosis areas, a high F content in cow's milk of 0.41–6.87 mg/L have been found [5]. Humanmilk obtained from mothers' lives in areas of 1 and 0.2 ppm F in the drinking water was 6.84 and 5.32 µg F/L, respectively [30]. The F content of 20 brands of powdered infant formulas ranged from 0.06 to 1.08 µg/g with an average 0.39 µg F/g [29].

4.3 Fluoride in Beverages

The main ingredient of beverages is water. Hence, their F content depends on the type of water used and the geographical origin. Analysis of soft drinks in Amman (Jordan) showed F concentrations in carbonated drinks were 0.16–0.38 ppm, with an average 0.23 ppm. The F concentration in drinking water in Amman was 0.37 ppm [31]. Tests of soft drinks of different origins in Hong Kong revealed F concentrations (ppm) in carbonated beverages ranged from 0.02 to 0.78 and in fruit-flavored juices 0.02 to 2.05 with a general average of 0.42 [29]. Examining 332 soft drinks in the USA showed F levels ranged from 0.02 to 1.28 ppm, with an average of 0.72 ppm [32]. In Canada, the F levels of soft drinks 0.21–0.96 ppm [27] and 0.014–0.35 ppm in Germany [2].

4.4 Fluoride in Bottled Water

Bottled drinking water dependence is growing rapidly around the world due to consumer confidence in its quality and taste preference. Some bottled water contains F and some do not. Fluoride in bottled waters can occur naturally from their sources or be added. The U.S. Food and Drug Administration (FDA) proposed that bottled water to which F is added by the manufacturer may not contain F that exceeds 0.7 ppm [33]. Fluoride concentrations (ppm) in bottled water in the United States varied from zero to 1.36 (mean 0.18), Canada 0.05–4.8, United Kingdom 0.01–0.37 [9], Hong Kong 0.02–0.54 [29], and 0.01–1.2 in the Gulf region [34,35].

4.5 Determination of Fluoride

In determination of Fin biological and other materials, it is necessary to separate F from other components prior determination. Acid-HMDS microdiffusion is the most commonly used analytical method. With this method, digestion / decomposition of the sample occurs by using perchloric acid or sulfuric acid. HMDS (hexamethyldisiloxane) increases the diffusion rate by releasing volatile trimethylfluorosilane, which is captured by the alkaline solution in a micro plastic cup placed above the digestion medium [36]. The alkali solution is neutralized, buffered, and the F concentration is determined using F ion–selective electrode [36,37]. Ion chromatography is also used for F analysis in a variety of media. It measures concentrations of ionic species depending on specie's type and size.

5. SYSTEMIC FLUORIDES OTHER THAN WATER

The use of F in caries prevention is systemic, local, or in combination. Systemic fluorides include water fluoridation, dietary F supplements (tablets, lozenges, drops), fluoridated salt, and fluoridated milk. They are used when drinking water has a low F concentration. Ingested F is incorporating into the forming tooth structure; making the enamel more resistant to acid dissolution. However, the systemic uptake of F by dental tissue is a slow process, and it may take months or years for the enamel to obtain an effective F concentration. The rational of using F concentrated topical fluorides in forms of toothpastes, mouthrinses, solutions, gels, foams, and varnishes is to speed the rate of enamel F uptake. Systemic F can also exert a beneficial local effect through its presence in saliva, thus constantly bathing the teeth. However, some workers questioned systemic methods to deliver F due to the fact that fluoride's action relies mainly on its post-eruptive effect from topical contact with the tooth structure [38,39].

5.1 Dietary Fluoride Supplements

Alternative to water fluoridation is the intake of dietary F supplements for children who are living in areas of F-deficient water supplies. Most supplements contain NaF as the active ingredient. If F supplements are recommended, they should begin at six months of age and continued to age of 16 [40]. Fluoride tablets and lozenges contain 0.25, 0.5 or 1.0 mg F. While the useof fluoridated water permit F ingestion in small at intervals throughout the day, the entire dailydose of F supplements is ingested at onetime which may lead to unwanted elevation in plasma F level [41] and DF [42]. Fluoride supplements should never be prescribed when F level in drinking water exceeds 0.7 ppm. To add local to the systemic effect of F, tablets and lozenges are to be chewed or sucked for 1–2 minutes before swallowed. A literature review shows that the use of F supplements can reduce permanent caries by 30-40% [1,4,40]. Childrenexposure to multiplesources of water may complicate proper prescribing. Today, post-eruptive topical F is considered as being more convenient than the pre-eruptive systemic effect of the dietary F supplements. Ingestion of higher than recommended levels of F by children associating with increased risk of mild DF in developing, unerupted teeth.

5.2 Fluoridated Salt

The successful addition of iodine to table salt for the prevention of a goiter encouraged the introduction of fluoridated salt. By 1967, three-quarters of the table salt sold in Switzerland contained 250 mg F/kg. Today, 250-350 mg F /kg fluoridated salts are available in many European and Latin American countries. Nowadays, 30 to 80% of marketed salt is fluoridated. Fluoridated salt did not achieve the cariostatic benefit provided by fluoridated water, because salt consumption of young children is relatively low. Therefore, DF is unexpected. The use of fluoridated salt showed caries reduction of 35% from the age of 5 onwards [4,40]. Salt fluoridation has the following advantages including: low cost, negligible waste of F, ease of use, and free choice for anyone. The main disadvantages are the F dose should be determined through knowledge of salt consumption at different ages and in different regions. Nevertheless, in parts of the world without piped water supplies, fluoridated saltis a useful alternative to water fluoridation.

5.3 Fluoridated Milk

Because milk is vital in our daily diet, it is considered a suitable vehicle for F supplementation to children living in areas of F-deficient water supplies. Fluoridated milk is distributing to school children in several countries; where 5 mg F (as NaF) is added to one liter of milk. Each child is given 200 mL (contained 1 mg F) fluoridated milk every school day, begin before the children are 4 years old [4,8,43]. *In vitro*, *in vivo*, and human studies showed that fluoridated milk significantly reduced enamel solubility, increased enamel F uptake, enhanced remineralization, elevate saliva and plaque F levels, and anticaries effects [43]. A clinical trial in Glasgow (UK) was conducted (1984) on school children aged 4.5 to 5.5 years received daily 200 ml of fluoridated milk at 7 ppm (1.5 mg F). After the fourth year, significant differences in caries incidence ($P<0.01$) were found between the test group (mean DMFT= 1.65) and control group (mean DMFT= 2.56). By the fifth year, the mean DMFS differences between the test and control groups increased to 39.6% and to 48.0% in the permanent teeth that were unerupted at baseline [44]. A 3-year study (1987) was carried out on 273 Palestinian schoolchildren, aged 4 to 7 years, in Bethlehem (West Bank). Each school day, children in the test group received 100 ml of reconstituted powdered cow's milk supplemented with 1 mg F as NaF (10 ppm F). After 3 years, dental caries in primary and permanent teeth were reduced by 60% compared with the non-fluorinated milk control group [45]. Milk fluoridation has the advantage of being selective and that children need to drink milk for their health. The disadvantages include: F incompletely ionized in milk; absorption of F from milk is lower than from water; technical difficulties; problems of distribution, and high cost.

6. TOPICAL FLUORIDES

It has been 60 years since topical fluoride was applied on erupted primary and permanent teeth. The mode of topical fluoride's action is increase enamel F concentration, reduce enamel solubilityduring acid attack, promote remineralization of early carious lesions, inhibit plaque bacterial metabolism and growth. Topical fluorides fall into two categories: (a) The self-applied toothpastes, mouthrinses, gels and (b) Professionally-applied F-concentrated solutions, gels, foams, and varnishes. According to the WHO report (4), the number of people using various F therapies and preventive measures worldwide (in millions):clinically-applied topical F (20), mouthrinses (20), fluoridated toothpastes (500) compared to systemic F intake in forms of tablets/drops (20), salt fluoridation (40), water fluoridation (210).

6.1 Self-applied Topical Fluorides

6.1.1 Toothpastes (dentifrices)

They are the most widely used F method for all ages. Today, almost all dentifrices contain F compounds in the forms of NaF, MFP, SnF_2, and amine F. The decline in the prevalence of dental caries in most industrialized countries over the past 40 years attributed mainly to the widespread use of toothpastes. Fluoride concentrations in conventional toothpastes ranged between 0.1% (1000 ppm) and 0.145% (1450 ppm) or higher. Low F concentrations (250 to 550 ppm) are sellingto pre-school children. Toothpastes differ in their composition, properties, and clinical performance [46,47]. Brushing with toothpaste raisethe saliva F concentration to a peak of 9 ppm and returned to baseline levels (0.02 ppm) after 2 hours [48]. Rinse follow tooth brushing will greatly reduce the salivary F levels, but it will lessen the amount of swallow toothpaste slurry.Clinical trials of F-dentifrices show a reduction in caries incidence ranged from 17% in subjects living in optimum F areas to about 37% in low-fluoride areas, with an average of 25% [38,49]. For children younger than 3 years, parents or caregivers should brush children's teeth once they erupt by using a low F-containing toothpaste in an amount only the size of a grain of rice (~ 0.125 g) smeared over the brush. For children from 3 to 6 years old, no more than a pea-size (~0.25 g) of toothpaste should be dispensed. In a study of preschoolers, the amount of swallowed toothpaste ranged from 55% to 79% of the paste used [50].

6.1.2 Fluoride Mouthrinses

Fluoride mouthrinses (mouthwashes) intended for daily or weekly use. They have become one of the most widely used caries-preventive measure for schoolchildren. The estimated annual cost of school-mouthrinse program ranged from $0.52 to 1.78 of an average about $1.2 (US dollars) per child per school year [1,8]. The most common F compound used in mouthrinse is NaF, which available over-the-counter at concentrations of 0.05% NaF (225 ppm F) for daily use. A meta-analysis of 36 studies showed that F-mouthwashes reduced caries by an average of 26% (24-29) [51]. Mouthrinses should not be using by children under 6 years old because they cannot control their swallowing reflex and may swallow as much as 40% of the mouthrinse. Children under the age of 4 may swallow the entire rinse solution. In children between the ages of 6 to 7 years, a reduced volume to 7 ml and shorter duration of 30 seconds is recommending. Remember that the use of a mouthwash is an adjunct and cannot replace the need to brush the teeth with toothpaste. Daily rinsing with 0.05% NaF are marginally more effective than weekly or fortnightly rinsing with 0.2% NaF (920 ppm F) [51]. In the mid1980's, supervised school-based weekly rinsing program was conducted on children aged 9–11 years in Baghdad city. Children received a supervised rinse of 10 ml of 0.2% NaF solution for 2 minutes per week. After 28–34 rinses for 7months, the enamel solubility was 18.4% less than of the control group who rinsed with tap water (0.11 ppm F). Three hours after mouthrinsing, the salivary F concentration was still 20-times higher than the baseline value. The average amount of F retained in the mouth and swallowed after rinsing was 29.2% (2.6 mgF) [52].

7. PROFESSIONALLY-APPLIED TOPICAL FLUORIDES

7.1 Fluoride Solutions

The commonly used F solutions contain 2% sodium fluoride (9,050 ppm F), 1.23% APF (acidulated phosphate fluoride, 12,300 ppm F; as 2.72% NaF) and 8% SnF_2 (stannous fluoride, 19,500 ppm F). Neutral 2% NaF solution applied by the "paint-on" technique was the first topical therapy used in public health programs. After cleaning the teeth; F solution is applied for 4 minutes using a cotton tipped applicator or a small cotton pellet saturated with the F solution. The teeth in each quadrant areisolated by cotton rolls and a saliva ejector is placed. Any excess solution is aspirated to prevent the patient from swallowing it. Eating, drinking, or rinsing should be avoided for 30 minutes after the treatment to increase enamel F uptake.

7.2 Fluoride Gels

The use of viscous gels instead of solutions as a vehicle for topical application has several practical advantages. The gel adheres to the teeth for a considerable time and eliminates the continuous wetting of the enamel surface required when using the F solution. Hence, F gels are more commonly used in dental practices than the solutions. The concentration of F in gels ranges from 5,000 ppm to 12,300 ppm. A variety of double-arch disposable (hinged) trays of different types and sizes are available on the market, allowing two arches to be treated at once.Treatment consisted of placing thin strip of Fgel; a few millimeters thick, into each tray,placing saliva ejector between the upper and lower trays,and traysholding in a position for 4 minutes. Theexcess gel should wipe off from the teeth with gauze after the tray withdrawing and let the patient to spit out but not rinsing. Applying 1.23% APF gel twice a year, resulting in a caries prevention ranged from 18% to 37% with an average of 27% [49,51]. Unintentional ingestion of F gel during topical application is not uncommon. The use of 3–5 mL of 1.23% APF gel for topical treatment, presenting a potential exposure of 36.9–61.5 mg F(12.3 mg F/mL).

Review of literature [53] showed that 20% [54] to 78% [55] (mean = 40% ± 22%) of the applied gel to children aged 5-12 (mean=10±1.7) was retained in the mouth/ingested during the gel application, corresponding to 9.9–31.2 mg F (mean=20.2±7.3mg F). The wide range of ingested gel is relating to the age of participants, the type of tray used, suctioning and expectoration. Inadvertent ingestion 31.2 mg F of the applied 1.23% APF gel raised plasma F levels in children from 300 to 1,443 ng/mL after 1 hour and remained high in the following hours; causing nausea, vomiting, and abdominal pain [55]. The high plasma F peaks can be sufficient to induce dental fluorosis. Experiment on rats showed the occurrence of enamel fluorosis following daily peak plasma F level of 10 μM (190 ng/ml) for one week [56]. A study on 10 adults treated with 4 g of 1.23% APF gel (49.2 mg F) for 4 minutes, using saliva ejector, showed only 2.8% (1.37 mg F) of the applied gel was retained in the mouth. Using the saliva ejector reduced retained gel by 33% [53].

7.3 Fluoride Foams

Concern expressing about the potential risk of excessive gel ingestion during treating children. In order to reduce the risk of an unintentional ingestion of the gel, a foam-based APF agent containing 1.23% F was developed. The amount of foam needed for full-mouth treatment is less than 1g. Experiments on extracted teeth showed the uptake of F in the outer 15 μm enamel from APF gel was 1.5 times more than of foam preparation [57]. In adults, the oral retention of 4-minutes applied 1.23% APF foam (0.9 g, 11mg F) using hinged design trays was I.67 mg F compared to and 2.53 mg F for the APF gel [53]. As mentioned, 40% of the applied gelto children is retained in mouth and ingested. The use of a saliva ejector during F foam application to adults has no appreciable effect on the amount of retained F. A 24-month clinical trial of 1.23% APF foam in children showed a 24% reduction in caries [58]. In a subsequent study, F foam application resulted in 76% reduction in white spot lesions. Advantage of foam over gel is less material needed for treatment, so the patient's risk of ingesting excess F is considerably reduced. For best results, dry teeth prior to application. Insert the filled tray, let the patient bite gently, and chew lightly to ensure interproximal coverage.

7.4 Fluoride Varnish

During a topical F treatment using a F solution or gel, about two-thirds of the enamel F is lost in the first few days. The rapid loss of F can be reduced by using a waterproof F varnish adhere to the tooth surface. One such product is Duraphat®, which contains 50 mg NaF/mL (2.26% F; 22.6 mg F/g or 22,600 ppm F), in an alcoholic solution of colophony resin. The varnish is applied onto freshly cleaned teeth and sets in contact with saliva. Few amounts (0.3–0.6 mL) containing 6.8–13.6 mg F of varnish is required to treat the entire dentition. An applicator or a small cotton pellet is used to apply the varnish. The patient should avoid brushing for the rest of the day. Applying Duraphat varnish every six months for two years resulted in caries reduction of 37%, which is more effective than gels and foams [49,51]. Another F varnish is Fluor Protector, which contains 0.9% difluorsilane (0.1% F or 1000 ppm) in a polyurethane base. As the solvents evaporate, the varnish hardens to a clear transparent film on the tooth surface. Pharmacokinetic study on toddlers aged 12 to 15 months showed that application of 5% NaF varnish raised the baseline plasma F concentration13 to 21 ng/mL at 5 hours after treatment. The mean peak plasma F level following varnish application was 57 ng/mL [59]; i.e., 5.26 times lesser than the lowest value reported for APF gel treatment (300 ng/mL) [55]. Recent studies of adults receiving 0.4 mL of 5% NaF varnish have shown that the average plasma F peak is 60 ng/mL [60]. There is no evidence that the use of F varnish poses adverse effects to children. Currently, F varnish is considered the best choice for preventing caries in children under age six. In patients of moderate or high risk to caries, topical F varnish should apply at least twice a year. School-based prevention programs in Sweden showed that the ratio benefits to costs were 1.8:1 for F-varnish treatment and 0.9:1 for F-mouthrinsing, suggested that F varnish program for school children can be a better alternative than mouthrinsing [51]. Application of fluoride varnish is unlikely to be cost-effective in low-risk populations.

7.5 Fluoridated Prophylaxis Pastes

Prophylaxis pastes are available in F or F-free varieties. The fluoridated pastes contain abrasive materials such as silicon dioxide (SiO_2) orzirconium silicate ($ZnSiO_4$) and F compound in forms of NaF, APF, or SnF_2. These pastes used to clean and polish the tooth surfaces by removing the extrinsicstains, salivary pellicle, and dental plaque. According to the American Dental Association there is no benefit by using a prophylaxis prior to APF gel application for caries prevention. Annual or biannual application of prophylaxis for caries prevention is much less beneficial than the use of other topical F products [61].

8. POTENTIAL RISK OF DENTAL PRODUCTS

Exposure to multiple sources of F may lead to the risk of developing DF in children. The use of F supplements (tablets 0.25–1 mg or drops) are effectivein reducing the incidence of dental caries in both primary and permanent teeth of children living in non fluoridated communities. However, their use during the first 6 years of life leads to the risk of developing very mild to mild DF [42,62]. The level of F intake between the ages of 15 and 30 months is considered the most critical for the development of fluorosis of the maxillary central incisors [40]. Topical fluorides contribute to total F exposure and can be a factor in the incidence of DF, especially when frequently used in fluoridated area. The occurrence of DF is related to the cumulative F intake during enamel development, but the severity of the condition depends on the dose, duration, and timing of F intake.

Use of F-toothpaste is a major risk factor for DF in children who brush and live in areas with fluoridated drinking water. Children aged less than 6 years cannot control their swallowing reflex, leading to ingestion of the toothpaste slurry. Using a pea-sized amount of toothpaste versus a smear, more than doubles the amount of F swallowed by a child. Evidence indicating that brushing infants and toddlers'teeth by conventional toothpaste containing 1%–1.45% F with lack of close parental supervision significantly contributes to the occurrence of DF. A 2-year-old (~15 kg) child who brushes his/her teeth twice a day with a smear of 1% F toothpaste and swallows all the toothpaste slurry would ingest 0.25 mg F, resulting in a dose of 0.017 mg F/kg body weight. If the same child brush twice a day with a pea-sized toothpaste and swallow the applied toothpaste, he/ she would ingest 0.5 mg F (0.033 mg F/kg body weight), which accounts half of the allowed (optimal) daily F intake (0.05 to 0.07 mg F/kg body weight).

High F concentrations in APF gels are the most hazardous F products currently used of topical treatments in children, if not properly applied. Using 4 mL of 1.23% APF gel in a tray exposes the body to 49.2 mgF. The acidity (pH 3.2–3.5) of the gel increases saliva flow during use, resulting in more gel intake. A 5-year-old child, weighing 18 kg, swallows 2.5 ml of 1.23% APF gel (30.75 mg F) during topical application will expose the body to an average of 1.71 mg/kg body weight, which is 24.4 times more than the highest optimal daily F intake (0.07 mg/kg/body weight). Using foam-lined trays, limiting the amount of gel dispensed, efficient saliva evacuation, and thorough expectoration after the application will significantly reduce oral F ingestion. It is not recommending to use applicator tray for young children due to the risk of accidental of swallowing the applied gel.

The use of F varnish introduces much less F into the mouth than F gels. Because of the small amount of varnish used, its adhesion to the tooth surface and its quality of slow F release; the possibility of ingesting applied varnish is much less than using a gel. Since the varnish wears off the teeth over hours, some of the applied F is ingested. Fluoride varnish is safe and well accepted topical treatment, particularly for young children at a high risk of caries.

Alginate impression materials have been used in dental practices since 1947. The local and systemic effects of F in alginate materials were not studied until 1978 [63,64]. Analysis of 10 brands of alginate impression powders contained 4.4 to 24.2 mg/g F (0.44–2.42% F).Human studies have shown that F in the alginate impression is transferred to oral fluids and systemic circulation. In the absence of a saliva suctioning and swallowing pooled saliva, the peak plasma F level of 119 ng F/ml and 200 ng /ml reached at 30 min after single and double impressions, respectively (64). Ingestion of 2 g alginate (~10 mg F) raised plasma F level to a peak of 120–158 ng/ml at 30–45 min after alginate ingestion compare to 140-176 ng/ml followed the intake of 3 mg F (as NaF) in aqueous solution as a reference [65]. These plasma F peaks are close to levels which induced DF in experimental animals [55]. The F distribution from the alginate impression justified effective saliva suction and inspection of the alginate debris remaining in the mouth. This practice is recommending to avoid the risk of excessive F intake.

9. TOTAL DAILY FLUORIDE INTAKE

Natural or artificially fluoridated water is the main source of F intake. The amount of F intake depends on the F content in water, and the daily water consumption that varies by age, weight, sex, air temperature, humidity, and activity level. Boiling water does not remove F. About 75% of the F intake comes from water and beverages. A person who consumes one liter of water contains 1 ppm F will receive 1mg F. In general, children aged 1 to 3 years consume 1.2 L/day including drinking water, beverages, and water from food, children 4–8 years 1.6 L/day, and 9–13 years 2.5 L/day. However, certain dietary habits (tea and seafood)and the use of topical fluoride, especially toothpaste can significantly increase daily F intake. For children aged 12 years and younger, 0.05 to 0.07 mg/kg of body weight is the optimal amount of the total daily intake of F widely accepted. At lower levels of daily F intake, DF have been observed in certain areas [4,50]. The daily F intake by adults in community of optimally fluoridated water (0.7–1 ppm) ranges from 1.4 to 3.4 mg/day (average 2 mg/day), and in non-fluoridated areas 0.3–1.0 mg/day (average 0.6 mg/day) [1,9]. Studies have shown that DF becomes apparent when the threshold of F in drinking water is 2.0 ppm. Thus, daily F intake should not exceed 0.10 mg/kg of body weight up to the age of 12 years to avoid DF.

In beverages, tea is the main source of daily intake of F. According to The Food and Agriculture Organization (FAO, 2018), global tea production and consumption continue to increase. China accounted for 42.6% of the world tea production and having more than doubled from 1.17 million tons in 2007 to 2.44 tons in 2016. Production in India is the second largest producer. If a 7-year-old child (~23 kg) drinks 250 mL tea infusion prepared in water contained 0.7 or 1.5 ppm, the body will be exposing to 0.55 or 0.75 mg F, which accounts 40 % or 54% of the average optimum daily F intake (0.06 mg F/ kg body weight).The F content in Indian tea infusion ranged from 1.55 mg/L to 3.21 mg/L [5]. The estimated F intake per mug (350 mL) of tea from New Zealand market ranged from 0.1 to 1.1 mg/day for nonfluoridated communities and 0.3 to 1.5 mg/day for fluoridated communities [66]. In Australia, daily tea consumption among infants and children was approximately 150 mL for infants aged 1–3 years; 250 mL for children aged 4–8 years; 300 mL for 9–13-year-old and 500 mL for 14–18-year-old [66]. The skeletal fluorosis has been found in some elderly persons who are chronic high tea drinkers.

The WHO recommends that infants be exclusively breastfed for the first six months of life to achieve optimal growth, development, and health. Instances where breast milk is not provided, infant formula is a substitute. Powder-milk formula (instant infant formula) is the main source of total F intake when prepared with fluorinated water. Infant formulas powders contained 0.06 to 1.08, with an average of 0.39 µg F/g [29]. Preparation of an infant formula involves 1 level scoop of powder (~8 g) for 58 mL or 13.8 g (5.38 µg F)for 100 mL reconstituted with nonfluoridated water. When water containing 0.7 ppm F is used, infants will consume 12.4 µg F / 100 mL.

10. FLUORIDE METABOLISM

Knowledge of F metabolism aspects is essential to understand the biological role of this ion in the prevention of dental caries and its toxicity above the optimal dose. The therapeutic effects and safety of the applied F can only be answered by understanding the dynamics of F absorption, distribution, and excretion. About 99% of the F in the human body accumulating in bones and teeth. The factors involved in F deposition in the hard tissue of the tooth are the same as those for bone. Fluoride in ionic form is a negatively charged (F^{-}) attracted by positively charged ions like calcium (Ca^{2+}). Bones and teeth having the highest amount of calcium in the body, will attract the largest amount of F that deposited as calcium fluorapatite [($Ca_5(PO4)_3F$]. From F intake; adults retain about 30–40%, children 50%–60%, infants 80–90% of F in the hard tissues and only 1% retain in the soft tissue [62,67]. Growing young people whose bones are being reshaped (remodeled) get more F than older people. During the life of the tooth, fluoride is deposited in the tooth tissue in successive stages. First, it occurs during processing of the organic and mineral phases. Next, F deposited from the tissue's fluids during the pre-eruptive maturation phase and finally, F is acquired by enamel during the post-eruptive maturation and aging period by topical application. Fluoride is reversibly bound to bone, should a person move from an area with high levels of F to an area with low levels, excess F releasing from mobilized bones, but not from teeth. About 90% of F ingested is absorbed in the gastrointestinal tract;25–40% in the stomach and 50–70% in proximal part of the small intestine. The remaining 5–10% is excreted in feces (Fig. 1).

10.1 Fluoride Absorption and Distribution

After ingestion, plasma fluoride levels increase rapidly due to the rapid absorption from the stomach. When F is taken orally, the amount of F absorbed and the rate of absorption is governed by many factors including the physical form of the dose, food in the stomach, gastric pH, gastric emptying, the solubility of the ingested F compound, and F interaction with the diet and food components. The higher the gastric acidity, the more F is absorbed. Fluoride compounds differ in their reactivity, structure, solubility, and ability to release Fin ionic form. Fluoride complexing cations (Ca^{2+}, Mg^{2+}, Al^{3+}, Fe^{3+}) inhibits F systemic absorption. Once absorbed into the bloodstream, F is readily distributed throughout the body, and almost all F retains in calcium-rich bones and teeth. Systemic absorption of soluble F compounds (e.g., NaF, H_2SiF_6, Na_2SiF_6, Na_2PO_3F) is rapid and nearly complete, whereas the absorption of F from less soluble compounds such as calcium fluoride (CaF_2) magnesium fluoride (MgF_2), and aluminum fluoride (AlF_3) is incomplete. On fasting (gastric pH ~1.7), almost all the ingested F in forms of tablets, lozenges, mouthrinses, or gels is absorbed by the gut. Absorption of F from ingested dentifrices is less than complete depending on the presence of cations, which complex F. The absorption of F from milk and other dairy products is slower and less complete than that from water because of F complexes with the high calcium content in these products [43,62,67]. Absorption of F from milk and other dairy products is slower and less complete Ingestion of dried seafoods showed marked delay in F absorption with bioavailability of 40.8% [28].

After the intake of F tablet (0.5 mg F) or 0.6 g toothpaste (0.6 mg F), the peak plasma F levels 84.9 or 69 ng /mL was reached at 30 minutes [41]. Laboratory studies on the dissolution and interaction of F in NaF tablets have shown that F in tablets is soluble in water, orange juice and Coca-Cola. In milk, the dissolved F^{-} is 35% less than the total F content in the tablet [68]. Interestingly, the results of these in vitro studies are comparable to reports of a 64.5% decrease in the bioavailability of F tablets taken with milk [41]. The placenta acts as a natural barrier to the passage of larger quantities of F to the fetus. At low F intake levels, the amount of F crosses the placenta and distributed to the mothers' milk was equal to those in blood [30]. Plasma F levels can indicate the F content in the water consumed.

10.2 Excretion of Fluoride

The three main avenues for the elimination of F from the body are urine, feces, and perspiration. Saliva and breast milk are negligible excretion routes. Fluoride is cleared from plasma through two main mechanism: uptake by bone and excretion in urine. Renal excretion is the most important route for the removal of F from the body. Around 50% of a single F dose in an adult is excreted in the urine during 24 hours (Fig. 1). However, several factors may influence the urinary excretion of F including previous exposures to F, age, urinary flow rate, glomerular filtration rate, exposures to F, age, urine pH, and kidney status [62].

11. FLUORIDE SAFETY AND TOXICITY

Excessive intake of F can be toxic. The American Dental Association has recommended that no more than 120 mg F (264 mg sodium fluoride) be dispensed at any one time (40). Numerous studies have shown that the consumption of F in drinking water artificially fluoridated or naturally available at optimal levels is recommending for better dental health and has no harmful effect on humans [4,8,19]. As many elements like zinc, iron, vitamins, chlorine are vital for good health; F as the others can be toxic in excess. Reports on the toxicity of F using dental products have shown that 68% is associated with toothpaste intake, 17% is associated with mouthwash, and 15% is associated with dietary F supplements. Children younger than 6 years' old account for more than 80% of suspected over-ingestion [69]. The risk of excessive F in drinking water in children is limited to the occurrence of DF. The highest recommended F level is 1.5 mg/L, but the optimum range is 0.5 to1 mg/L; depend on average ambient temperatures and amount of water consumption [1,4,8]. The toxic effects of F can be classified as acute; due to a single ingestion of a large amount of F, or chronic due to long-term ingestion of lesser F amounts.

11.1 Acute Toxicity

Most of the reported acute F poisonings are caused by accidental contamination of food with F salts or exposure to a gaseous hydrogen fluoride. The exact toxicity and lethal dose of F vary due to the wide range of individual responses to F.In general, F dose of 0.1–0.3 mg F/kg body weight can induce toxicity manifested by nausea, vomiting, abdominal pain [1,9,62]. The minimum lethal dose (MLD) also named 'probably toxic dose' for a man is about 5 g as NaF (2.2 gF or 32 mg F/kg body weight). A fourth of the MLD is tolerating [9,62]. The estimated acute toxic F dose for a 15-kg child (age~3 years) would be about 1.6 g as NaF (730 mg F). Ingesting fourth of the acute toxic dose (182.5 mg F) is safely tolerated.A 10-kg child who ingests 50 mg F (4.1 g 1.23% APF gel; 33.3 g 1,500 ppm F toothpaste; 50 g 1,000 ppm F toothpaste; and 221 mL 0.05% NaF rinse) will have ingested a toxic dose of 5 mg/kg body weight [69]. For a 15-kg child (age ~ 3 years) the lethal dose would be about 345 mg F (0.76 g NaF).Usually, acute exposure to F produces a toxic effect within 1 or 2 hours, and death can occur within 4 hours. Due to the rapid elimination of F in urine, subjects who survive within the first 24 hours have a good prognosis. If the F dose is less than 5 mg, calcium (milk) taking orally will relieve abdominal pain. If the dose more than 5 mg empty the stomach by inducing vomiting. Give the patient milk or 5% calcium gluconate solution. If the F overdoses more than 15 mg/kg body weight, admit to hospital immediately.

11.2 Chronic Toxicity

Long-term ingestion of high F content in drinking water result in skeletal changes (osteofluorosis) and if the exposure occurs during the period of tooth development, DF occurs. Hence, the development of DF precedes skeletal fluorosis. Endemic fluorosis detecting in many cities and districts in tropical regions with high F concentrations in drinking water and increased water consumption. However, nutritional factors such as protein, vitamin C, and calcium deficiency increase person susceptibility to fluorosis. Cases of skeletal fluorosis have been found among chronic high F tea drinkers.

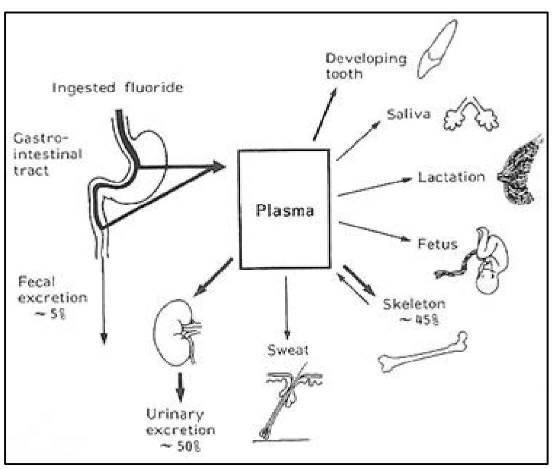

Fig. 1. Metabolism of fluoride

Absorption, distribution, and elimination of fluoride from the body. The relative influence of each organ on the metabolism of F is presented by the thickness of the arrows. In children, more F is deposited in skeleton and less is excreted in urine [1].

11.2.1 Dental fluorosis

Dental or enamel fluorosis is a developmental disturbance of enamel formation due to excessive F intake during the amelogenesis process. This event exerts a direct inhibitory effect on enzymatic functions of the ameloblasts, resulting in defective enamel matrix formation and subsequent hypomineralization. Enamel formation of permanent teeth, other than third molars, occurs from the time of birth until about five years of age and completely formed at the age of 8 years. After the enamel is formed, even if too much F is taken in, the DF cannot be developed. The occurrence and severity of DF is mainly related to high F levels in the drinking water. In areas where F in water contains 2 ppm and higher, pitting, staining, and porosity of moderately severe DF is evident (Plate 1). A mild fluorosis has been noticed in communities with F levels in drinking water of 1.2–1.5 ppm [17,31] or lower in tropical regions. The multiplesources of Ffrom the toothpastes, mouthrinses, topical F agents, F supplements, foods, beverages, and infant formulas processed with fluoridated water are related to the increase in the incidence of DF [1,9,42,50]. Many other developmental changes that affect the appearance and structure of tooth enamel are not related to F intake. In order to distinguish between white spots of early caries andwhite enamel fluorotic defects is that white spot lesion will partly or totally disappear visually when the enamel is wetted, while fluorotic enamel is unaffected by drying and wetting. Dental fluorosis is generalized in distribution with definite bilateral occurrence.

Dental fluorosis is classifying according to the degree of severity using indices for epidemiologic assessment of the condition. One of the universally accepted indices was developed by Dean in 1942. In Dean's index, each tooth is rating to a score ranging from 0 (normal) to 5 (severe) as depicted in Plate 1. The persons' fluorosis score is based upon the severest form of fluorosis recorded for two or more teeth. The other index (TF) was developed by Thylstrup & Fejerskov (1978) where DF was classified according to the histological enamel changes, ranged from 0 to 9 scores. Very mild to mild fluorosis has no effect on tooth function and may make the tooth enamel more resistant to decay and barely visible. However, the moderate and severe DF is characterized by aesthetically objectionable changes in tooth color with enamel pitting and irregularities.

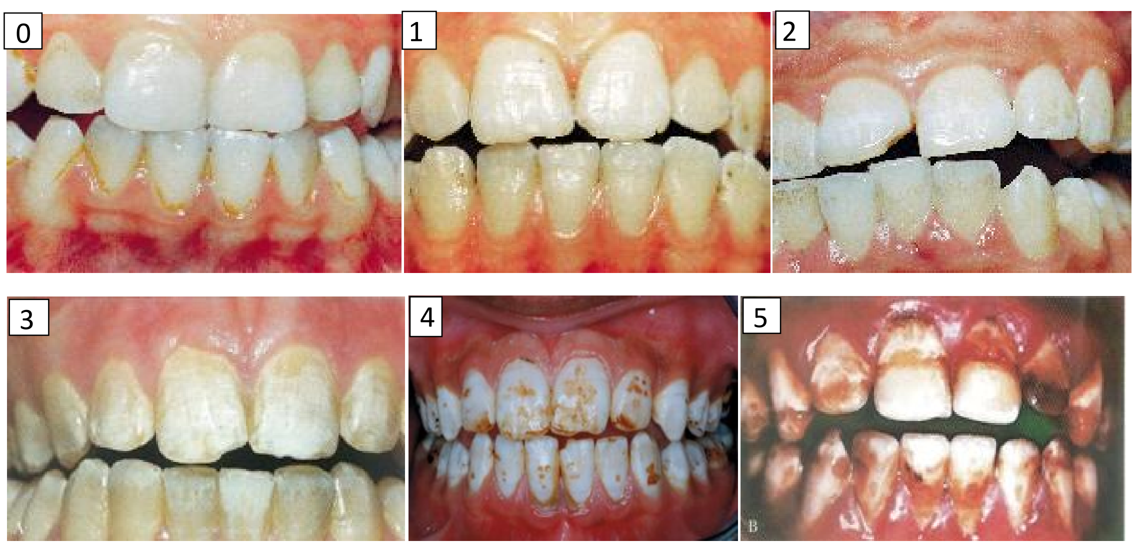

Plate 1. Grades ofenamelfluorosis according to Dean's index criteria (Hattab FN, original)
Grades: [0] Normal:The enamel is smooth, glossy, pale milky-whitetransparent surface.
[1] Questionable: aberrations from the translucency of normal enamel, with few white flecks or spots. [2] Very mild:Opaque, small paper-white areas involving less than 25% of the labial tooth surface.
[3] Mild: Opaque, white areas covering less than 50% of the teeth surfaces. [4] Moderate:Enamel surfaces show marked wear and brown stain is frequently a disfiguring feature. [5] Severe: Enamel surfaces are often hypoplastic with discrete or confluent pitting, intense disfiguring brown stains. Teeth often show a corroded-like appearance.

Plate 2. Crippling fluorosis caused by chronic exposure to excessive amounts of F in drinking water *[Source: Google images].*

11.2.2 Skeletal fluorosis

Lifetime ingestion of excessive amounts of high F-containing drinking water results in bonefluorosis (osteofluorosis). Early symptoms of skeletal fluorosis are vague pain in joints of the hands, feet, and knee joints, which may be misdiagnosed as rheumatoid arthritis or osteoarthritis. In the more advanced stages, the bone density increased with calcification in ligaments, tendons, and muscle insertion. With increasing severities(final stages), there is stiffness of the spine, limit of movements, severe pain, and virtually patient immobilizing “crippling fluorosis” (Plate 2). The dose of F that produces pathological skeletal fluorosis is 10 mg / day for 10 to 20 years [9,13].There is no cure for skeletal fluorosis, and only effortsare to reduce the disability that has occurred. However, the condition can be prevented if diagnosed early and steps are taken to prevent excessive intake of F by providing safe drinking water. Bone density measurement is a tool for an early diagnosis of skeletal fluorosis. The crippling malady of fluorosis not only affects the bones and teeth, but every tissue and organ of the body,

12. DENTAL HEALTH OF CHILDREN IN THE GULF REGION

12.1 Saudi Arabia

Dental caries and dental fluorosis (DF) are public health problems in many regions of Saudi Arabia with different F concentrations in drinking water. Because the kingdom is devoid of rivers and lakes, it relied on groundwater and desalinated seawater. Saudi Arabiais the largest producer of
prevalence of 79.7%, with 88.9% in boys and
desalinated water in the world where more than 70% of its water needs are provided by desalination. The F content of groundwater is between 0.95 and 14.8 ppm [70]. The water F levels of 1,060 wells in 13 regions ranged from 0.10 to 5.4 ppm [71]. Today, about 50% of drinking water comes from desalination; 40% from the groundwater; and only 10% from surface water. Although, tap water is considering safe to drink, demand for bottled water is increasing. In Riyadh, the average F content of local bottled water is 0.79 ppm and 0.67 ppm of imported brands [72]. Fluoride levels in 52 brands of bottled drinking water throughout the kingdom ranged from nil to 1.2 ppm with an average of 0.86 ppm [34]. Desalination reduces Fcontent in seawater (average 1.1 ppm F) and groundwater to a very low level.

A study on 1,104 children;431 (6-7-year-old) primary schoolchildren and 673 (12-13-year-old) Intermediate schoolchildren in Riyadh and Qaseem regions conducted in 2004. Examination showed a caries prevalence in the 6-7-year group was up to 91.2% in both regions with the mean dmft (decayed, missing, and filled teeth, primary teeth) of 6.53 and 6.35, respectively. Among the 12-13-year group, the prevalence of caries in Riyadh was 92.3% (mean DMFT=5.06); and in Qaseem 87.9% (mean DMFT=4.53) [73]. A recent study in Riyadh (2017) of1844 male students aged 6–9-year showed an average dmft score of 4.30±3.87 [74]. A survey in Medina, showed the prevalence of dental caries in 360 male students aged 12-years was 57.2%, with mean DMFT of 3.63±1.66 [75]. Examination of 734 schoolchildren aged 14–19 years (mean 16.02±1.61) in Jeddah revealed a caries prevalence of 79.7%, with 88.9% in boys and 69.0% in girls [76].

Prevalence of dental caries was determined on 987 children from 17 nursery schools in Jeddah. The results showed that 73% of patients had dmft of 4.80 ± 4.87 and dmfs of 12.67 ± 15.46; 336 (34%) of them had rampant caries [77]. An examination of 103 aged 5 years children from Al-Kharj's preschool nursery showed that only

16.5% of children were caries free (mean dmft = 7.1) [78]. Reviews of literature until 2010, showed the prevalence of dental caries was 80% for the primary dentition (dmft = 5.0) and 70% for the permanent dentition with a mean DMFT = 3.5 [79]. A review from 1982 to 2012 showed in the primary dentition of children aged 3–7 years, the highest caries prevalence was 95% and the maximum dmft was 7.34. Among participants aged 12 to 19 years, 91% had the highest prevalence of caries with DMFT =7.35 [80].

The association between F in drinking water, caries, and fluorosis was studied on 12,200 subjects aged 6–7, 12–13, and 15–18 years according to the F concentration of water. Examination revealed no significant difference in the prevalence of caries and DF when F levels in drinking water increased from 0.3 ppm to 0.6 ppm. At F concentrations above 0.6 ppm, the incidence of dental caries is relatively low, and the severity of fluorosis is significantly increased [81]. The relationship between the F content in drinking water and the severity of DF was determined in 2,355 rural children aged 12-15 years in Hail region. Over 90% of the children had DF. A strong association ($P < 0.001$) was found between the F level in the drinking water (0.5–2.8 ppm, average 1.37 ppm) and severity of DF [82]. Prevalence and severity of DF among 1292 children (mean age 8.5±1.75 years) in Al-Rass city and two rural suburbs in Qassem Provincerevealed 43% of Al-Rass children had some degree of fluorosis, while in the rural suburbs 61% and 75% exhibited DF. The severity of fluorosis ranges from mild to moderate grades [83]. Analysis of 817 drinking water samples from 260 locations in the Central Province (Riyadh and Qassim) showed that the F content varied from zero to 6.20 ppm [84]. In the same city, the F content in drinking water and its relationship with DF are somewhat inconsistent between studies.

12.2 United Arab Emirates (UAE)

There are two sources of water in UAE, the desalinated seawater and groundwater. Drinking water is provided from desalinated seawater. Groundwater contributed to the total water demand for all purposes. Analysis of water sources showed F content of tap water ranged from 0.04 to 0.3 ppm (mean 0.14). The mean F content for both bottled water and beverages was 0.07 ppm, ranged 0.02–0.50 ppm and 0.04–0.1 ppm, respectively [35]. Other studies have found that the average F content in local bottled water is 0.58 ppm, and the average F content in imported bottles is 0.14 ppm [85].

A study on dental caries status in children aged 2, 4 and 5 years from Abu Dhabi, Al-Ain, and Western region was conducted in 1996. The prevalence of caries ranging from 36% to 47% at age 2 years, 71% to 86% at age 4 years, and 82% to 94% at age 5 years. The mean dmft in the 5-year-old children was 8.4 in Abu Dhabi, 8.6 in Al-Ain, and 5.7 in Western region. Few teeth had been restored [86]. A national survey of oral health in UAE was conducted in 2009 where 2651 schoolchildren aged 12 and 15 years were examined. The prevalence of dental caries in the permanent teeth of 12-year-old was 54% (mean DMFT=1.6) and the 15-year-old was 65% (mean DMFT=2.5). No DF was found in 70% of 12-year-old schoolchildren [87]. A study on 1340 children aged 5-years found only 17% of the children were caries-free. The mean dmft was 5.1, ranged from 3.8 in Ajman to 6.6 in Dubai. The majority of carious teeth were untreated [88]. A survey on 1036 children in Ajman showed a prevalence of caries in 5- and 6-year-old was 72.9% (dmft 4.0±4.1) and 80.0% (dmft 4.9±4.3), with the mandibular second molars were the most affected [89].

The severity of and contributing factors of early childhood caries (ECC) was determined on 176 preschool children, mean age of 3.7 years. The average dmft and dmfs values were 10.9 and 32.1.Questionnaire show that 44% of children are still bottle fed daily, and more than half of them eat sweets more than once a day. Poor oral hygiene was found in 63% of the examined children [90]. A survey (2017) was performed on 5617 schoolchildren in Dubai, stratified into age groups 5–6 years, 12–15 years and 15–17 years old. The prevalence of caries in the three groups was 65% (mean dmft=3.87), 59% (mean DMFT=1.83) and 66% (mean DMFT=2.70), respectively. Approximately 94% of children had no DF, while 1.7% exhibited very mild to mild fluorosis [91]. In Abu Dhabi (2018), a survey on caries prevalence among 186 nursery children aged 18 months to 4 years (mean 2.46 years) showed 41% of the children had dental caries (dmft=1.70 ± 2.81). The decayed component (dt) was 1.68 ± 2.80 and the filled component (ft) 0.02 ± 0.19. Emirati children showed higher caries prevalence and plaque index than non-Emirati children [92]. A review of literature till 2014 revealed the dmft in children aged 4–6 years ranged from 5.1 to 8.4 and the DMFT for 12-year-old group ranged from 1.6 to 3.24 [93].

12.3 Kuwait

Kuwait depends on seawater distillation to meet the increasing demand on drinking water. There are no permanent rivers or lakes. Groundwater is the only natural water resource. Kuwait was the first state in the Gulf region to adopt seawater desalination where seven desalination plants installing. Desalination of seawater is the primary source of freshwater for drinking and domestic purposes. The average annual rainfall is about 80 millimeters. Fluoride determination in 55 brands of bottled water showed a mean 0.5±0.5 ppm with half of the bands contained 0.7 to 1.2 ppm [94]. Most of the people (68.4%) consumed both bottled and tap water, whereas 7.3% consumed bottled water alone and 23.5% used only tap water [94].

A review of earlier studies on children (1986-1996) found inconsistent rates of dental caries [95]. A study of 227 children aged 18 to 48 months showed that 47% of children had no dental caries, 18% had dmft score of 5 or more, and 19% had dental caries [96]. Examination of 3,500 children aged 4-, 6-, 12- and 15-year revealed a mean deft 4.6 in aged 4 and 6.2 in aged 6. In the 12- and 15-year-old children, the DMFT value was 2.6 and 3.6 respectively [97]. A national survey (2006) on 5–14-year old children (no=4,588) showed the dmft for 5–6-year old children was 4.6 and the DMFT for 12 and 14-year-olds was 2.6 [98]. A study on 4-and 5-year-old kindergarten schoolchildren (no=1,277) found 32% of the 4-year old group had caries (mean dft/dfs=3.7/6.9) and 24% of the 5-year old group had caries (mean dft/dfs=4.8/9.6). The decayed score was the major component in the mean scores [99]. The prevalence of DF assessed on 832 disabled subjects aged 3–29 years (mean=12.1 years). Findings revealed 2.5% had very mild, 0.7% had mild, and less than 1.0% had moderate fluorosis [100]. Examination and interviewing the parents of 336 infants and toddlers aged 2 to 23 months (mean 11.1±2.4) showed 3% of the children had caries, 73% had good oral hygiene, 19% had the teeth brushed or cleaned by parents, 86% were bottle-feeding at night [95]. Oral hygiene status on schoolchildren aged 5–14 years was evaluated using the debris index simplified (DI-S). Of the 3294 children examined, 3.9% had good oral hygiene (DI-S score: 0.3–0.6), 67% fair (score 0.7–1.8) and 29.1% poor (score 1.9–3.0), with the overall mean score of 1.5 [101].

12.4 Qatar

Qatar is relying on desalination of seawater to meet the domestic demand. Of the total water consumption; desalination accounts of 50%, groundwater 36%, and recycled wastewater 14% [102]. The F content of bottled water ranged from 0.06 to 3.0 ppm with a mean value of 0.8 ppm. There was a considerable difference between the measured F levels and the F level on the label [103].

Totaling 2113 schoolchildren aged 12–14 was examined for the occurrence of dental caries (2011–2012). Caries prevalence was 85%. The mean DMFT values for 12, 13, and 14-year-old children were 4.62 ± 3.2, 4.79 ± 3.5, and 5.5 ±3.7, respectively. The DT component was the major constituent of the DMFT index. Female exhibited a higher mean DMFT value 5.23 ± 3.6 than male children 4.74 ± 3.4. Qatari children showed a lower mean DMFT value 4.89 ±3.5 than non-Qatari children 5.10 ± 3.5 [104]. A survey on 527 students aged 15 years showed more than 60% of teeth examined were decayed with males showed more decay than females (74.1% versus 64.8%). One-third of males (33%) failed to brush their teeth compared to 12% of females [105]. A study on the occurrence of dental caries in 1124 six-year-old primary school children showed 71.4% of children ha decayed teeth (dmft was 4.2±4.2), with a higher incidence among girls versus boys (73.8% versus 68.9%). Qatari children had 3.8-time more caries than non-Qatari children ($P < 0.001$). The majority of children had no fluorosis; 2.4% had very mild fluorosis, 1% had mild, and only 0.3% had moderate fluorosis [106]. Examination of oral health on 12 and 15-year-old students showed 53% of the 12 aged and 55% of the 15-aged children had decayed teeth. Caries prevalence was higher among girls than boys with odd's ratio about 1.3. Qatari had a higher mean DMFT value (1.3±1.2) than non-Qataris (0.82±1.1). Dental fluorosis was found among 15% of 12-year-old and 17% of 15-year-old [107].

12.5 Oman

There are two main types of water sources in Oman: conventional water resources (natural) including surface and ground water about 87% and non-conventional water resources including desalination water and treated wastewater 13% of the total water use [108]. Bottled water has a labeled F content of 0.06 to 0.2 ppm. A national oral health survey on 3,435 children aged 12 years conducting in 1993 showed 41.9% were caries-free with regional variations ranged from 24.8% to 61.9%. The DMFT averaged 1.53 and the majority of caries lesions were untreated. Occlusal surfaces of first permanent molars were the most commonly affected. Oral hygiene was poor and only 11% of children were plaque-free [109]. In 1996, a follow-up survey was performing of the same subjects of 15-year-olds. The mean DMFT was found to have doubled from 1.5 to 3.2 [110]. A study on 3,114 children aged 6-years showed only 15.5% were caries free. Regional differences ranged from 4.4% to 31%, with an average dmft value of 4.61. The occlusal surface of the first primary molar was most affected [111]. According to the Ministry of Health Annual Health [112], the mean deft of 6-year-old children recorded between 2007 and 2011 were: 2007 (4.25), 2008 (4.4), 2009 (4.9), 2010 (5.3), 2011 (5.1). Percentages of caries-free children aged between 2 and 5 years were: age-2 (62%), age-3 (42%), age-4 (28%), age-5 (16%) derived from the histogram [113].

12.6 Bahrain

The three main water sources are groundwater (54%), desalinated water (35.6%) and 9.7% treated wastewater [114]. There is no rivers or streams exist on the islands. The average annual rainfall is about 72 millimeters. Tap water contained 0.85 ppm F [115] and considered not safe to drink unless treated or boiled [116]. The F concentrations in bottled water ranged between 0.12 and 0.80 ppm [85].

A survey of oral health undertaking in 2011-2012 on schoolchildren aged 6, 12 and 15 years from five governorates showed the following findings [117]:

- Prevalence of dental caries was 88% (dmft = 4.56) in aged 6, 70% (DMFT=2.26) in aged 12, and 75% (DMFT=2.71) in aged 15 years.
- In aged 6-year 8% of the children had one decayed tooth, 44% had 2–5 decayed teeth, and 32% had 6–10 decayed teeth.
- In aged 12 and 15-year 17% and 16% had one decayed tooth, 43% had 2–5 decayed teeth, 7% and 10% had 6–10 decayed teeth.
- Prevalence of DF was 54.5%, of which 31% had very mild to mild and 5.5% had moderate fluorosis.
- Questionnaires on dietary habits revealed 31.5% of the children drinks sugared tea every day with 7.2% drinks several times a day.

13. CLOSING COMMENTS

This is to review current data on the occurrence of dental caries and DF in children in the Gulf countries. Analysis of 14 studies published from 2003 to 2018 showed the frequency of dental caries ranges from 65 to 92% (mean=77.4 ±8.4%) in children aged 4–6 years. The dmft value ranges from 3.9 to 7.1 (mean= 5.2±1.22). Four studies in Saudi Arabia and the UAE show that only 12% to 16 % of 5-year old children were caries free. A study of nursery children showed that 34% of children have rampant caries [76]. Collectively, only 15–33% of children aged 3-6 were caries free. The caries frequency in children aged between 12 and 16 years ranges 60 to 92% (mean=73.9±13.8%). The DMFT ranges from 3.5 to 5.7 (mean=4.6±0.84).

World Health Organization (WHO) described the prevalence of caries (DMFT) above 5.6 as very high, 4.5–5.5 high, 2.7–4.4 moderate, and less than 2.6 low caries experience. In 1981, WHO formulated goals for oral health to be achieved by the year 2000 as follows: (1) 50% of 5-6-year-old to be free of dental caries. (2) No more than 3 DMFT at 12 years of age. This review of the available epidemiological data from Gulf countries clearly indicates that there is a marked increase in the prevalence of dental caries, which is well below the global goal of the WHO.

The high caries incidence reported among children could relating to the on-demand baby bottle feeding, high amounts and frequent sugar intake, poor oral hygiene, inadequate access to F therapy, lack of regular dental visits, and limited community preventive programs. Children with a high risk of dental caries risk need special dental care, including using fissure sealants and regular topical fluorides. Prevention programs should include oral health education and dietary advice for parents / children. The restoration of carious lesions will avoid unnecessary extraction. It should be remembered that every increase of 1 in the DMF would require about 200 dentists per million children. The current data on the dmft and DMFT indicate that dental caries is a public health problem in the Gulf region that warrants attention by the government and policy makers. As the workforce are relatively low for treating so many decayed teeth, the only hope for dealing with the caries problem is by sugar control, oral hygiene education, and implementing preventive measures.

Since the endemic fluorosis is prevalent in some districts in Saudi Arabia, defluorination of drinking water is the only preventive measure that should be implemented for providing safe water. Approaches for water defluoridation include chemical precipitation (alum coagulation or electrolyte defluoridation) and adsorption, in which water is filtering through column packed with strong absorbent such as alumina (Al_2O_3), charcoal or ion exchange resin. This method is also suitable for home use.

14. CONCLUSIONS

1. The F content in all surface and groundwater / wells vary, depending on the availability and solubility of F minerals in contact with water. The F content in a beverage reflects the concentration of F in the water used in its production. Fluoride pollution in the air contaminates food.
2. In dental products, F is being delivered systemically, locally or both. Systemic F is incorporated into the forming tooth structures. Local /topical F strengthen the teeth, promote remineralization, inhibit plaque bacterial metabolism and growth. fluoride anticaries effects relay mainly on its post-eruptive effect.
3. The daily F intake by adults in optimum fluoridated drinking water average 2 mg/day, and in non-fluoridated areas 0.6 mg/day.
4. Fluoride dietary supplements, fluoridated toothpastes, mouthrinses, professionally-applied topical fluorides if not well controlled can pose the risk of DF in age-susceptible children. Severity of DF depends on the dose, duration, and timing of F exposure.
5. In population, there is a direct relationship between F concentration in drinking water and the degree of fluorosis as well as F levels in blood and bone.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

CONSENT AND ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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