

Original Article

Cross-Sectional Analysis of the Relationship Between Secondhand Smoke Exposure and Dental Caries in Children

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ABSTRACT

Childhood dental caries are influenced by a variety of factors, including diet, oral hygiene habits, socioeconomic conditions, and environmental exposures. Among these, maternal smoking has been identified as a particularly strong contributor compared to paternal or other household smoking. This study investigated how exposure to environmental tobacco smoke (ETS) relates to the occurrence of dental caries in children aged 5–10 years attending both private and public schools. A cross-sectional study was carried out involving schoolchildren, with data collected from caregivers through a structured questionnaire addressing five domains of ETS exposure: during pregnancy, early life, around schools, in eateries/roadside locations, and at public transport areas. Dental caries were diagnosed according to WHO 1997 criteria. Associations between ETS exposure and caries were quantified using prevalence ratios (PRs) and 95% confidence intervals (CIs). Among 211 participants (60.2% in private schools, 39.8% in government schools), nearly half (49.3%; 95% CI: 42.5–56.1%) had dental caries. Exposure to ETS emerged as a significant risk factor for developing caries. While variations in maternal education and high sugar intake influenced the adjusted prevalence ratio (APR), these differences were not statistically significant. Dental caries affected a moderate proportion of children, consistent with national estimates. Prenatal ETS exposure was associated with a 41% higher risk of caries after accounting for other factors, highlighting the importance of raising awareness among parents about the harmful impact of tobacco smoke on children's oral health.

Keywords: Environmental tobacco smoke (ETS) exposure, Prevalence, Dental caries, Risk factors

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Introduction

Dental caries is a complex microbial disease described as “a biofilm-mediated, diet-modulated, multifactorial, non-communicable, dynamic disease resulting in net mineral loss of dental hard tissues” [1]. Its prevalence among children aged 5 to 10 years has been rising globally over the past few decades [2], coinciding with the onset of independent dietary habits and exposure to environments outside the home, such as school. From 2000 to 2015, children aged 5–6 years in lower-middle-income countries exhibited a median dental caries

prevalence of 83.4%, with a range of 64.0–88.6% [3], while in India, nearly half of children aged 5–10 years were affected [4].

The development of caries is influenced by multiple factors, including sociodemographic background, dietary patterns, oral hygiene practices, and other miscellaneous contributors [5]. Among these, high sugar intake consistently emerges as a key dietary risk factor [6]. Despite extensive study, the role of some potential contributors, particularly environmental tobacco smoke (ETS), remains unclear. ETS, commonly known as secondhand smoke, consists of smoke inhaled by non-smokers from both exhaled

smoke and the burning end of a cigarette. Research in adults has established a causal link between tobacco smoking and caries, and ETS has been associated with decreased vitamin C levels, which may facilitate the growth of *Streptococcus mutans* [7]. Laboratory experiments have demonstrated that the proliferation of *S. mutans* and *Streptococcus sanguinis* is enhanced under cigarette smoke exposure compared to air or carbon dioxide, with nicotine acting as a growth promoter [8, 9]. Furthermore, ETS can compromise immune defenses by lowering IgG levels, impairing T-helper cell function, and reducing phagocytosis [10, 11].

Children are particularly vulnerable to ETS due to faster breathing rates and a larger surface-area-to-volume ratio, resulting in higher intake of toxic compounds per unit time. Evidence from a systematic review focusing on permanent teeth indicates that 10 out of 11 studies observed a significant association between ETS and dental caries [12], although sugar consumption often remains the dominant factor influencing caries in children.

While antenatal ETS exposure has been confirmed as a causative factor in childhood caries, the effect of postnatal exposure is still debated [13, 14]. Recent meta-analytic evidence suggests a positive relationship between postnatal ETS and caries, particularly with maternal smoking showing stronger effects than paternal or other household smoking [15]. Most studies addressing passive smoking in children have been conducted in regions with higher female smoking prevalence. In India, where female smoking is relatively rare—estimated at 2% by the Global Adult Tobacco Survey-2 (GATS-2) [16]—the impact of ETS may be less visible, though some studies indicate it still contributes to childhood caries. This study was therefore undertaken to investigate dental caries prevalence and its association with ETS exposure in Indian children.

Materials and Methods

This analytical cross-sectional study was carried out from July 2019 to January 2021 among children aged 5–10 years attending selected government and private schools. Most participating schools routinely perform health screenings, including oral examinations. Children with systemic diseases or psychiatric conditions were excluded. The target sample size was determined to be 207 using OpenEpi v. 3.1 (https://www.openepi.com/Menu/OE_Menu.htm), considering a 65% caries prevalence, 5% type I error, and 10% relative precision. Schools were chosen through stratified cluster sampling, with each school

representing a cluster. Primary schools were stratified into government and private categories, and proportional sampling ensured representation from different municipal wards. Permission for participation was secured from each school principal, and parents were notified through school diaries. Four government and four private schools consented to participate. After obtaining informed consent from mothers or primary caregivers, 211 children were enrolled, including 127 from private and 84 from government schools, with a mean age of 7.8 ± 1.8 years.

Information on potential risk factors, such as sociodemographic background, dietary habits, oral hygiene, and ETS exposure, was collected using a pre-tested semi-structured questionnaire administered to mothers or primary caregivers. The questionnaire was piloted and refined based on caregiver feedback. Parental education was classified using the International Standard Classification of Education (ISCED) [17], occupations according to the International Standard Classification of Occupations (ISCO-08) [18], and socioeconomic status using the modified Kuppuswamy scale (2019) [19].

Children's oral hygiene practices were assessed through questions on teeth cleaning methods, frequency, parental supervision, brushing before bedtime, and type of toothpaste or alternatives used, including verification of fluoride content. Data on breastfeeding duration, nighttime feeding, and bottle-feeding (age of initiation, duration, and frequency) were recorded. Sugar intake was measured using a 24-hour dietary recall, with scoring based on the type, amount, consistency, and frequency of sugary foods and drinks [20].

ETS exposure was determined via caregiver interviews across three domains: antenatal exposure, exposure within the preceding year (index period), and exposure outside the home. ETS was considered present if any household member smoked during the antenatal or index period. For exposure outside the home, caregivers reported smoking in the school vicinity, restaurants or street food stalls, and public transport areas. Any observation of smoking in these locations was recorded as ETS exposure.

Oral examinations were conducted following WHO type III survey criteria [21]. Data collection coincided with strict school isolation measures, and no children reported COVID-19 symptoms. Examinations were performed in daylight, recording dental caries status using the DMFT index for permanent teeth and the deft index for mixed dentition. All assessments were conducted by a single calibrated investigator to minimize variability, with an assistant documenting the

findings. Children requiring dental care were either treated or referred appropriately based on clinical findings.

Statistical analysis

Dental caries prevalence was expressed along with 95% confidence intervals (CI). To explore associations between environmental tobacco smoke (ETS) exposure, other potential risk factors, and dental caries, χ^2 tests were applied, and the results were summarized as prevalence ratios (PR) with corresponding 95% CI. Binomial regression in Stata 14 (StatCorp LLC, College Station, USA) was used to estimate PRs. Differences in DMFT and deft scores between children exposed and unexposed to ETS were evaluated using the Mann–Whitney U test. For multivariate assessment, log-binomial regression models were fitted to calculate adjusted prevalence ratios (95% CI). Variables with p-values <0.5 in univariate analyses were included in multivariate models, while those exhibiting multicollinearity were excluded. All statistical analyses were performed using IBM SPSS Statistics version 20.0 (IBM Corp., Armonk, USA).

Results

A total of 211 children participated in the study, of whom 127 (60.2%) attended private schools, and 120 (56.9%) were boys. The average age of participants was comparable between school types, with government school children averaging 7.7 ± 1.7 years and private school children 7.9 ± 1.8 years. Sociodemographic details of the cohort are presented in **Table 1**. Around one-third of mothers (33.6%) and 42.2% of fathers had attained graduation (ISCED levels 6–7). Approximately one-quarter of households were engaged in elementary occupations such as daily-wage work, while 30% held higher-level positions, including technicians, associate professionals, and professionals. Regarding socioeconomic status, slightly more than half of the families (54.6%) belonged to the lower strata, encompassing upper-lower and lower-middle classes. Median per capita income for the study population was 3,750 INR (IQR: 2,500–6,667).

Overall, nearly half of the children (49.3%; 95% CI: 42.5–56.1%) had dental caries, with primary teeth more frequently affected (46.4%; 95% CI: 39.8–53.3%) than permanent teeth (6.6%; 95% CI: 3.95–10.9%), as depicted in **Figure 1**. The median DMFT score was 1 (IQR: 1–1.25), while the median deft score for primary teeth was 2 (IQR: 1–4), reflecting a higher caries burden in deciduous dentition compared to permanent teeth.

Table 1. Sociodemographic Profile of the Study Participants

Sociodemographic Characteristics	n (%)
School Type	
Government	84 (39.8)
Private	127 (60.2)
Gender	
Female	91 (43.1)
Male	120 (56.9)
Birth Order	
First	99 (46.9)
Second	90 (42.7)
Third or higher	22 (10.4)
Mother’s Education (ISCED Level [17])	
Level 0 (No formal education)	39 (18.5)
Level 1 (Primary education)	45 (21.3)
Level 2 (Middle school)	36 (17.1)
Level 3 (High school)	20 (9.5)
Level 6 (Graduation)	47 (22.3)
Level 7 (Post-graduation)	24 (11.3)
Father’s Education (ISCED Level [17])	
Level 0 (No formal education)	30 (14.2)
Level 1 (Primary education)	46 (21.8)
Level 2 (Middle school)	30 (14.2)
Level 3 (High school)	16 (7.6)
Level 6 (Graduation)	54 (25.6)
Level 7 (Post-graduation)	35 (16.6)
Occupation of Household Head (ISCO-08 [18])	
Elementary occupations	53 (25.1)
Plant & machine operators and assemblers	1 (0.5)
Craft & related trade workers	10 (4.7)
Skilled workers, shop & market sales workers	44 (20.9)
Clerks	2 (0.9)
Technicians and associate professionals	50 (23.7)
Professionals	15 (7.1)
Legislators, senior officials and managers	36 (17.1)
Socioeconomic Status (Modified Kuppuswamy SES 2019 [19])	
Upper lower	65 (30.8)
Lower middle	51 (24.2)
Upper middle	71 (33.6)
Upper	24 (11.4)

ISCED – International Standard Classification of Education; ISCED level 1 – completed primary education; ISCED level 2 – completed middle school; ISCED level 3 – completed high school; ISCED level 6 – completed graduation; ISCED level 7 – completed post-graduation; ISCO-08 – International Standard Classification of Occupations; SES – socioeconomic status scale.

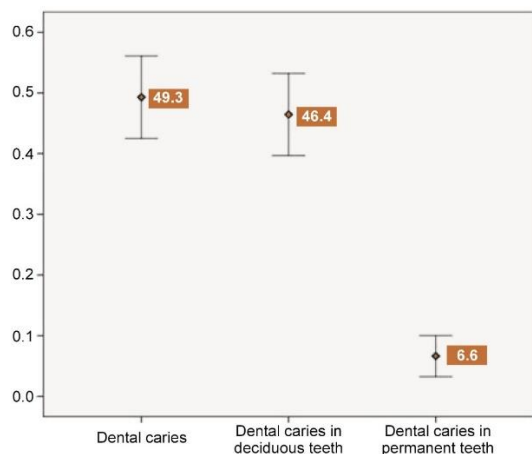


Figure 1. Prevalence of dental caries in children

Table 2 summarizes the relationship between dental caries and sociodemographic characteristics. While children enrolled in government schools exhibited a higher prevalence of caries compared to those in private schools, the difference was not statistically significant. Among parental factors, the mother’s level of education showed a stronger link with dental caries than the father’s, although none of the examined sociodemographic variables were significantly associated with caries in this study.

Table 2. Relationship Between Dental Caries and Sociodemographic Factors in the Study Population

Sociodemographic Factor	Subgroup Sample Size (n)	Dental Caries Prevalence (%)	Prevalence Ratio (PR) (95% CI)	p-value*
School Type				0.312
Government	84	53.6	1	
Private	127	46.5	0.87 (0.66–1.14)	
Gender				0.428
Female	120	51.7	1	
Male	91	46.2	0.89 (0.67–1.18)	
Birth Order				0.377
First	99	52.5	1	
Second or Higher	112	46.4	0.89 (0.67–1.16)	
Mother’s Education				0.145
High School or Below	140	52.9	1	
Graduation or Above	71	42.3	0.80 (0.58–1.10)	
Father’s Education				0.603
High School or Below	122	50.8	1	
Graduation or Above	89	47.2	0.93 (0.70–1.22)	
Socioeconomic Status (Modified Kuppuswamy SES 2019)[19]				0.484
Upper Lower	65	46.2	1	
Lower Middle	51	58.8	1.27 (0.90–1.80)	
Upper Middle	71	46.5	1.01 (0.70–1.44)	
Upper	24	45.8	0.99 (0.59–1.65)	
Source of Water Supply				0.309
Public Tap or Well	94	53.2	1	
Mineral Water	117	46.2	0.87 (0.66–1.14)	

CI – confidence interval; * χ^2 test.

Table 3 illustrates how dental caries relates to oral hygiene, feeding practices, sugar consumption, and environmental tobacco smoke (ETS) exposure. Only a small fraction of children (6.2%; n = 13) reported brushing their teeth twice per day. Nighttime breastfeeding during infancy was prevalent (87.7 percent; n = 185), while just over one-third (36%; n = 76) had been bottle-fed, of whom 16 (21.0 percent) used the bottle as a pacifier. About 30% of participants (n = 64) had high sugar intake, indicated by a sugar score exceeding 15.

ETS exposure was lower during the antenatal period (54.5 percent; n = 115) compared to the index period (64.9 percent; n = 137). When examining exposure outside the home, children encountered ETS most frequently at transit points such as bus or railway stations (59.7 percent; n = 126), followed by school surroundings (46.9 percent; n = 99) and restaurants or roadside stalls (42.2 percent; n = 89). None of the oral hygiene or dietary behaviors, however, were significantly associated with caries.

Within households, grandparents were the main source of ETS (24.2 percent; n = 52), followed by fathers (11.8

percent; n = 25). Cigarettes were the most commonly reported form of exposure (26.1 percent; n = 55), with beedis accounting for 17.5 percent (n = 37). Similar trends were observed during the index period. Notably,

antenatal ETS exposure was significantly linked to higher dental caries risk (PR = 1.44; 95% CI: 1.08–1.94), whereas other variables did not show meaningful associations.

Table 3. Relationships Between Dental Caries and Oral Hygiene Practices, Breastfeeding, Sugar Exposure, and Environmental Tobacco Smoke (ETS) Exposure

Parameter	Subgroup Sample Size (n)	Dental Caries Prevalence (%)	Prevalence Ratio (95% CI)	p-value**
Brushing by parents				
No	183	49.7	1	0.745
Yes	28	46.4	0.93 (0.61–1.42)	
Brushing under parental supervision				
No	156	50.6	1	0.508
Yes	55	45.5	0.90 (0.65–1.25)	
Brushing before bedtime				
No	199	48.7	1	0.519
Yes	12	58.3	1.20 (0.72–1.97)	
Fluoride toothpaste use				
No	55	40.0	1	0.109
Yes	156	52.6	1.31 (0.92–1.87)	
Breastfeeding during sleep				
No	26	53.8	1	0.620
Yes	185	48.6	0.90 (0.61–1.32)	
Bottle feeding				
No	135	52.6	1	0.201
Yes	76	43.4	0.83 (0.61–1.11)	
Bottle used as pacifier				
No	59	44.1	1	0.982
Yes	16	43.8	0.99 (0.53–1.85)	
Sugar exposure*				
Low	147	46.3	1	0.182
High	64	56.3	1.21 (0.92–1.60)	
ETS exposure (antenatal period)				
No	96	39.6	1	0.010
Yes	115	57.4	1.44 (1.08–1.94)	
ETS exposure (index period)				
No	74	40.5	1	0.062
Yes	137	54.0	1.33 (0.97–1.82)	
ETS exposure (school neighborhood)				
No	112	54.5	1	0.110
Yes	99	43.4	0.79 (0.60–1.05)	
ETS exposure (restaurants/roadside stalls)				
No	122	46.7	1	0.382
Yes	89	52.8	1.13 (0.86–1.48)	
ETS exposure (bus stops/railway stations)				
No	85	52.9	1	0.383
Yes	126	46.8	0.88 (0.67–1.16)	

*sugar score ≤15 was defined as low sugar exposure and >15 as high sugar exposure; ** χ^2 test.

Among children exposed to ETS in their school neighborhoods, the prevalence of dental caries was 43.4%, compared to 54.5% in those without such

exposure; however, this difference was not statistically significant. Variables with a p-value <0.2 in univariate analyses were selected for multivariate modeling

(Table 4). The binomial regression included maternal education, sugar intake (categorized as low or high), and antenatal ETS exposure. ETS exposure at school and during the index period was excluded due to strong collinearity with antenatal ETS exposure. In the multivariate analysis, only antenatal ETS exposure remained significantly associated with dental caries, with exposed children showing a 41% higher prevalence compared to unexposed children. No other factors demonstrated a significant relationship with dental caries in this analysis.

Table 4. Independent Factors Associated with Dental Caries in Children

Parameter	Exposure Level	Adjusted Prevalence Ratio (APR) (95% CI)	p-value [§]
Mother's Education	High school or lower	1	0.383
	College degree or higher	0.87 (0.64–1.19)	
Sugar Exposure	Low	1	0.244
	High	1.17 (0.90–1.54)	
ETS Exposure During Antenatal Period	No	1	0.021
	Yes	1.41 (1.05–1.90)	

[§] multivariate log-binomial regression analysis

Discussion

This cross-sectional analytical study among schoolchildren aged 5–10 years assessed the prevalence of dental caries and its relationship with exposure to environmental tobacco smoke (ETS). The overall prevalence of dental caries was 49.3% (95% CI: 42.5–56.1%), with primary teeth (46.4%; 95% CI: 39.8–53.3%) affected significantly more than permanent teeth (6.6%; 95% CI: 3.95–10.9%). Among the various risk factors examined, antenatal ETS exposure was the only factor significantly associated with an increased risk of dental caries, with an adjusted prevalence ratio (APR) of 1.41 (95% CI: 1.05–1.90). The observed prevalence aligns closely with the pooled prevalence of 49.6% reported by Ganesh *et al.* [4] and Janakiram *et al.* [22]. However, several studies from South India have reported higher prevalence rates [23–25], which may be explained by differences in geographic regions, population characteristics, and age distributions. Consistent with previous observations, caries was notably more common in primary teeth. A

systematic review examining childhood caries reported similar prevalence in primary and permanent dentition in Asia (53% vs. 58%) [26], but this trend was not observed in the 5–10 year age group in the current study.

No significant associations were found between sociodemographic variables and dental caries in this cohort. Although male gender, lower maternal education, and lower family income are frequently reported as risk factors for childhood caries [5], these variables did not reach statistical significance in the present study.

Dietary factors, including breastfeeding, bottle feeding, and sugar intake, were not significantly linked to dental caries in this analysis. While prior research consistently demonstrates a strong connection between sugar consumption and caries [27–29], the lack of association here may be due to methodological limitations, such as reliance on a 24-hour dietary recall that may not accurately capture habitual intake, as well as potential recall bias and limited sample size.

Similarly, oral hygiene practices—including brushing frequency, parental supervision, and use of fluoride toothpaste—did not show a significant protective effect in this study, despite previous reports highlighting their importance in reducing caries risk [23, 30]. This discrepancy may reflect sampling variability or insufficient statistical power.

Antenatal ETS exposure was consistently associated with a higher likelihood of dental caries (PR: 1.44; 95% CI: 1.08–1.94). Even after adjusting for maternal education and sugar intake, antenatal ETS exposure remained a significant predictor (APR: 1.41; 95% CI: 1.05–1.90), whereas no other factors demonstrated a significant effect.

The findings of this study corroborate evidence from González-Valero *et al.* [15], whose meta-analysis indicated that prenatal exposure to secondhand smoke raises the likelihood of dental caries in primary teeth, with a pooled odds ratio (OR) of 1.72 (95% CI: 1.45–2.05). Positive associations between antenatal ETS exposure and caries have also been reported by Kellesarian *et al.* [14] and Hanioka *et al.* [31], reinforcing conclusions from earlier systematic reviews. Tanaka *et al.* [32] observed a similar effect (PR: 1.43; 95% CI: 1.07–1.91), and studies by Iida *et al.* [33], Tanaka and Miyake [34], and Majorana *et al.* [35] also documented an elevated risk of dental caries linked to prenatal tobacco exposure. In contrast, Shulman [36], Tanaka *et al.* [37], and Claudia *et al.* [38] reported non-significant associations, although the differences were minimal and may not reflect a true absence of effect.

The potential biological mechanism behind antenatal ETS exposure involves the transplacental passage of toxic substances. Noakes *et al.* [39] demonstrated that impaired toll-like receptor-mediated immunity in neonates increases vulnerability to infections, which could contribute to a higher risk of dental caries. Genetic factors, including polymorphisms in the MSX1 gene, may further mediate susceptibility to caries in children whose mothers were exposed to tobacco [40, 41]. The impact of tobacco exposure may be similar to other chemical agents [42], and maternal ETS can alter the infant's oral microbiome, paralleling the changes observed in adult smokers [7]. Comparable effects on the oral microbiome have also been reported with maternal exposure to disinfectants and antibiotics [43]. Prolonged prenatal exposure may extend into early postnatal life, leading to cumulative effects on oral health.

Unlike antenatal exposure, ETS during the index period did not significantly influence caries prevalence in this cohort. Previous reviews, including González-Valero *et al.* [15] and Hanioka *et al.* [31], have reported postnatal ETS as a risk factor for dental caries, but the current study's findings may reflect the lower prevalence of smoking in India and the limited sample size, reducing statistical power.

Parental education, which often correlates with socioeconomic status, has been linked to dental caries risk [44]. Both maternal and paternal education were assessed in this study, and findings were consistent with earlier studies examining the relationship between ETS and caries [16, 31, 32]. None of the children in this sample belonged to the lower socioeconomic class.

This study was conducted during the initial wave of the COVID-19 pandemic, a period that disrupted dental services and led to innovative strategies in clinical practice [45–48]. As none of the participants contracted COVID-19, the potential influence of the pandemic on dental caries could not be evaluated. Interestingly, household smoking prevalence among the study participants (35.1% during the index period) exceeded the national average of 19% reported in GATS-2 [16]. Differential recall bias is possible, as caregivers of children with dental caries might have been more likely to report ETS exposure compared to those of children without caries.

Limitations

The primary limitation of this study was its relatively small sample size, which may have reduced the ability to detect associations with several established risk factors. Additionally, the low prevalence of caries in permanent teeth limited the statistical power to

separately analyze associations for primary and permanent dentition. ETS exposure was assessed based on caregiver recall, preventing accurate evaluation of cumulative exposure, and the study lacked objective biomarkers, such as serum or urine cotinine levels, to validate reported exposure. Despite these limitations, the study remains important, as few investigations in India have explored the link between ETS and dental caries in children [30]. Efforts were made to ensure representative sampling by stratifying participants between government and private schools, and dental caries prevalence was recorded using standardized WHO forms. The study focused on an age group at high risk for caries with mixed dentition, and the observed prevalence among schoolchildren in Nellore aligns with national averages reported in systematic reviews. Further research is needed to elucidate differences in caries patterns between primary and permanent teeth. Awareness of the impact of ETS on dental caries remains low in India, underscoring the need for oral health education programs targeting both parents and children.

Conclusions

Among schoolchildren aged 5–10 years, dental caries prevalence was 49.6%. After accounting for other variables, antenatal ETS exposure was associated with a modest but significant 41% increase in caries prevalence. Nonetheless, the influence of ETS on dental caries warrants further investigation through well-designed cohort studies. The study also highlighted suboptimal oral hygiene practices, including low rates of parental supervision during brushing and limited use of fluoride toothpaste. Targeted interventions addressing these behaviors could help further reduce the burden of dental caries in this population.

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