Salt fluoridation – an alternative in automatic prevention of dental caries

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Despite great improvements in terms of reduced prevalence and amount of dental caries in populations worldwide, problems still persist particularly among the underprivileged groups of both developed and developing countries. Research and practical experience gained in several countries have demonstrated however, that dental caries can be prevented effectively through establishment of fluoride programmes. Water fluoridation, salt fluoridation, milk fluoridation and use of affordable fluoridated toothpastes play the major roles in public health. The present paper outlines the relevance and some practical aspects in relation to implementation of salt fluoridation programmes. The World Health Organisation Oral Health Programme provides technical assistance to countries in the process of planning, implementing and evaluating salt fluoridation projects.

Key words: Dental caries, fluorides, preventive dentistry, fluoride intake, fluoridated salt production

Dental caries continues to be the most prevalent chronic disease to affect human populations. Research and practical experience in numerous industrialised countries have demonstrated however, that it can be controlled and reduced to very low levels[1,2]. The addition of fluoride to drinking water was the first breakthrough in preventive dentistry to be followed by several forms of topical applications. Fluorides in toothpastes, perfectly compatible with water fluoridation, have become increasingly important since the 1960s[3,4]. The first studies of the effect on dental caries of fluoride added to alimentary salt were carried out from around 1965 to 1985 in Switzerland, Hungary and Colombia and proved this to be as effective as water fluoridation; the number of teeth affected by caries was reduced by approximately 50%[4,5].

Improved oral hygiene and the use of fluoride toothpastes, often in combination with water or salt fluoridation to reach all socio-economic strata, are amongst the leading factors in caries reduction in western industrialised countries. Developing countries have been slow in introducing preventive dental care programmes and due to nutrition transition and adoption of modern lifestyles dental caries prevalences tend to increase particularly in those countries without exposure to appropriate fluoride levels[1,6]. A low level of dental caries, and in a wider context improved oral health, is the ultimate goal for national oral health planners. Thirty years of caries decline have shown that various uses of fluorides are one of the most effective methods to achieve this goal. The objective of the present paper is to describe and discuss the important practical aspects related to implementation of salt fluoridation programmes.

Salt as a vehicle for iodine and fluoride – the historical background

The use of salt as a vehicle for fluoride has two historical bases. Since around 1920 iodisation (mostly KI or iodate) of salt has been increasingly and successfully used to prevent iodine deficiency diseases (IDD) and is now being promoted in all parts of the world. Austria and Switzerland, where endemic goitre was once prevalent in many alpine valleys, are now virtually free of IDD due to nationwide and universal compulsory iodization of salt for human consumption. Fluorida-

0020-6539/05/06351-08

tion of drinking water, first introduced in 1945 in north America has been very successful in controlling dental caries, particularly when fluoride toothpaste or other forms of topical applications were not then available. However, technical, political as well as psychological barriers have often hampered its wider use. Outside the USA, Australia, Singapore, Hong Kong, the United Kingdom, Ireland and Spain water fluoridation is making little progress even though this method would be ideal for many countries and large cities in other parts of the world. In central and eastern European countries water fluoridation schemes stopped immediately before or after the political transition in the 1990s, and since then dental caries prevalence rates have increased or remained stable[7-10].

Frequently used terms for alimentary or edible salt for human consumption are[3,11]:

1) *Domestic salt*
- salt sold in bags or packages of 250-1500g for use in private households in some countries, salt in small bags is also used by large restaurant or hospital kitchens, canteens etc.

2) *Table salt*
- salt used exclusively on the table
- special table salt containing free-flowing agents (In some old papers the term "table salt", which is part of domestic salt, was used where in fact it meant domestic salt)

3) *Bakers' salt*, used in some countries, in large bags or sacks

4) Salt distributed in *large sacks* used by the food industry

Comparisons of biological effects of iodine and fluoride

A universally implemented salt iodisation programme could totally prevent iodine deficiency diseases. Physiologists generally regard the minimum and maximum daily supply - total iodine intake - as 150 and 300μg per day respectively; these recommended limits are averages for adults as well as adolescents (12-18 years). The maximum recommended average daily intake of fluoride is usually 4mg fluoride for adults. *Table 1* shows expected outcomes at low, optimal and excessive intake.

Highly detailed knowledge of water fluoridation and fluorides used in oral health care products has been accumulated over 55 years of systematic research[3,12]. With respect to caries prevention, metabolism and cariostatic mechanisms, most of the experiences gained through water fluoridation also apply to salt fluoridation. In 1983, Marthaler summarised some practical aspects of use of fluoridated salt and the information presented is still useful[11]. The sections 'sources of ingested salt', 'freedom of choice', 'salt fluoridation and regions with naturally high or optimal fluoride in the drinking water' and 'coexistence of fluoridation of water and salt' are still up-to-date. WHO Technical Report 846, 'Fluorides and Oral Health'[3], presents basic aspects of salt fluoridation and for the most part this text is still valid. Finally, a review on the impact of salt fluoridation was published recently by Burt and Marthaler[4].

Public health aspects of addition of fluoride to salt versus addition to water

With *water fluoridation*, the situation may be characterised as follows. Through fluoridated water, all consumers are reached within the region served by the respective water supply[13]. In recent decades 'mineral' water has become fashionable, and among parts of the population drinking water is being replaced by bottled water. It must be considered, however, that drinking water continues to be used in kitchens for preparation of a large variety of foods, notably tea, syrups, pastes, soups etc.

On the other hand, *fluoridated salt* reaches the user by several channels (*Table 2*). The initiatives to obtain full effectiveness should focus on both domestic salt and on salt distributed to large kitchens in restaurants, canteens, hospitals etc., bakeries and large bread factories, and catering enterprises. Fluoridation of salt destined for human consumption has been used in Switzerland since 1955. Since 1986 an increasing number of countries, now approximately 15 and mainly in Europe and the Americas, have adopted salt fluoridation schemes.

The first results documenting the cariostatic effect of fluoride added to salt were obtained in Switzerland[14], Colombia[15] and Hungary[5]. Caries reduction was obtained in all three countries in studies carried out among children. During the 1990s further reports appeared from countries where salt fluoridation has been implemented[16-19] and recently studies have been published which demonstrate the persistence of the caries-protective effect into adulthood[20,21]. The full potential of salt fluoridation, at least equivalent to that of water fluoridation, is reached when most of the salt for human consumption is fluoridated. It is important to distribute fluoridated salt through channels used by the low socio-economic strata; in these strata caries prevalence is highest and dental care is often unaffordable or neglected[22].

Apparently, Jamaicans have had great benefit from salt fluoridation because virtually all salt destined for human consumption on the island has been fluoridated since 1987[18,19]. As shown in *Figure 1*, the decline in the mean number of Decayed, Missing and Filled Teeth (DMFT) has been dramatic as the reduction in Jamaica was above 50%. Fluoride toothpastes were available in the country long before 1984. While their use may have had an additional caries protective effect, the notable decline in caries prevalence after 1984 may be considered

Table 1 Consequences of low or high total intake of iodine and fluoride; intake figures apply to adults, they are lower for infants and children

Intake level	Iodine	Fluoride
Low intake	below 150µg/day Iodine Deficiency Diseases (I)	below 1.5mg/day High caries (F)
Optimal intake	Absence of Iodine Deficiency Diseases	Reduction of number of teeth affected by caries around 50%
High intake, up to 4 times the optimal	above 600µg/day (to EU) above 1000µg/day (to USA) Hyperthyroidism in part of the population	above 4mg/day (F) Slight to unsightly mottled teeth, but no health hazard (FF)

(I) Goitre diagnosed by palpation and/or visible as swelling of the neck. Assessment using radioactive iodine results in higher prevalence of goitre.

(F) Fluoride is primarily used as a topical means against caries. Small children often swallow substantial proportions of fluoridated products for oral care (dentifrices primarily) while this amounts to only a small fraction in adults.

(FF) Dental fluorosis results from high fluoride intake during tooth formation in the jaws, mainly below 6 years of age.

Table 2 Use of fluoridated salt in selected countries

Country	Domestic salt	Meals at school	Large kitchens	Bread
Jamaica, Colombia	All	All	All	All
Costa Rica	All	All	All	No
Switzerland				
Canton of Vaud	All	All	Most	Most
Other cantons	84%	No	No	No
France, Germany	35-60%	A few	No	No

'All' means at least 90%

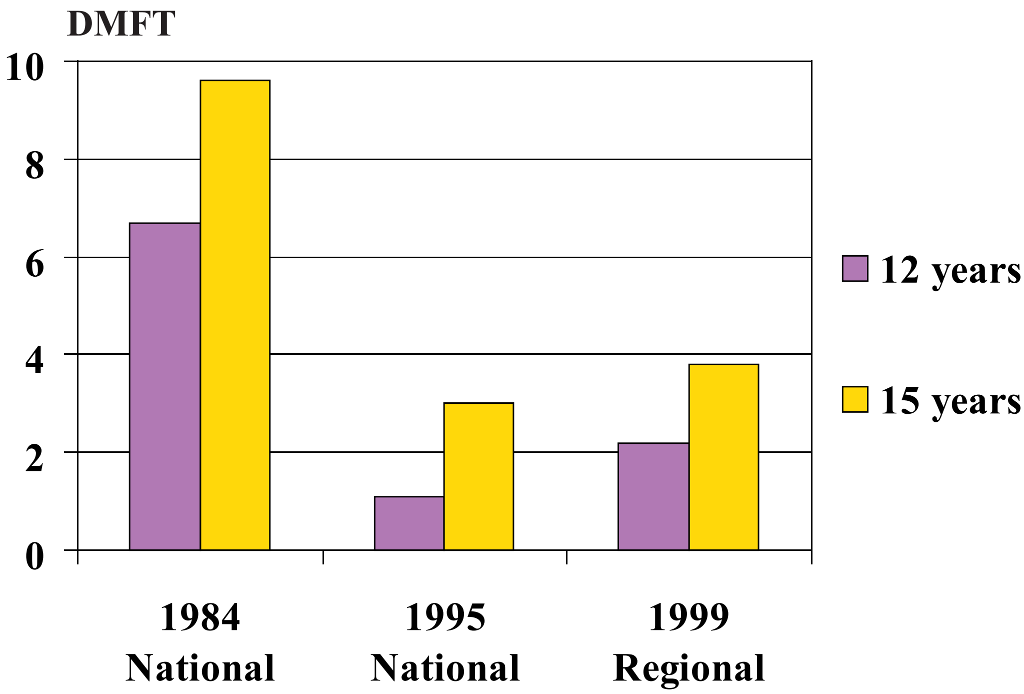

Figure 1. Mean dental caries experience (DMFT) of 12- and 15-year-olds in Jamaica after introduction of salt fluoridation in 1987[18]

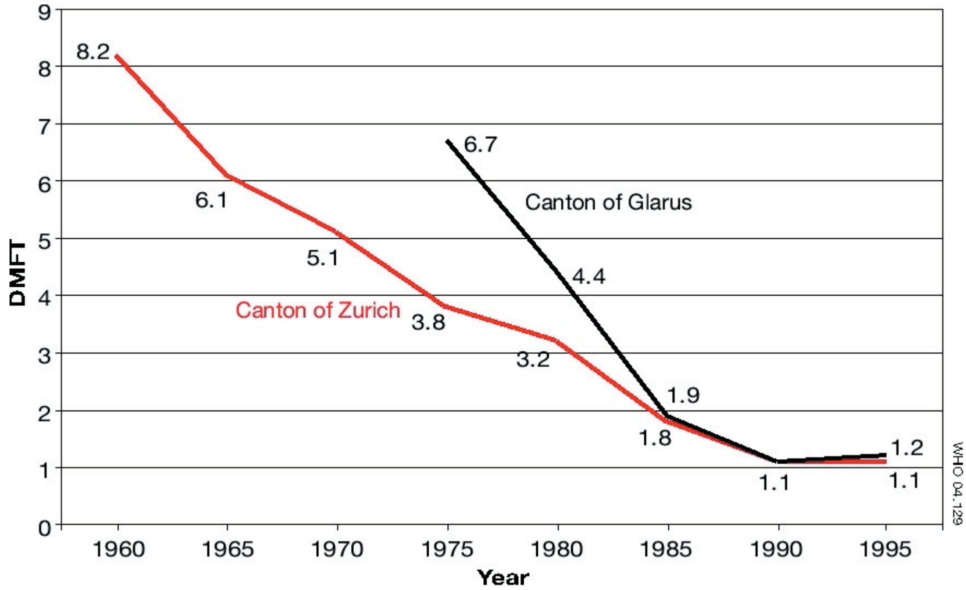

Figure 2. Changing DMFT of 12-year-olds in Switzerland[14] after introduction of school-based topical fluoride programmes (i.e. toothbrushing with concentrated fluoride preparations) in the 1960s (Zurich) and of fluoridated salt (250ppm F) in the 1970s (Glarus). Salt fluoridation was introduced in 1983 in the Canton of Zurich and all of Switzerland

due primarily to fluoridated salt. A similar pattern has been observed in Switzerland (*Figure 2*); this country has had salt fluoridation in operation since the 1960s[14].

In Switzerland and Hungary several studies have focussed on the importance of fluoride concentration in salt for reduction in dental caries prevalence. The Hungarian salt fluoridation studies began in various communities with fluoride concentrations of 250ppm (1966), 200ppm (1968) and 350ppm (1972). These studies showed that the preventive effect on caries was most pronounced at fluoride concentrations of 250ppm and 350ppm[5]. In Switzerland, initial investigations showed that a fluoride concentration of 90ppm was insufficient and later studies confirmed the positive effects on dental caries with a fluoride concentration at the level of 250ppm[11,14].

Several reports have clearly demonstrated that children and adults of the high socio-economic strata have improved oral hygiene and make regular use of fluoride toothpastes and topical fluorides[22]. In most industrialised countries, preventive measures are now used in combination to the extent that the children of the highest socio-economic strata have very little caries or none at all. The benefits are rapidly expanding to young adults, at present already up to 40 years of age[4,20,21].

Initial steps in planning salt fluoridation projects

When salt fluoridation is being considered, a situation analysis of all aspects of salt production, importation, exportation, etc. is necessary. The basic questions relate to the present situation as regards consumption of salt, feasibility of fluoridation of salt, preparations for introduction of salt fluoridation, and cost of salt fluoridation, and these issues are described in the following.

1. *Present situation*

1.1 Identify main producers, importers and exporters of salt

1.2 Identify packaging and distribution channels of salt

1.3 Identify all forms of salt which are offered to the public, to large kitchens, restaurants (canteens, hospitals etc.), bakeries and food industry

1.4 Are data available about salt consumption (or disappearance) and/or ingestion regarding
a) domestic salt
b) salt added in large kitchens
c) salt used in bakeries
d) salt added during processing in the food industry
e) other

1.5 What are the common or official names used for the different types of salt destined for human consumption?

1.6 Is salt iodisation used against goitre; nationwide or regionally? If yes, through which types of salt according to the subdivisions obtained according to 1.4?

1.7 Is the general level of technology and industrial hygiene sufficient for salt fluoridation

2. *Feasibility of fluoridation of salt*

2.1 Which types of salt can technically be fluoridated when considering grain size, humidity, additives and other properties?

2.2 How many fluoridation installations are necessary in order to fluoridate, or what other steps are necessary to make fluoridated salt available for
a) 60% to 80% of the population?
b) more than 90% of the population?

2.3 Besides domestic salt, which other possibilities exist for fluoridated salt to be used in
a) institutions of all kinds, e.g. for children as well as for elderly persons
b) canteens, restaurants, etc.
c) bakeries, etc.
d) food industry
e) other

2.4 What is the legal situation regarding additives to salt?

3. Preparations for the introduction of fluoridation of salt

3.1 With which medical bodies (who may be engaged in a campaign for reduction of salt consumption) is coordination necessary or indicated?

3.2 Coordination with existing food control system with respect to obtaining samples of salt (or food) and urine

3.3 Possibilities of F-analyses in water, salt, urine and fingernails

3.4 Possibilities of foodstuffs to be analysed for fluoride

3.5 Mapping of natural F^- content of water, and measures to be taken to keep fluoridated salt away from regions with more than e.g. 0.7ppm F in water

3.6 Develop a monitoring system at the production level and with respect to urinary fluoride excretion (urinary samples should be taken already prior to fluoridation), and every 6 months after introduction during the first two years, in schoolchildren and adults[23,24]

3.7 Is salt iodisation also to be considered or further developed?

4. Cost of salt fluoridation

4.1 Installation cost for covering
a) 60% to 80% of the population
b) more than 90% of the population, consider this also for 2.2 a) and 2.2 b)

4.2 Cost of the initial campaign for inviting the population to switch from unfluoridated to fluoridated (and possibly iodised) salt, and cost of public health campaigns, informing about the benefits of universal salt fluoridation

4.3 Yearly cost of
a) installation maintenance
b) fluoride compound (KF, Na_2SiF_6, NaF or other)
c) monitoring at the 3 following levels:
- production, samples from producer
- samples from the market and distribution to non-domestic use
- level of total fluoride intake by humans (urinary fluoride output; fluoride concentration in fingernails)
d) amortisation of the installations

4.4 Total cost
a) per year for the whole country
b) per year and person
c) per kg of salt or per customary package sizes, also as percent rise of price at the production site and in retail sales

A fundamental decision is whether to strive immediately for full coverage by fluoridated (and possibly iodised) salt or whether, at least in initial stages, to allow free choice between salt with and without fluoride. Decisions such as whether to fluoridate the salt used for bread or expand fluoridation beyond domestic salt may in principle be taken at a later stage. In Europe, fluoridation is for the most part limited to domestic salt (*Table 2*). In Latin America, most fluoridation schemes are more comprehensive and yield a proportionately much greater benefit to public health.

Where salt fluoridation appears feasible, there will be regulatory and organisational issues to resolve. Many of these are presented in *Table 3*.

Production of fluoridated salt

For effective caries prevention, fluoride must be present in ionic form when salt (NaCl) is dissolved in water. Calcium carbonate and certain heavy metals strongly reduce the ionic form of fluoride. This problem must be checked at the earliest stages of the salt fluoridation planning process. Problems relating to the production of fluoridated salt and its distribution are described in the following:

How to obtain a homogeneous distribution of fluoride in the salt at the production site

Factors that may pose problems relate to coarse salt with strongly varying grain size, use of either NaF (cheap, fine powder) or KF (hygroscopic), and variable humidity in the production plant. There are essentially two different salt production processes: batch processing or continuous processing.

Batch processing
A fixed amount of a fluoride compound (mostly NaF or KF) is added to a fixed amount of refined salt. Example: 765g of KF are added to one ton (999,235g or roughly

Table 3 Organisational aspects related to introduction of salt fluoridation

Task	Agency or body, basic details
Decision to start salt fluoridation	Nation or state, on the basis of the established scientific evidence supporting the cariostatic efficacy
Addition of fluoride	At the salt refineries, required by law, possibly with state subsidies
Production	Preferentially by batch process: 'Robust' procedures, easy surveillance
Production control	1. Continually at the production plant as customary in advanced industry 2. From packages/sacks on sale, to be done by national or regional food control agencies
Distribution	Food commerce, except in regions with high-fluoride drinking water
Retail price of salt	The fluoridated (and iodinated) salt should in no case be more expensive than plain salt
Promotion of fluoridated (domestic) salt	To be done jointly by the health authority, dental association, medical association, paediatric association, sick funds, health insurances. Regulations to the large food distributors for a favourable 'positioning' of fluoridated (and iodinated) salt on the shelves. This promotion goes along with the one for iodinated salt.
Monitoring of total fluoride intake	Indispensable: baseline survey and monitoring in intervals of years.
Timed urinary samples, covering at least 12-18 hours of the day, or full 24-hour collections. For later routine monitoring: Urinary fluoride concentration in spot samples and/or analysis of fingernails for fluoride.	
Age (2 or) 3 to 5 years, when children are most susceptible to excessive fluoride, resulting in enamel fluorosis, a purely cosmetic consequence of no importance when limited to slight cases. The fluoride excretion per hour, obtained from longer collection periods, should not exceed 30-33µgF except for the period immediately after the main (salted) meal. Concentration averages: 0.6 to 1.2ppm F, ideally 1ppm, up to age 15.	
Age 10 to 15 years; standards are available from work in Switzerland and other countries.	

one million grams) of refined salt; 765g F salt contain 250mg of fluoride). In the resulting mixture of one ton, the fluoride concentration is then 250ppm F. Correspondingly, 552g of NaF are needed to produce one ton of salt containing 250ppm F. For batch processing, NaF can be used, this fluoride salt being much cheaper.

Powder mixing refutes the assumption that the longer the mixing time, the better the homogeneity. In Costa Rica for instance, one-ton mixers (customarily used for mixing animal feed) are used to add the fluoride. It was found that the best mixture - i.e. the most homogeneous distribution of fluoride in a ton of salt - was obtained after 20 minutes of mixing. Beyond this point the fluoride tended to accumulate selectively at the bottom of the mixing cone. Only simple observation on site was necessary to arrive at the best result.

Continuous processing of salt

In large production plants where continuous processing of salt is common, the procedure is often to spray a dosed concentrated fluoride solution through a nozzle onto the salt passing on a conveyor belt below. The amount of salt passing under the nozzle must be continually assessed and determines the amount of fluoride solution to be sprayed, according to the fluoride concentration specified by law or decree. Example: in one second, one kilogram of already refined and dried salt passes under the nozzle from which the concentrated solution is sprayed (1kg salt per second corresponds to an annual production of 10,000 to 20,000 tons, depending on production in night shifts and weekends). The solution must therefore spray 0.25g of fluoride per second. If a concentrated solution of 15% KF is used for spraying (15% KF solution is equivalent to 5% F), 5g of the solution (containing 250mg of fluoride) must be sprayed on the salt passing below. It must be considered that this adds about 0.4% humidity to the salt.

In continuous production facilities, potassium fluoride (KF) is the preferred compound because of its high solubility in water. While the cost of KF is negligible in affluent countries, developing countries may find the purchase of the relatively expensive KF from abroad prohibitive and its very strong hygroscopic properties are likely to pose storage problems.

Some very simple methods of checking production

Any refinery chosen for adding fluoride will at the very least keep records of its salt production. If production amounts to one thousand (metric) tons of fluoridated salt (250ppm F) in one month, the amount of, say, NaF used must be 552kg. If the stock was depleted by less than 552kg, the salt cannot contain 250mgF/kg as required. If stock was depleted by more than 552 kg, the concentration in the final product - the salt - was too high, and/or some fluoride was lost in the production process.

When fluoride is added before the drying of salt, the final drying, which requires air, may remove part of the fluoride in the form of a very fine dust. In trials in Switzerland approximately 300ppm F was added to salt (in a supersaturated solution of NaF) still retaining about 5% humidity. After the final drying leading to some loss, the required concentration (250ppmF) was eventually obtained, but not with satisfactory reliability. In the experimental stages necessitating production of only approximately 50 tons per year this was considered acceptable. For subsequent nationwide production, use of concentrated KF-solution sprayed on the salt was the definitive solution.

Tolerance limits regarding variations of concentrations

The standards for quality control of fluoridated salt can be characterised as follows:

- Fluoride is not a pharmaceutical. Its concentrations need not be strictly constant as required for pharmaceutical preparations.
- On the other hand, variations must not exceed certain limits. There are two kinds of variations:

Hour-to-hour or day-to-day variations (in continuous production) or variations from batch to batch. This type of variation is largely dependent on the technique used by the production plant. In the European Union, the minimum weight of salt samples suitable for fluoride analyses is 50g. Variations within these 50g can be considerable and sample weights of 5-10g may be appropriate particularly in the initial stages of testing the machinery.

Long-term systematic deviations from the required concentration. This means that most of, or possibly all the samples are either below or above the required concentration. Such inaccuracy is visualised by plotting the sample averages over time. Obviously, accuracy must ultimately be attained. In the first months of production, the average concentration may be 20 or 30 per cent below or above the required level due to unpredictabilities in the machinery. This is of no concern when the necessary corrections are made within four to six months after beginning fluoridation, following which the inaccuracy should not exceed 15%.

In all records, the average concentrations should be very close to the concentration recommended by law or directives.

How to ascertain that segregation is minimal

Segregation may not occur at all, it may be minimal or it may reach undesirable levels. This must be monitored in the initial phases of salt fluoridation programmes. There has been some concern about possible segregation of the fluoride (NaF or KF) from the sodium chloride crystals. In fact, no crystals can incorporate F, Cl and Na simultaneously. NaF is normally a very fine powder and consequently has a tendency to accumulate at the bottom of any package of whatever size. While the mixture may have been homogeneous at the conclusion of the production process, the small NaF-particles tend to fall through the empty spaces between the coarser NaCl-crystals. Humidity is an important factor. When it is 2, 3 or 4 percent, segregation is greatly reduced. For domestic use, however, a very dry salt is usually preferred.

The size of NaCl granules typically varies within 0.2-1.0mm in diameter. In a few countries, notably France, a segment of consumers prefers a fairly coarse salt a few millimetres in grain size. This type is very difficult to fluoridate, as the surface area to which the fluoride should remain attached is substantially reduced. French salt factories (producing since 1986) have been able to overcome this difficulty. In other countries, the salt is very fine.

Segregation is not a problem as long as the salt is distributed in bags of not more than 1.5kg. When large amounts of fluoridated salt, e.g. over 10kg, are contained in bags or sacks, considerable amounts of NaF or KF accumulate at the bottom. Segregation is unlikely to occur during storage but may arise during transportation from the production site to the end user. Since 1975, sacks containing 25kg have been distributed to two Swiss cantons (total population approx. 600,000) for use in restaurants, cafeterias, canteens and hospitals (i.e. large kitchens) and by bakeries. In initial tests, such sacks of fluoridated salt were left in trucks for months and were thus thoroughly shaken. No segregation in these sacks was observed, as they could maintain 3-4% humidity, which has a stabilising effect. The addition of Yellow Prussian Salt $Fe(CN)_6$ will also counteract segregation.

Occupational health: How to assure that workers are protected against accidents and chronic high fluoride intake

Dust masks and gloves are to be used whenever necessary. All safety measures are dependent on the type of apparatus used for fluoridation. Safeguards are necessary against accidents as well as against chronic high intake of fluoride by workers. Today, values of less than 4mg/l urine (or 4ppmF) are considered safe. Chronic intake of unusually high amounts of fluoride has been seen in workers at aluminium plants. Up to 7ppm F in urine does not lead to skeletal fluorosis. Dental fluorosis is caused by high fluoride intake during tooth formation, and is thus not a problem in humans over 8-10 years of age.

Conclusion

The WHO recently published a global overview of oral health and described the WHO Oral Health Programme's approach to promoting continuing improvement in the 21st century[1]. The report emphasised that despite great improvements in terms of reduced amount of dental caries in populations across the world, problems still persist particularly among the underprivileged groups of both developed and developing countries. Dental caries remains a major public health problem in most industrialised countries and it is also the most prevalent oral disease in several Asian and Latin American countries. Although for the moment it appears to be less common and less severe in the greater part of Africa, the report anticipates that, in light of changing living conditions and dietary habits, the incidence of dental caries will increase in many of that continent's developing countries. This is particularly as a result of the growing consumption of sugars and inadequate exposure to fluorides.

In many developing countries however, access to oral health services is limited and significant numbers of population groups are underserved. For these reasons professionally applied fluorides have little public health relevance. Also, water fluoridation, due to practical barriers and lack of centralised water supplies, is not feasible. Alternatives to automatic fluoridation by means of water fluoridation are salt fluoridation, milk fluoridation and use of affordable fluoridated toothpaste and the WHO Oral Health Programme is currently undertaking evaluation of demonstration projects in several countries. The use of fluoridated toothpastes is recommended in all circumstances, except in locations with excessive fluoride intake. The combination of fluoride-containing toothpaste with fluoridation of either water, salt or milk has been successful in lowering caries prevalence in virtually all regions of the world. The present paper has focussed on the advantages and practical aspects of implementation of salt fluoridation programmes. The WHO Oral Health Programme provides technical assistance to countries in the process of planning, implementing and evaluating salt fluoridation projects. The Programme also supports countries in sharing and disseminating experiences and documentation of results. Further information about the Programme is available at: www.who.int/oral_health. Most recently WHO has re-emphasised the public health approaches to effective use of fluorides for the prevention of dental caries in the 21st century[12] and policy guidelines for countries are provided.

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