DENTAL CARIES: A DISORDER OF HIGH FLUORIDE AND LOW DIETARY CALCIUM INTERACTIONS
(30 YEARS OF PERSONAL RESEARCH)

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SUMMARY: This comprehensive epidemiological study - performed during the period 1963-1993 on 0.4003 million children residing in non-endemic ($F^- \leq 1.0$ ppm) and endemic ($F^- > 1.0$ ppm) fluorosis villages of India - was designed to investigate the essentiality or otherwise of fluoride and calcium nutrition in the prevention and control of dental caries. In non-endemic areas, of the children with adequate calcium nutrition, 7 percent showed dental fluorosis and 2 percent had dental caries, while of children with inadequate calcium nutrition 14.2 percent showed dental fluorosis and 31.4 percent had dental caries. In endemic areas, of the children with adequate calcium intakes, 59 percent had dental fluorosis and 10 percent had dental caries, while in the calcium-inadequate group, 100 percent exhibited dental fluorosis and 74 percent had dental caries.

Our findings indicate that dental caries was caused by high fluoride and low dietary calcium intakes, separately and through their interactions. Dental caries was most severe and complex in calcium-deficient children exposed to high intakes of endemic fluoride in drinking water.

The only practical and effective public health measure for the prevention and control of dental caries is the limitation of the fluoride content of drinking water to < 0.5 ppm, and adequate calcium nutrition (dietary calcium > 1 g/day). The World Health Organisation policy and recommendations on fluorides are not universally acceptable, especially for the environment of developing countries, with nutritional deficiencies, endemic fluorosis, and different caries prevalence trends. In the light of our scientific data, WHO recommendations require modifications to achieve dental health for all by the year AD 2000.

Key Words: Calcium nutrition; Dental caries; Dental fluorosis; Fluoridation; High fluoride; Hypomineralized enamel; Low dietary calcium; Secondary hyperparathyroidism.

Introduction

For the past three decades we have been continuously engaged in studies on fluorides and endemic fluorosis in India. During epidemiological studies on the prevalence of endemic fluorosis, our attention was drawn to a high level of dental caries in children living in villages endemic for fluorosis. The present study was therefore designed to discover the prevalence of dental fluorosis and dental caries in growing children residing in non-endemic and endemic fluorosis villages.

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Materials and Methods

Epidemiological surveys for endemic dental fluorosis and dental caries were performed in villages througout the 14 states of India during the period 1963-1993.

After geographical location of the villages and fluoride analysis of drinking water samples from all sources in each village, the two groups of rural child population, (i) non-endemic ($F^- \leq 1.0$ ppm) and (ii) endemic ($F^- > 1.0$ ppm) were identified. Children in both groups were further classified as calcium nutrition adequate (dietary Ca > 800 mg/day) and inadequate (dietary Ca < 300 mg/day). The field team made complete house listings of the entire population, and details were recorded in a specially designed format. The total population of children surveyed was 0.80075 million, while the children who volunteered for complete examination, and inclusion in the study during the period 1963-1993, numbered 0.4003 million (Table 1).

All children studied had lived in their villages since birth, and had matched socioeconomic and education backgrounds, similar dietary and food patterns, similar habits in respect to oral health and hygiene, and identical facilities for health and dental clinics.

Each child was subjected to a thorough history-taking, to a clinical examination, and to nutritional assessment and dietary evaluation, in particular for calcium intake (1). The dental examinations were performed by one of the authors (SPST) assisted by trained dental, medical and public health field staff. Radiological and laboratory investigations of plasma and urine were done where found necessary. Established laboratory procedures reported previously (2-5) were employed. The alveolar bone density was determined on dental radiographs.

A group of 23,273 children, all from similar social groups with matched habits, and living in non-endemic ($F^- < 0.6$ ppm) and endemic ($F^- > 2.5$ ppm) areas, participated in a study designed to evaluate the effectiveness of calcium intervention in the prevention of dental caries. Their baseline dietary intakes of calcium were identical and less than 0.5 g/day. They were randomly divided into two groups. The treatment group received one gram of elemental calcium supplements per day for 5 years, and the group of children serving as controls was followed for 5 years on a placebo but received no calcium supplements. This five-year controlled calcium intervention programme was started in 10-year-olds and the results of follow-up examinations at the end of 5 years (in 15-year-olds) were compared in all the groups (Table 2).

TABLE 1. CALCIUM AND FLUORIDE INTAKES OF THE CHILDREN STUDIED

Group	Mean water F- (ppm)	Mean fluoride intake (mg/day)* Age groups 0-5	5-10	10-15	Total no. of children	Calcium nutrition Adequate (>800 mg/d)	Inadequate (<300 mg/d)
Nonendemic	0.50 ± 0.24	0.8	1.6	2.8	200,000	100,290 (50.15%)	99,710 (49.85%)
Endemic	4.19 ± 2.03	2.6	6.9	8.7	200,300	100,385 (50.12%)	99,915 (49.88%)

The intakes of fluoride per day may increase two- to four-fold or more during hard physical work in a hot climate - even greater if the water used in cooking and in beverages is taken into account.

Results and Discussion

During the period 1963-1993 extensive epidemiological, environmental, nutritional, clinical, radiological, and relevant laboratory studies were performed for ætiological prevalence (related to fluoride and calcium intakes) and pathophysiology of dental caries in rural children residing in non-endemic and endemic fluorosis villages. The possible essentiality of fluoride and calcium nutrition as caries-preventive agents was also investigated. Children of group I (non-endemic) had been drinking water with fluoride concentration of 0.50 ± 0.24 ppm and of group II (endemic) with fluoride content of 4.19 ± 2.03 ppm. The clinical and relevant epidemiological data of the children studied are summarised in Table 1.

In non-endemic villages, in children with adequate calcium nutrition, 7% showed dental fluorosis and 2% dental caries, while in children with inadequate calcium nutrition 14.2% showed dental fluorosis and 31.4% showed dental caries. In endemic areas children with adequate calcium intakes 59% had dental fluorosis and 9.8% had dental caries, while in the calcium-inadequate group practically 100% revealed dental fluorosis and 74% had dental caries. The incidence of dental fluorosis and caries increased with fluoride intakes and dietary calcium deficiency (Figure 1). Statistical analysis of the data by Student's 't' test revealed highly significant differences between non-endemic and endemic groups and between children with adequate and inadequate calcium intakes ($p < 0.0001$).

Our studies on the epidemiology of decayed teeth as a function of drinking-water fluoride exposure and calcium nutrition revealed a very interesting situation (Figure 2). Decayed teeth per hundred children were maximum in the 5-10 year olds and minimum in the 0-5 year olds. Teeth with caries were much less frequent in children of both the groups with adequate calcium nutrition. The worst situation, with the largest number of decayed teeth, occurred in 5-10 year olds who had inadequate calcium nutrition and were exposed to high fluoride intakes.

The fasting plasma fluoride concentration measured in 425 children of the endemic group, with adequate calcium nutrition was 2.5 ± 0.2 μM/L and in 385 children with inadequate calcium nutrition was 6.2 ± 0.5 μM/L. This finding suggests that calcium is a strong antagonist of fluoride and inhibits its intestinal absorption, as we have previously reported (6-10).

TABLE 2. CALCIUM SUPPLEMENTS INTERVENTION IN THE PREVENTION OF DENTAL CARIES•

			Data on control group				Data on treatment group**			
Mean water fluoride	Fluoride intake mg/day from water	Total no. of children*	No. of children	% of children with caries (10-yr-old)	% of new children with caries (15-yr-old)	% of total children with caries (15-yr-old)	No. of children	% of children with caries (10-yr-old)	% of new children with caries (15-yr-old)	% of total children with caries (15-yr-old)
0.70 ± 0.25	1.3	12150	6350	22.0	11.0	33.0	5800	20.8	1.8	22.6
2.85 ± 0.75	4.8	11120	5500	32.5	40.1	72.6	5620	34.0	5.5	39.5

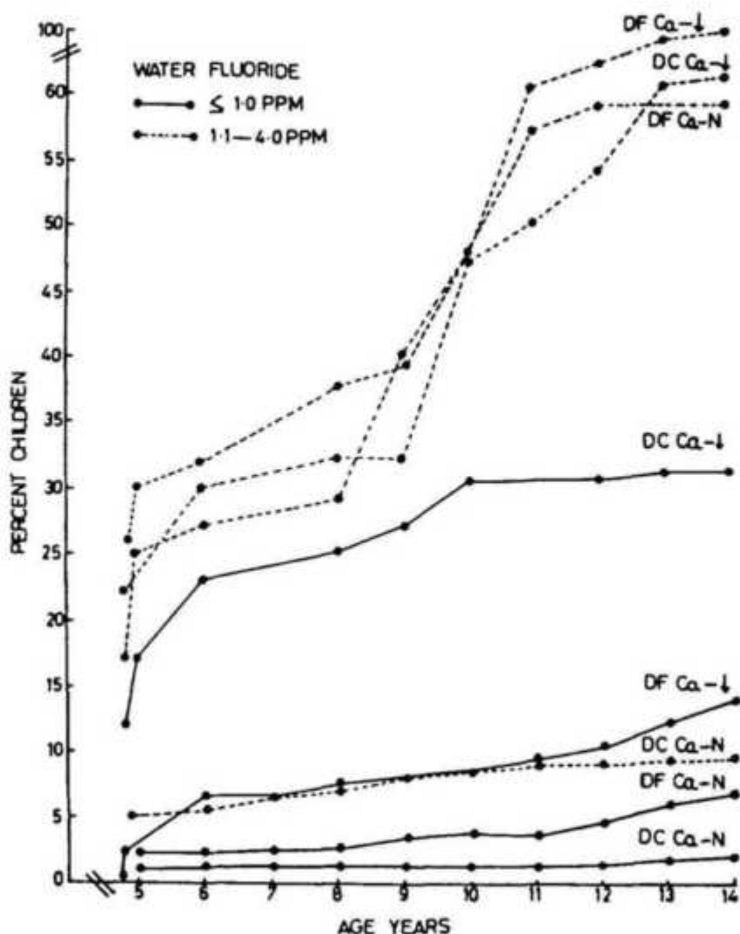
* Children with regular follow up only. All had baseline dietary Ca intakes of approximately 0.5 g/day. Ca intervention programme was commenced in 10-yr-olds (baseline data) and was continued till the children became 15-year-olds (final intervention data).

** Received one gram elemental calcium supplement per day for five years.

• Clinical and radiographic examination results were statistically highly significant for control v. treatment groups ($p < 0.0001$).

The follow-up examinations at the end of 5 years (of the children already affected with caries at the age of 10 years) revealed that the incidence of new carious lesions was greater in the children of the control group, 17% (non-endemic), 43% (endemic) compared to the incidence of 2.2% (non-endemic) and 6.8% (endemic) in the treatment group. Also at the end of 5 years the incidence of caries in new children (not affected with caries at age 10 years) was compared in all the groups (Table 2). We also observed the increased alveolar bone density in the calcium-treated children - caused, we believe, by increased retention of calcium during the pubertal growth spurt. Increased frequency of carious teeth in children with vitamin D deficiency rickets further indicates the intimate metabolic interaction between calcium nutrition and dental caries.

FIGURE 1. Prevalence of dental fluorosis (DF) and dental caries (DC) in children living in endemic and nonendemic fluorosis areas. Prevalences of dental fluorosis and dental caries were greater and more severe in children exposed to high intakes of fluoride and with dietary calcium deficiencies (Ca-↓ = calcium deficient, Ca-N = calcium adequate)

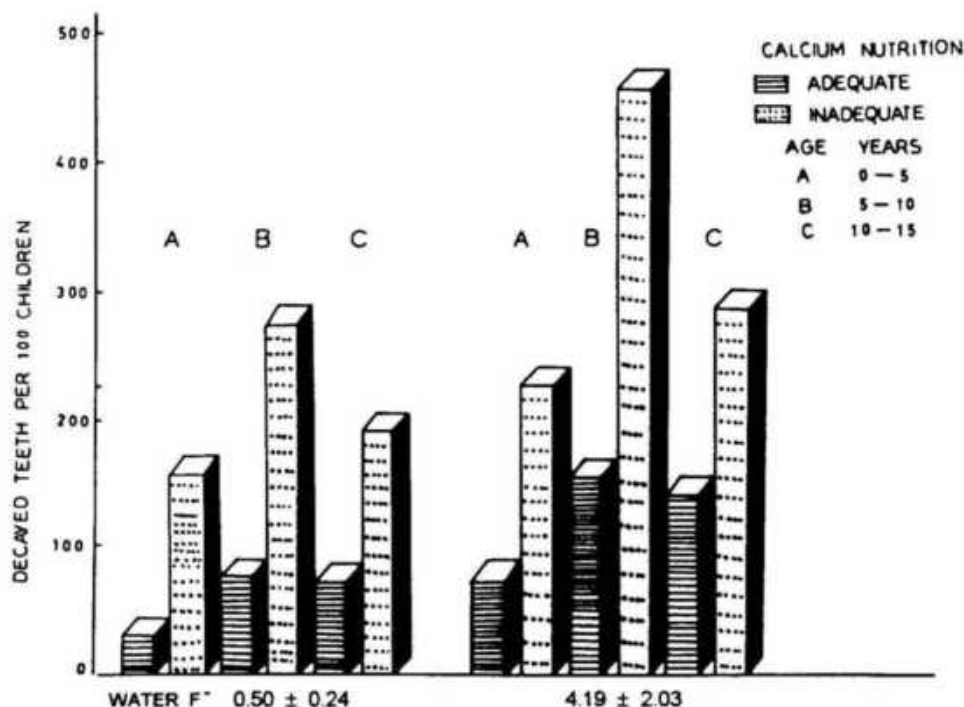


Our observations in the present study are consistent with our studies on dental caries and endemic fluorosis previously reported (11-13). The effects of chronic ingestion of endemic fluoride on dental metabolism, and the possible pathophysiological mechanisms involved in the causation of dental caries, are summarised in Figure 3. Though the precise mechanism of fluoride action is not fully known (14, 15), it is our view that in children exposed to endemic fluoride the enamel and the protein matrix laid down during the period of mineralisation (12-14 years) remain diffusely hypomineralised with abnormal crystal growth (16-18).

The effects of fluoride on enamel formation also lead to insufficient closure of intercrystalline spaces, the processes responsible for the drainage of water and inorganic materials (19-21). These structural changes - immature and hypomineralised matrix, increased porosity and possible effects on dental calcium homeostasis - markedly increase the vulnerability of the teeth to bacterial invasion, and to formation of plaque which contains microorganisms. All these factors possibly operate and cannot be ignored in the etiopathogenesis of dental caries in children residing in endemic fluorosis villages.

Dental caries was more severe and complex in calcium-deficient children exposed to endemic fluoride. The interaction of fluoride and parathyroid hormone in calcium-deficient children may increase the porosity of the enamel and resorption of

FIGURE 2. Epidemiological prevalence of decayed teeth as a function of exposure to endemic fluoride and calcium nutrition

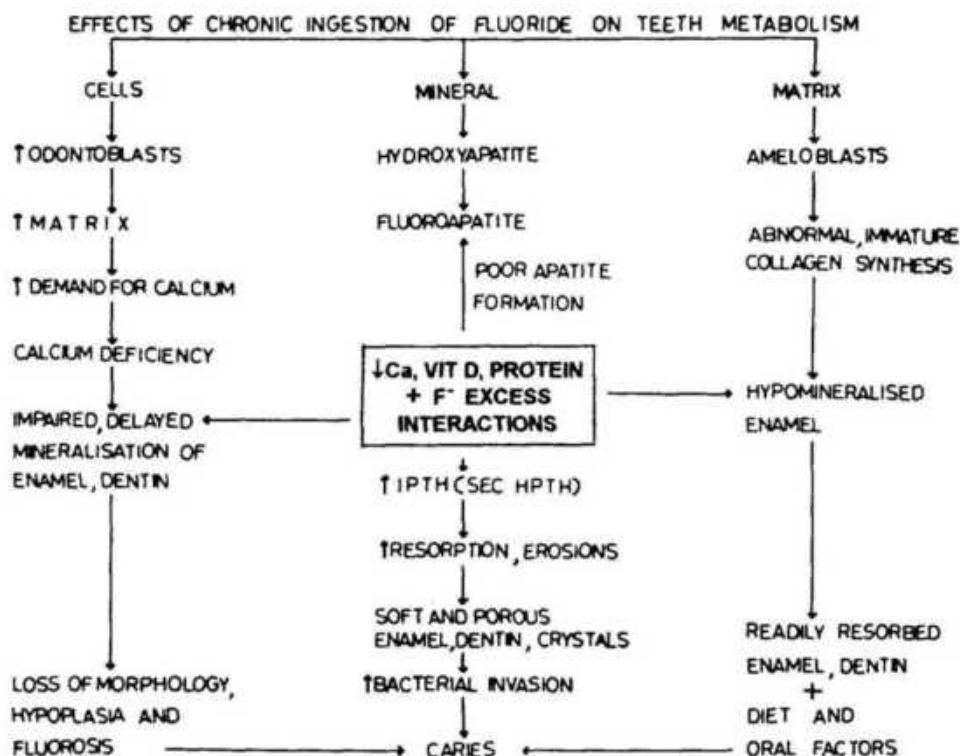


the teeth, and thus may aggravate the risk of dental caries. Dental caries does not occur in all children to the same degree. The various factors which could have influenced the course and severity of dental caries in our children include: 1) fluoride concentration in the drinking water; 2) daily intake of fluoride; 3) duration of fluoride exposure; 4) continuity of residence in the endemic area; 5) fluctuations in the fluoride intake; 6) age at the time of fluoride ingestion; 7) nutritional status, particularly the dietary intakes of calcium and vitamin D; 8) physical hard work in a hot environment; 9) individual oral and dental hygiene; and 10) individual consumption of refined carbohydrates.

We have not found, during our 30 years of study, any appreciable change in caries prevalence trends in children of comparable socio-economic strata. Therefore time is unlikely to be an additional variable in the analysis of our results.

More than a hundred studies have reported that community water fluoridation prevents and reduces dental caries (22). However, our extensive review indicates that, in most of the reports, several parameters of vital importance in the pathogenesis of dental caries were not investigated. Some of the aspects which require in-depth attention in such published reports are: 1) changing dietary and food patterns,

FIGURE 3. Mechanisms underlying the development of dental fluorosis and the evolution of dental caries in children exposed to high intakes of fluoride during the period when enamel is laid down and mineralised (based on nutritional, metabolic and histomorphometric studies)



particularly the consumption of refined carbohydrates; 2) recognition and monitoring of trends in oral health, embracing all its components, such as (a) oral and dental health education in schools and at home, (b) facilities for oral and dental health clinics, (c) public and government concern for prevention of dental caries; 3) individual and community nutritional status, particularly the dietary intakes of calcium and vitamin D; and 4) inclusion in the studies of matched communities, not exposed to fluoridated water and with similar socio-economic backgrounds (*e.g.* 23, 24).

All these factors should have been recognised and assessed simultaneously with fluoridation of public water supplies and monitored during the entire length of the fluoridation studies reported. Because of these lacunae, we have reservations about the scientific documentation for the fluoridation of drinking water being the main agent responsible for the reduction in dental caries in the studies published.

From our present study two sets of important observations have emerged:

1) In India, exposure to high intakes of natural fluoride in drinking water is associated with high prevalences of dental fluorosis and dental caries, both having a very strong direct correlation with the increasing fluoride content of drinking water. Taken together, the correlation and the dose-response relationship suggest a causal relationship. Specifically, high intakes of fluoride increase the prevalence of dental fluorosis as well as dental caries. Similar observations were made by one of us (SPST in 1990) during short term surveys and examinations of schoolchildren in endemic fluorosis villages of Zilin Province of China.

2) Adequate dietary calcium intakes (> 800 mg/day) provide an effective control and prevention of dental fluorosis and dental caries. Dietary calcium deficiency (Ca intakes < 300 mg/day) aggravates the toxic dental effects of fluoride making them more severe and complex. Even the marginally high intakes of fluoride (> 2.5 mg/d) continuously for more than six months in calcium-deficient children may cause severe dental fluorosis and caries (25).

On the basis of our comprehensive epidemiological data, supported by the benefits of intervention with calcium supplements, we recommend the limitation of fluoride in the drinking water to < 0.5 ppm, and adequate calcium nutrition (Ca intake > 1 g/day), as the most effective strategies for the prevention and control of dental caries. Oral and dental health care and avoiding consumption of refined carbohydrates are additional factors requiring attention. The World Health Organisation policy and recommendations on fluoride are not universally applicable. In the light of our studies, WHO needs to recognise that fluoridation of public water supplies cannot be documented as a scientifically proven and community-acceptable method for the prevention of dental caries.

The conclusions reached in this report - we believe the most comprehensive and single largest epidemiological study on dental caries in the world literature - are based on our experience over thirty years (1963-1993) studying the effects of endemic fluoride in the drinking water and community calcium nutrition status.

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