ORIGINAL RESEARCH

Prevalence and Correlation between Dental Fluorosis and Drinking Water Fluoride Levels among 12–15-year-old School-going Children of Rayalaseema Region of Andhra Pradesh, India

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Abstract

Background: Dental fluorosis causes tooth color changes, creating esthetic, functional, and physiological problems. High fluoride consumption impairs mental development and lowers intelligence quotient (IQ) in children, affecting dental esthetics and well-being.

Objectives: To estimate fluoride levels and the relation between water fluoride levels and dental fluorosis in 12- to 15-year-old schoolchildren.

Materials and methods: A cross-sectional study was conducted among 1,182 schoolchildren aged 12–15 years. Fluoride analysis by ion-selective electrode method covered 41 villages of Chittoor mandal, Chittoor district, Andhra Pradesh. Among these, 25 villages had suboptimal fluoride levels, 16 had optimal levels, and none exceeded the optimal level. A stratified random sampling technique was employed. Dental fluorosis was recorded using the modified Dean's fluorosis index (1942) and community fluorosis index (CFI). Statistical analysis was done using the Chi-squared test and Pearson's correlation.

Results: Dental fluorosis prevalence was 66.5%. Children who consumed borewell water had 75% fluorosis. Boys showed 53.3% higher prevalence than girls. About 99.8% had no history of fluoride toothpaste or tablet usage in fluoride zones. Also, 83.6% had no familial history of fluorosis. Pearson correlation between fluoride concentration in drinking water and CFI shows positive correlation ($r = 0.960$). CFI scores ranged 0.48–1.17. The majority of villages showed medium public health significance (1.02–1.17).

Conclusion: Even at optimum fluoride levels, the prevalence of fluorosis is at a higher level. Scanty rainfall, deep borewells, and drought were the reasons for increased prevalence even at optimum fluoride levels. Optimum level of 1 parts per million (ppm) does not seem to be appreciable for Indian conditions. Results serve as a blueprint for public health administrators, dental professionals, and policymakers.

Keywords: Correlation, Dental fluorosis, Prevalence, Schoolchildren.

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Background

Dental public health challenges prevalent among children in numerous developing countries, such as India, include dental fluorosis and dental caries. Fluoride is recognized as one of the most effective interventions in the history of dental public health; however, excessive fluoride ingestion can lead to various adverse effects. Due to its electronegative properties, fluoride combines with various soil substances to form fluoride salts. When water percolates through the soil, these fluoride compounds dissolve, increasing the groundwater fluoride concentration in the presence of lithium, cesium, chloride, and bromide.[1] Elevated fluoride concentrations in drinking water, leading to fluorosis, are rapidly becoming an endemic public health issue.[2] Fluoride acts as a double-edged sword. At optimal levels, it reduces the incidence of dental caries and is essential for maintaining the integrity of oral tissues. Conversely, excessive exposure during developmental stages can result in dental fluorosis and skeletal fluorosis.[3]

The World Health Organization (WHO) has established an upper limit for fluoride concentration in drinking water at 1.5 mg/L.[4] The Bureau of Indian Standards (BIS) has specified an Indian standard of 1.0 mg/L as the maximum permissible limit for fluoride, with an additional note: "the lesser, the better."[5] During tooth development, the continuous ingestion of elevated fluoride levels results in fluorosis, characterized by hypomineralization, which leads to surface and subsurface porosity. This condition can manifest in varying degrees of severity, including changes in tooth color, and can cause significant esthetic, functional, and physiological issues. The consumption of high fluoride levels gradually impairs

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cognitive development and reduces the intelligence quotient (IQ) in schoolchildren; if not addressed during childhood, it can adversely affect dental esthetics and the psychological well-being of the child.[6]

Indian states are ranked in descending order according to fluoride concentration, with Haryana exhibiting the highest level at 48 mg/L, while Jammu and Kashmir presents the lowest at 4.21 mg/L. This issue has reached critical proportions, affecting at least 19 states in India. Notably, Andhra Pradesh, Gujarat, and Rajasthan have between 50 and 100% of their districts impacted by fluoride contamination.[7]

Rayalaseema, meaning "rocky region," includes the districts of Anantapur, Kurnool, Cuddapah, and Chittoor, located south of the Krishna River in Andhra Pradesh. This area is characterized by a hot, semi-arid climate.[8] Chittoor mandal, situated within the Chittoor district, is identified as one of the chronically drought-affected regions in Rayalaseema, Andhra Pradesh. It comprises 41 revenue villages, where borewells (groundwater) serve as the primary source of potable water.[9] During an oral health examination at a dental camp in this mandal, cases of dental fluorosis were observed among children. The presence of dental fluoride stains, which conveniently indicate fluoride exposure, led to the decision to conduct the present study in this mandal. The age of 12 years is globally recognized as the standard monitoring age for caries, as all permanent teeth, except third molars, are likely to have erupted by then.[10] By age 15 years, individuals typically have established dietary habits, and their permanent teeth have been exposed to the oral environment for 3–9 years.[11] Estimating fluoride levels in drinking water and assessing the relationship between dental fluorosis and drinking water fluoride levels will aid in evaluating strategies to address dental fluorosis in this mandal.

Materials and Methods

Study is a prospective cross-sectional study conducted among 12–15 years school-going children of Chittoor mandal, Chittoor district, Andhra Pradesh and the duration of study was from March 2019–July 2020.

Procedure for Data Collection

Field Work for the Study

The list of villages of Chittoor mandal was obtained from District Survey and Land Records Department, Chittoor. Prior to the start of the study, drinking water samples from all the 41 villages of Chittoor mandal were collected.

Collection of Drinking Water Samples

The source of drinking water collected in the study was the most common primary source used by residents of the village. Water samples were collected in clean, sterile polyethylene bottles with a capacity of 200 mL. When taking a sample of piped water, the pipeline was flushed for 5 minutes. For borewell water, water was pumped out for 5 minutes in order to prevent the collection of any soil remnants before collecting the samples. There were no wells in the sources of water collection in the mandal.

All the water bottle samples were labeled and sent to Mandal Water Quality Monitoring Laboratory, Rural Water Supply and Sanitation Department, Chittoor, and to Water Analysis Laboratory, Metropolitan Water Supply and Sewage Board, Chennai. Ion-selective electrode method was employed to determine the fluoride content in drinking water. Out of 41 villages, 25 villages were in the below-optimum level, 16 villages were in the optimum level, and there were no villages in the above-optimum level.

Scaling of Mandal Map into Zones

Revenue village map of Chittoor mandal was obtained from District Revenue Department, Chittoor, scaled up properly by measuring the entire mandal and by choosing the villages lying in the geographical zone. The entire mandal map was divided into 4 zones—North (N), West (W), East (E), and South (S). With the help of directions of the scaled map, villages were allocated into respective zones according to the geographical location. Out of 41 villages of Chittoor mandal, 8 villages fall in the north zone, 8 villages lie in the west zone, 20 villages lie in the east zone, and 5 villages lie in the south zone (Table 1). From the results of the fluoride analysis report, villages were segregated as:

- Villages lying in optimum [0.7–1.2 parts per million (ppm)] fluoride area.
- Villages lying in below-optimum (<0.7 ppm) areas.
- No villages in above-optimum fluoride level.

Sampling Procedure

Stratified random sampling was employed. The villages were stratified into four zones by employing the lottery method. The finalized villages with their fluoride content in each of the zones were segregated, and children selected fulfilling the inclusion and exclusion criteria.

Inclusion Criteria

- Who were continuous residents since birth.
- Who were present on the day of examination.

Exclusive Criteria

- Children whose source of drinking water is not from primary sources.
- Who were migrants from other places.
- Teeth that were not fully erupted and fractured teeth, as they hinders diagnosing enamel defects.
- Who were wearing orthodontic brackets.

Training and calibration were carried out under expert guidance. A group of 20 subjects was examined to observe intraexaminer reproducibility and found to be 90%.

Pro Forma Used for Study Participants

Pro forma used were of two parts. The first part includes demographic data along with materials used for brushing, device used for brushing, brushing frequency, source of drinking water, history of usage of fluoride toothpaste/tablets, and history of dental fluorosis in family members. The second part includes recording format for clinical examination. Oral health status was assessed by WHO oral health assessment 2013. Modified Dean's fluorosis index 1942 was used to determine dental fluorosis.

Pilot Study

A pilot study was conducted among 236 children of 12–15 years. Out of 100, 32.6 and 26.3% had mild and very mild fluorosis, respectively. About 29.7% were normal, 8.9 and 2.5% had moderate and severe fluorosis. The prevalence rate obtained by the pilot study was 54%. G*Power 3.0.10 software was employed. Desired sample size calculated for the main study was 1182. Participants were equally screened in the zones of different fluoride areas. Each 591 students were selected from optimum and below optimum fluoride areas.

Table 1: List of villages of Chittoor mandal along with fluoride levels (ppm) in each of the zones

North zone (ppm)	*West zone (ppm)*	*East zone (ppm)*	*South zone (ppm)*
Murakkambattu—0.7	Thenebanda—1.02	Muthukuru—0.1	Thumminda—0.88
Doddipalle—0.69	Gremspeta—1.15	Ayanavedu—0.6	Pedisettipalle—0.3
Thimmasamudram—0.85	Iruvarum—0.54	Anagallu—0.3	Narigapalle—1.07
Kattamanchi—0.75	Anupalle—0.8	Bakranasingarayanipetta—0.4	Bangareddipalle—0.31
Gandlapalli—0.41	Mapakshi—0.6	Diguvamasapalli—0.4	Cherlopalli—1.19
Mangasamudram—0.79	Chittoor rural—0.98	Arathala—0.4	
Bandlapalli—0.3	Chavatapalli—0.43	Krishnapuram—0.4	
Gollpalli—0.4	Lakshmibambapuram—0.6	Paluru—0.1	
		Varadarajupallem—0.6 Guvvakalu—1 Chinthalagunta—1 Siddampalli—0.99 Perumalkandriga—0.6 Thalambedu—1.13 Paschanapalle—0.4 Alukurupalle—0.6 Settiapathangal—0.6 Venkatapuram—0.4 Anathapuram—0.5 Kuruchivedu—0.8*	

*ppm = parts per million

The American Dental Association (ADA) standardized type III clinical examination using mouth mirror, explorer, and adequate illumination was carried out. Dental caries severity and experience of study subjects were calculated with WHO oral health assessment 2013. Fluorosis severity was detected through Modified Dean's fluorosis index (1942). Community fluorosis index (CFI) was also calculated to identify villages where dental fluorosis has been a public health problem. CFI was computed by summing up scores of individual grades of dental fluorosis as per Dean's criteria and dividing the sum by total sample size of that particular area.

$$\text{CFI} = \frac{\text{Frequency} \times \text{weight}}{\text{Number of individuals examined}}$$

CFI value ranges and their public health significance are classified as follows: 0.0–0.4 (negative), 0.4–0.6 (borderline), 0.6–1.0 (slight), 1.0–2.0 (medium), 2.0–3.0 (marked), and 3.0–4.0 (very marked).

Statistical Analysis

Statistical Package for the Social Sciences (SPSS version 21, Chicago, USA) was used for analysis. The power of the study was 95%. The alpha error (type I) was kept at 5%, with a p-value <0.05, 95% confidence interval, and 5% level of significance was set for the above analysis. Mean and standard deviation were used to express quantitative data. Pearson's Chi-squared test was used to find the association between the variables. Pearson's correlation was used to calculate the relation between drinking water fluoride levels and CFI.

Results

The number of children enrolled in the study was 1,182. Among these, 591 were selected from the optimum fluoride area and the others from the below-optimum fluoride area. In the distribution of study subjects according to gender, 53.3% of schoolchildren were boys, and 46.7% were girls. In the optimum fluoride area, 29.9% were 13 years of age, followed by 12 and 15 years, with percentages of 25.2 and 24.2%, respectively. In the below-optimum fluoride area, 33% were 13 years, followed by 25% in 14 years, 22.7% in 12 years, and 19.3% in 15 years age-group, respectively. In the comparison of age-groups, the Chi-squared test gave a value of 7.042 and was statistically significant ($p < 0.05$). A greater percentage of individuals were boys, that is, 56.2 and 50.4%, compared to girls, with percentages of 43.8 and 49.6%, respectively, in below-optimum and optimum fluoride areas. The Chi-squared test gave a value of 3.929 ($p < 0.05$), which was statistically significant. Among the 1,182 study participants, 75.5% of the children consumed drinking water from borewells, while 24.5% consumed tap water. The Chi-squared test yielded a value of 11.423, with a p-value <0.001 (Table 2). About 79% of individuals consuming borewell water resided in areas with optimal fluoride levels. Regarding oral hygiene materials, toothpaste usage was 83.6% in optimal fluoride zones and 81.7% in suboptimal fluoride zones. A notable percentage of subjects used toothpowder, with 8.8% in optimal and 16.6% in suboptimal fluoride areas, while the use of charcoal and brick powder was minimal. A total of 99.8% of participants reported no history of using fluoride toothpaste or tablets in fluoride zones, with only 0.2% having such a history. Furthermore, 83.6% reported no history of fluorosis in the family. Of the 1,182 participants, 786 exhibited dental fluorosis, resulting in an overall prevalence of 66.5%. The prevalence of fluorosis was higher in areas with optimal fluoride levels compared to suboptimal areas. In optimal fluoride regions, 42.1% of individuals exhibited mild fluorosis, 22.8% had very mild fluorosis, followed by moderate, questionable, and severe categories at 14.6, 3.3, and 3%, respectively. Only 14% were free from fluorosis. The Pearson Chi-squared test yielded a value of 327.93, with a p-value of <0.001 (Table 3). The Pearson correlation between fluoride concentration in drinking water (ppm) and CFI was $r = 0.960$, at the 0.01 level (two-tailed). A strong positive correlation was observed between fluoride concentration in drinking water and CFI scores (Fig. 1).

Table 2: Distribution of schoolchildren according to age, gender, and source of drinking water in different fluoride levels

	Fluoride level							
	Optimum		*Below-optimum*		*Total*		*Chi-square value*	*p-value*
Age, gender, and source of drinking water	*N*	*%*	*N*	*%*	*N*	*%*	X^2	
12	149	25.2	134	22.7	283	23.9		
13	177	29.9	195	33.0	372	31.5		
14	122	20.6	148	25.0	270	22.8		
15	143	24.2	114	19.3	257	21.7		
Total	591	100	591	100	118 2	100.0	7.442	0.05*
Boys	298	50.4	332	56.2	630	53.3		
Girls	293	49.6	259	43.8	552	46.7		
Total	591	100	591	100	1182	100.0	3.929	0.04*
Tap water	120	20.3	170	28.8	290	24.5		
Borewell	471	79.7	421	71.2	892	75.5		
Total	591	100	591	100	1182	100	11.423	0.001*

*p-value <0.05, statistically significant

Table 3: Study subjects in different fluoride areas with different forms of fluorosis

	Fluoride level					
	Optimum		*Below-optimum*		*Total*	
Fluorosis score	*N*	*%*	*N*	*%*	*N*	*%*
Normal	83	14.0	313	53.0	396	33.5
Very mild	155	26.2	199	33.7	354	29.9
Mild	249	42.1	74	12.5	323	27.3
Moderate	86	14.6	5	0.8	91	7.7
Severe	18	3.0	0	0.0	18	1.5
Total	591	100.0	591	100.0	1182	100.0
Chi-squared test		*Value*			**p-value*	
Pearson Chi-square		323.97			<0.001	

*p-value <0.05 (significant); N = no. of participants

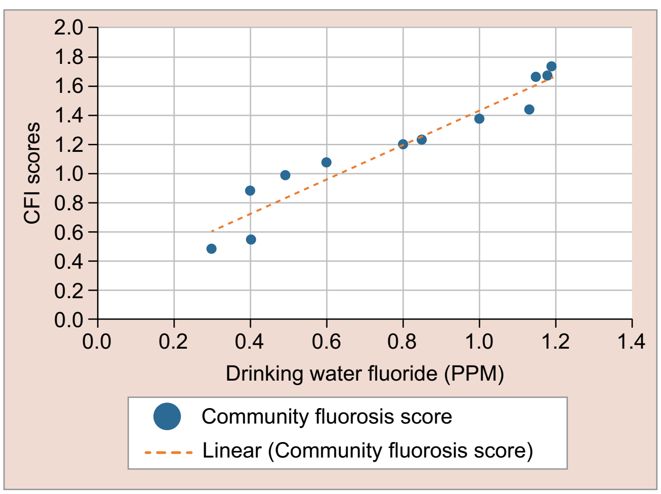

Fig. 1: Correlation between drinking water fluoride concentration and CFI scores

Community fluorosis index scores of the villages ranged from 0.48 to 1.17. The majority of villages ranged from 1.02 to 1.17. The severity of dental fluorosis in most of the villages was in medium public health significance. Villages of Peddisettipalle, Gajulapalle, Bakranarasingarayanipeta, and Gandlapalli were in borderline category. Villages of Mapakshi, Thumminda, and Thimmasamudram were in slight public health significance for fluorosis (Table 4).

Discussion

The undivided state of Andhra Pradesh is recognized as one of the regions endemic to fluorosis. The Rayalaseema and Telangana regions of Andhra Pradesh are primarily affected areas.[12] The majority of existing literature has predominantly focused on the Telangana region, with the Nalgonda district serving as a notable example. However, research concerning the prevalence of dental fluorosis and dental caries in relation to fluoride levels in drinking water is limited in the Rayalaseema region.[4] The districts of Kurnool, Kadapa, Chittoor, and Ananthapur are encompassed within the Rayalaseema region.[13]

Chittoor mandal, located in the Chittoor district, is recognized as one of the hottest and chronically drought-affected regions within Rayalaseema, where groundwater serves as the primary source of drinking water.[14] The region's limited rainfall, high temperatures, and persistent drought conditions, coupled with a lack of prior research on the correlation between fluoride levels in drinking water and dental fluorosis, prompted this study. The current investigation revealed an overall prevalence of dental fluorosis among schoolchildren at 66.5%. The mild, very mild, and moderate forms of fluorosis were found to be more common. Notably, areas with optimal fluoride

Table 4: CFI values in the villages along with their fluoride level in drinking water (ppm)

Sl. no.	*Village name*	*Fluoride concentration in drinking water (ppm)**	*CFI*
1	Peddisettipalle	0.3	0.48
2	Gajulapalli	0.4	0.52
3	Bakranarasingarayanipeta	0.4	0.57
4	Gandlapalli	0.49	0.57
5	Mapakshi	0.6	0.71
6	Thumminda	0.8	0.78
7	Thimmasamudram	0.85	0.83
8	Siddampalli	1	1.02
9	Thalambedu	1.13	1.07
10	Gremspeta	1.15	1.10
11	Chittoor rural	1.18	1.14
12	Cherlopalli	1.19	1.17

*ppm = parts per million

levels exhibited a higher prevalence of fluorosis compared to areas with suboptimal fluoride levels.

The BIS has established the maximum allowable concentration of fluoride in drinking water at 1 ppm.[5,15] In the current study, a 66.5% prevalence of dental fluorosis was observed in areas with fluoride concentrations considered optimal (0.7–1.2 ppm). This finding indicates that even at optimal fluoride levels, the prevalence of fluorosis remains high. These results are consistent with studies conducted by Khan et al. in Pakistan and by Menon and Indusekhar in Dharwad, India, where fluoride levels of 0.5–1.2 ppm in drinking water were associated with a 57% prevalence of fluorosis.[16,17]

The report from the Department of Groundwater, Andhra Pradesh, concerning the groundwater level scenario in Chittoor mandal indicates that the groundwater level in deep borewells exceeds 20 m from the ground surface, specifically measuring 26.56 m. This level is significantly higher compared to other regions within Rayalaseema.[18] The conditions of drought and the presence of deep borewells are potential contributors to the prevalence of dental fluorosis.[19] Fluoride crystals are found in higher concentrations in drinking water sourced from deep underground.[20] As groundwater serves as the primary source of drinking water in this mandal, and given the interaction of crystalline rocks containing fluorapatite minerals with groundwater, fluoride is dissolved in the water used for both irrigation and drinking purposes.

The prevalence of fluorosis was observed to be higher among boys compared to girls. This can be attributed to the generally larger body surface area of males relative to females. In rural settings, boys tend to engage in more physical activities than girls, which exposes them to hot climatic conditions and results in increased water consumption. Consequently, boys experience greater exposure to fluoridated water. These findings are hand-in-hand with those of studies conducted by Saravanan et al. and Mane et al., which reported a higher percentage of fluorosis among boys.[21,22]

Sudhir et al. reported that 100% of children residing in areas with water fluoride levels ranging from 0.0 to 0.6 ppm exhibited dental fluorosis.[23] This high prevalence in regions with low water fluoride concentrations can be attributed to Susheela's explanation that, in endemic fluorosis areas, a significant amount of fluoride is incorporated into food materials and subsequently ingested.[4] Additionally, elevated temperatures, which necessitate increased water consumption, may also contribute to this phenomenon. In areas with optimal fluoride levels, 42.1% of schoolchildren presented with mild forms of fluorosis, characterized by more extensive white opaque areas on the tooth surfaces. This finding highlights the esthetic concerns among schoolchildren. If left unaddressed, such conditions may lead to embarrassment, psychological stress, and diminished self-esteem in affected children.

There was no significant variation in the history of fluoride toothpaste or tablet use among children residing in these areas. The majority of these children were unaware of the use of fluoridated toothpaste or tablets. A positive correlation was identified between the concentration of fluoride ions in drinking water and the CFI scores. Specifically, an increase in fluoride concentration in water corresponded with elevated CFI values. These findings align with those reported by Saravanan et al. and Chandrashekar and Anuradha, where an increase in dental fluorosis was associated with higher CFI values.[3,21] The mean annual temperature of the study area was recorded at 100.70°F, with mild and very mild dental fluorosis observed in 42.1 and 22.8% of cases, respectively, in areas with optimal fluoride levels. This suggests a high mean temperature at the optimal fluoride concentration. Dental fluorosis was attributed to increased water consumption, which led to heightened fluorosis levels. These results are corroborated by Saravanan et al., who reported a dental fluorosis prevalence of 31.4% at a mean maximum annual temperature of 97.30°F.[21]

The Ministry of Health (MOH), Government of India (GOI), has established 1.0 and 2.0 mg F/L as the permissible and excessive limits, respectively.[24] Recently, experts from the International Society for Fluoride Research (ISFR) have recommended that the safety levels of fluoride in drinking water in India be reduced to 0.5 ppm from the current 1 ppm.[25] The universal acceptance of 1 ppm is not deemed suitable for regions with high temperatures.[26] Consequently, it is imperative to monitor fluoride levels in drinking water periodically. According to a study conducted by Lakshmi, residents in this area were unaware of this type of fluorosis, for which drinking water is the primary causative factor. With the issue remaining unrecognized and neglected, there is a pressing need for guidance and health education.[27] An outreach program conducted in Chittoor by a nonprofit organization, the Arghyam grant team, recently provided activated alumina filters, which have contributed to reduced fluoride levels in this mandal. However, the study subjects had previously been exposed to elevated fluoride levels in drinking water from birth.[28] These filters, however, failed to function effectively because villagers lacked knowledge of how to reactivate the filters or whom to contact for maintenance. Training villagers in the operation and maintenance of these filters is a critical concern.

Comprehensive education on dental health, particularly concerning the use of fluoride and the potential risks associated with excessive fluoride levels in drinking water, is essential in this region. This study is subject to certain limitations, including time constraints inherent in its cross-sectional design and the assumption that water sources remain unchanged. Additionally, data regarding the daily consumption of drinking water were not collected.

Conclusion

The study revealed a 66.5% prevalence of dental fluorosis. Even when fluoride levels are optimal, the occurrence of fluorosis remains high. Factors such as limited rainfall, deep borewells, and drought contribute to this increased prevalence, even at optimal fluoride concentrations. An increase in the CFI values and the prevalence of dental fluorosis was noted as water fluoride levels rose. A positive correlation was found between fluoride levels in drinking water and dental fluorosis, with boys showing a higher prevalence than girls. Those who consumed borewell water had a higher incidence of fluorosis compared to individuals using other water sources. A significant 99.8% of participants had no history of using fluoride toothpaste or tablets across different fluoride zones. The optimal level of 1 ppm does not seem suitable for Indian conditions. The findings of this study provide a framework for public health officials, water supply authorities, dental professionals, and policymakers. This information can serve as preliminary data, paving the way for a comprehensive epidemiological study at the mandal and district levels.

Author Contributions

Conceptualization: Prabu D and Swetha R.
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Formal analysis: Swetha R, Rajmohan M.
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Writing—original draft: Swetha R, Sunayana Manipal, and Rajmohan M.
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Ethical Approval

The nature and purpose of the study were presented to the Institutional Review Board of SRM Dental College, Ramapuram, and ethical clearance, review no. SRMDC/IRB/2019/MDS/No. 701, was obtained.

Informed Consent

Written informed consent was obtained from the parent/guardian/teacher of the schoolchildren after explaining the study. Informed consent was in both English and the vernacular language (Telugu).

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AI Disclosure

No AI tool, Artificial intelligence–based language assistance, was involved in clinical decision-making, data interpretation, or generation of scientific conclusions.

Data Availability

The data supporting the findings of this study are available within the article. No additional datasets were generated or analyzed during the current study.

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