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Correlation between Dental Caries, Gingivitis, and Malocclusion in School-aged Children: A Cross-sectional Study

Ruijie Zeng[1*], Yiyao Jin[1], Skakodub Alla Anatolyevna[2], Mikhailovich Dybov Andrey[3], Alexandrovna Kozlitina Yulia[4], Sibulaeva Samira[5]

[1, 2, 3, 4, 5] Institute of Dentistry named after E.V. Borovsky, First Moscow State Medical University named after I.M. Sechenov, Moscow 121059, Russia
zengruijie0101111@gmail.com[1*]
jinyiyao111@gmail.com[1]
skalla71@mail.ru[2]
AMDybov@gmail.com[3]
kozlitina_yu_a@staff.sechenov.ru[4]

(Corresponding author): Ruijie Zen

ABSTRACT
Oral diseases are important public health issues affecting school-aged children, yet comprehensive studies on interrelationships among dental caries, gingivitis, and malocclusion remain lacking. This cross-sectional study assessed prevalence, correlations, and risk factors of these three diseases in 502 children aged 6-12 years from three elementary schools in Guangzhou, China (October 2024-January 2025). Demographic characteristics, oral hygiene habits, and dietary behaviors were collected through questionnaires. Clinical assessments used DMFT/dmft index, Gingival Index, ICDAS, and Angle classification. Dental caries prevalence was 45.4%, exhibiting an inverted U-shaped age pattern: 52.7% (6-8 years), 39.7% (9-10 years), and 44.4% (11-12 years), reflecting primary-to-permanent dentition transition. Gingivitis prevalence was 48.6% and malocclusion 68.3%, with 23.7% experiencing all three conditions simultaneously. Correlation analysis revealed moderate positive correlation between caries and gingivitis (r=0.342), and weak correlations between caries-malocclusion (r=0.268) and gingivitis-malocclusion (r=0.231), all statistically significant. Multivariate analysis identified major risk factors: daily sweet consumption (OR=2.14), inadequate brushing (OR=1.87), no dental floss use (OR=2.23), and thumb-sucking (OR=2.87). Age demonstrated significant quadratic relationship with caries (P=0.031), confirming the non-linear pattern. These oral diseases show high prevalence and significant interrelationships, requiring comprehensive prevention strategies and age-specific interventions targeting primary tooth preservation (6-8 years), timely sealants (9-10 years), and comprehensive prevention (11-12 years).

KEYWORDS: School-aged children; Dental caries; Gingivitis; Malocclusion; Cross-sectional study; Risk factors.

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INTRODUCTION
Oral diseases have become an important public health issue affecting children's health globally. The latest World Health Organization report indicates that oral diseases affect nearly 3.5 billion people worldwide, with school-aged children being one of the most severely affected groups [1]. Dental caries, gingivitis, and malocclusion, as the three most common oral diseases in childhood, not only affect children's masticatory function, language development, and facial aesthetics, but also have profound impacts on their psychological health and social interactions [2]. If these diseases are not diagnosed and treated promptly, they will persist into adulthood and lead to more serious oral health problems, imposing a heavy economic burden on individuals and society [3].

Among childhood oral diseases, dental caries remains the most prevalent chronic disease. Despite continuous improvements in preventive measures, the prevalence of dental caries in school-aged children remains high globally, particularly severe in developing countries and among populations with lower socioeconomic status [4]. Meanwhile, the incidence of gingivitis in children is also showing an upward trend, with studies indicating that over 60% of school-aged children exhibit varying degrees of gingival inflammation [5]. The prevalence of malocclusion is equally concerning, as it not only affects oral function but may also become a potential risk factor for other oral diseases [6]. An expert consensus by Zhou et al. points out that if childhood malocclusion is not corrected promptly, it will have long-term negative impacts on oral health [7].

Increasing evidence suggests complex interrelationships among these three oral diseases. Wang et al. found significant correlations between malocclusion, poor oral habits, and caries incidence [8]. Dental crowding and occlusal abnormalities caused by malocclusion may increase the risk of food impaction and plaque accumulation, thereby promoting the occurrence of dental caries and gingivitis [9]. Research by Baskaradoss et al. further confirmed the negative impact of malocclusion on children's oral health-related quality of life [2]. However, existing research results are inconsistent regarding the specific interaction mechanisms and degree of influence among the three conditions.

Socioeconomic factors play an important role in children's oral health. Studies show that parental education level is closely related to children's oral health status, with significantly higher caries rates and gingivitis incidence among children from families with lower education levels [10]. A cohort study by Costa et al. in impoverished Brazilian communities revealed the combined effects of socioeconomic status, psychosocial factors, and health behaviors on childhood caries occurrence [4]. These findings emphasize the importance of considering social determinants when developing oral health promotion strategies.

Schools, as important venues for children's oral health education, have received considerable attention for their intervention effectiveness. A systematic review by Bramantoro et al. showed that school oral health promotion programs from preschool to high school can effectively improve students' oral health status [11]. Theory-based educational intervention research by Shirahmadi et al. demonstrated the effectiveness of conducting oral health education among elementary school students [12]. Cost-effectiveness analysis of school oral health promotion programs by Rochmah et al. provided important evidence for public health policy formulation [13].

Although existing studies have explored various aspects of childhood oral diseases, current literature still has obvious limitations. Most studies focus only on single diseases or relationships between two diseases, lacking comprehensive analysis of the interrelationships among dental caries, gingivitis, and malocclusion [5]. Regarding diagnostic criteria, assessment methods vary significantly across different studies. Gudipaneni et al. compared different caries diagnostic criteria including DMFT, ICDAS II, and CAST, finding significant impacts on prevalence estimates [14]. Additionally, most existing studies are conducted in foreign populations, with relatively few large-sample studies targeting Chinese school-aged children. Due to the particularity of Chinese children's dietary habits, oral health awareness, and other factors, their oral disease patterns may differ from those in Western countries.

Rodrigues et al., in outlining the future development of pediatric oral medicine, pointed out the need for more integrative research to understand the complex interactions of oral diseases [15]. This study aims to systematically analyze the prevalence and correlations of dental caries, gingivitis, and malocclusion in school-aged children through a large-sample cross-sectional survey using standardized assessment methods, identify common risk factors, and provide scientific evidence for developing comprehensive oral disease prevention and treatment strategies. The research results will help optimize school oral health education content, improve early screening efficiency for oral diseases, and provide references for clinicians in developing personalized treatment plans.

MATERIALS AND METHODS

2.1 Study Design and Ethical Approval

This study was a cross-sectional observational study, designed and implemented in strict accordance with the guidelines of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [16]. The study period was from October 2024 to January 2025, conducted during the autumn semester to avoid the impact of holidays on data collection. The study protocol was approved by the Ethics Committee of [Institution Name] (Approval No.: 2024-XXX), and all procedures complied with the ethical principles of the Declaration of Helsinki [17]. Prior to the study commencement, written informed consent was obtained from all legal guardians of participating children, and verbal assent was obtained from children aged 10 years and above.

2.2 Study Population and Sample Size Calculation

Sample size calculation was based on the cross-sectional study sample size estimation method proposed by Browner et al. [18]. Based on the previously reported prevalence of dental caries in school-aged children (approximately 40%), with $\alpha=0.05$ (two-tailed test), $\beta=0.20$ (80% statistical power), and allowable error $d=0.05$. Using the sample size calculation method developed by Naing et al. [19], considering a design effect of 1.2 for cluster sampling, the minimum sample size was calculated to be 442 participants. Accounting for a 15% non-response rate and missing data, the final plan was to recruit at least 510 school-aged children.

A two-stage cluster sampling method was employed in urban districts of Guangzhou, Guangdong Province. In the first stage, 3 schools were randomly selected from 12 elementary schools in the urban area; in the second stage, 2 classes were randomly selected from each grade level in each school. Inclusion criteria comprised: (1) school students aged 6-12 years; (2) in mixed dentition or early permanent dentition stage; (3) able to cooperate with oral examination; (4) guardian consent to participate in the study. Exclusion criteria were: (1) presence of systemic diseases affecting oral health; (2) currently undergoing orthodontic treatment; (3) antibiotic use within the past 3 months; (4) presence of craniofacial congenital anomalies.

A total of 502 children were successfully recruited from 3 elementary schools in Guangzhou, Guangdong Province. The sample consisted of 263 boys (52.4%) and 239 girls (47.6%), with a mean age of 8.9±1.8 years. The age distribution was as follows: 165 children (32.9%) in the 6-8 years group, 184 children (36.7%) in the 9-10 years group, and 153 children (30.4%) in the 11-12 years group. This age grouping corresponds to different stages of dentition development: early mixed dentition (6-8 years), late mixed dentition (9-10 years), and early permanent dentition (11-12 years). The response rate was 91.3% (502/550), with 48 children excluded due to ongoing orthodontic treatment (n=23), systemic diseases (n=12), recent antibiotic use (n=8), or incomplete data (n=5).

2.3 Data Collection

Data collection followed the standard procedures of the World Health Organization's "Oral Health Surveys: Basic Methods" [20]. The research team consisted of 2 trained dental physicians and 2 auxiliary personnel. The survey was conducted in two phases: first a questionnaire survey, followed by clinical oral examination. The questionnaire was developed by our research team based on WHO Oral Health Survey guidelines [20] and the American Academy of Pediatric Dentistry recommendations [21], adapted to the local context of Guangzhou. The questionnaire consisted of 28 items covering four domains: demographic characteristics (5 items), oral hygiene habits (8 items), dietary behaviors (10 items), and oral habits (5 items). Questions were formulated to capture comprehensive information about risk factors specific to the study population, including demographic characteristics (age, gender, family monthly income), oral hygiene habits (brushing frequency, dental floss use, toothpaste type), and dietary habits (sweet food intake frequency, carbonated beverage consumption, meal patterns).

The questionnaire design underwent expert review and pre-survey validation to ensure content comprehensiveness and comprehensibility. To reduce information bias, questionnaire completion was conducted with parents assisting children. For younger children (6-8 years old), trained surveyors read and explained each question to ensure accurate understanding. Key questions included validation items to improve data quality. Questionnaires were distributed with the assistance of class teachers, and children completed them under parental guidance, with completion time controlled within 15-20 minutes. The research process is shown in Figure 1.

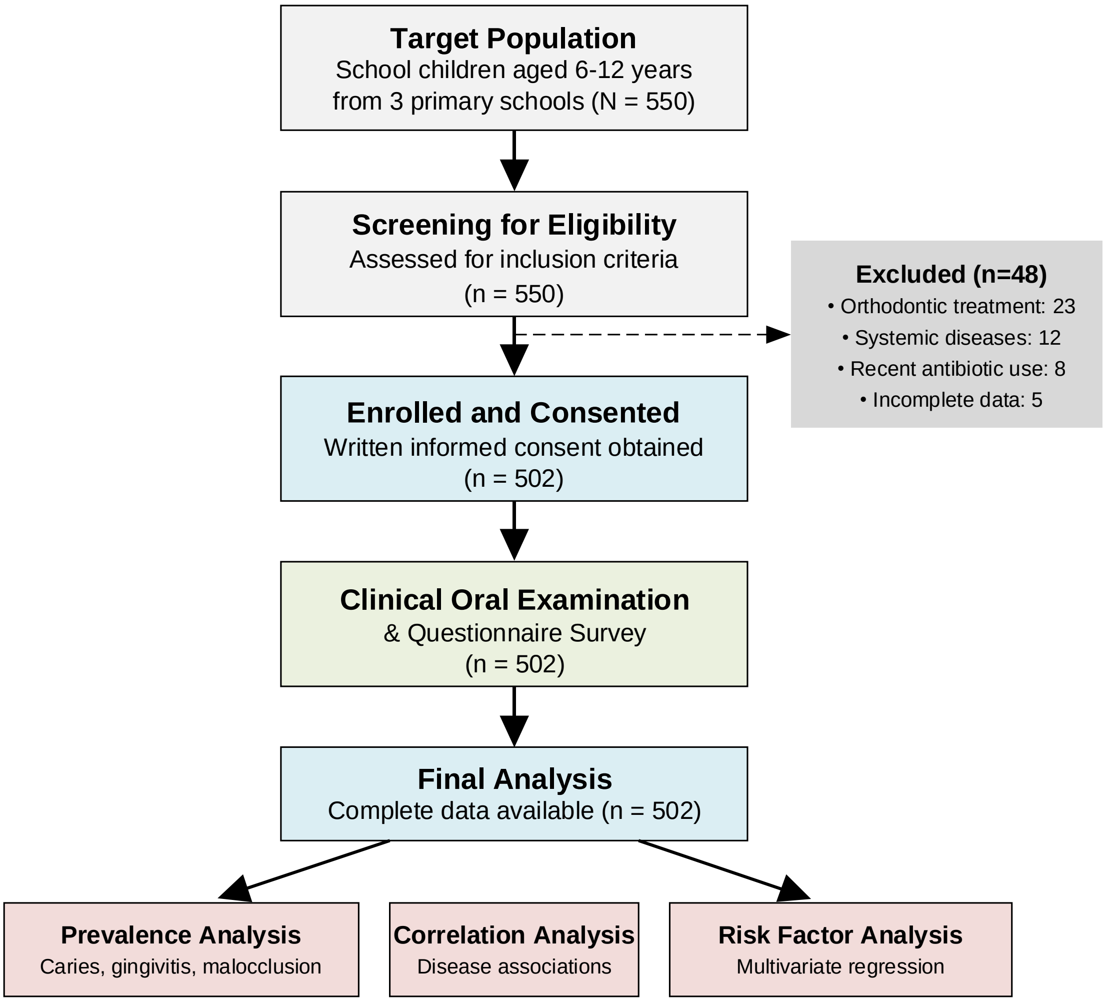

Figure 1. Flow diagram of participant recruitment and study procedures

2.4 Clinical Assessment Criteria

Clinical oral examinations were conducted in school health rooms using portable examination kits, including disposable mouth mirrors, WHO-recommended CPI probes (0.5mm ball tip, used for detecting carious cavities, measuring pocket depths, and avoiding excessive pressure during examination), and LED headlamp illumination. Dental caries assessment employed the DMFT/dmft index modified with ICDAS II criteria integration. The modification allows detection of non-cavitated lesions (ICDAS codes 1-2) in addition to traditional cavitated lesions, providing more comprehensive caries assessment than the original WHO criteria which only records cavitated lesions (D3 level) [22]. The rationale for selecting this combined approach was to balance the operability of epidemiological surveys with the sensitivity of early caries detection, improving examination efficiency while ensuring diagnostic accuracy. Rai et al.'s comparative study demonstrated that combining WHO standards with ICDAS grading can more accurately assess caries severity [22]. In this study, caries diagnosis was primarily based on visual inspection, supplemented by probing, avoiding iatrogenic damage from excessive probing. For borderline cases with unclear diagnosis, a consultation between two examiners was used to determine the final diagnosis. Zaazou et al. validated the reliability and practicality of this method in adolescent populations [23].

Gingivitis assessment utilized the simplified Löe-Silness Gingival Index, examining the buccal and lingual gingival status of six index teeth.

Oral hygiene status was evaluated using the Simplified Oral Hygiene Index (OHI-S) developed by Greene and Vermillion. Six index teeth surfaces (16-buccal, 11-labial, 26-buccal, 36-lingual, 31-labial, 46-lingual) were examined for debris index (DI-S) and calculus index (CI-S). The OHI-S score was calculated as the sum of DI-S and CI-S, with scores categorized as: good (0-1.2), fair (1.3-3.0), or poor (3.1-6.0). This index was critical for assessing the relationship between oral hygiene and disease occurrence, as poor oral hygiene is the most significant modifiable risk factor for oral diseases. The detailed OHI-S scoring criteria are presented in Table 1B.

Malocclusion assessment followed the pediatric periodontal disease classification standards recommended by the American Academy of Pediatric Dentistry [24], using Angle's classification to record molar relationships and calculating the Dental Aesthetic Index (DAI) to quantify malocclusion severity. In addition to basic classification, specific malocclusion characteristics were recorded, such as the degree of anterior crowding and overbite/overjet conditions. These detailed data help in subsequent analysis of the mechanisms linking malocclusion with other oral diseases. The specific clinical assessment criteria and grading systems are shown in Table 1, with additional details for ICDAS II criteria in Table 1A and OHI-S scoring criteria in Table 1B.

Table 1. Clinical assessment criteria and classification systems for dental caries, gingivitis, and malocclusion

Assessment Item	Diagnostic Criteria	Grade	Clinical Manifestation
Dental Caries (DMFT/dmft)			
Sound	No evidence of caries	0	Healthy tooth surface
Initial caries	First visual change in enamel	D1	White/brown spot, intact surface
Enamel caries	Localized enamel breakdown	D2	Small cavity limited to enamel
Dentin caries	Cavitation into dentin	D3	Obvious cavity with dentin exposure
Deep caries	Extensive cavity	D4	Large cavity, possible pulp involvement
Gingivitis (GI Index)			
Normal	No inflammation	0	Pink, firm gingiva
Mild	Slight color change and edema	1	Slight redness, no bleeding on probing
Moderate	Redness, edema, glazing	2	Moderate inflammation, bleeding on probing
Severe	Marked redness and edema	3	Severe inflammation, spontaneous bleeding
Malocclusion (Angle Classification)			
Class I	Normal molar relationship	I	Mesiobuccal cusp of upper first molar occludes with mesiobuccal groove of lower first molar
Class II	Distal molar relationship	II	Lower molar positioned distally relative to upper molar
Class III	Mesial molar relationship	III	Lower molar positioned mesially relative to upper molar
DAI Score			
No abnormality	DAI ≤ 25	0	No or minor treatment need
Definite malocclusion	DAI 26-30	1	Elective treatment
Severe malocclusion	DAI 31-35	2	Treatment highly desirable
Very severe	DAI ≥ 36	3	Mandatory treatment need

Table 1A. ICDAS II Criteria for Dental Caries Assessment

ICDAS Code	Clinical Criteria	Visual Signs	Corresponding DMFT
0	Sound tooth surface	No evidence of caries after air drying (5s)	Sound
1	First visual change in enamel	Opacity visible only after prolonged drying	d1/D1*
2	Distinct visual change in enamel	White/brown spot visible when wet	d1/D1*
3	Localized enamel breakdown	Cavitation <0.5mm, no visible dentin	d2/D2*
4	Underlying dark shadow from dentin	Shadow visible through intact enamel	d3/D3
5	Distinct cavity with visible dentin	Cavitation exposing dentin (<50% surface)	d3/D3
6	Extensive cavity with visible dentin	Large cavity (>50% surface)	d4/D4

Note: Codes 1-2 represent non-cavitated lesions detected only with ICDAS modification

Table 1B. Simplified Oral Hygiene Index (OHI-S) Scoring Criteria

Component	Score	Criteria
Debris Index (DI-S)		
	0	No debris or stain
	1	Soft debris covering ≤1/3 of surface
	2	Soft debris covering 1/3-2/3 of surface
	3	Soft debris covering >2/3 of surface
Calculus Index (CI-S)		
	0	No calculus
	1	Supragingival calculus ≤1/3 of surface
	2	Supragingival calculus 1/3-2/3 or subgingival spots
	3	Supragingival calculus >2/3 or continuous subgingival band
OHI-S Total Score	**Interpretation**	**Oral Hygiene Status**
0-1.2	Good	Good oral hygiene
1.3-3.0	Fair	Fair oral hygiene
3.1-6.0	Poor	Poor oral hygiene

2.5 Quality Control

To ensure data quality, multi-level quality control measures were implemented. Both examiners were dentists with over 5 years of clinical experience who underwent 3 days of standardized training before the study commenced. Training content included theoretical learning, standard case discussions, and pre-survey practice with 20 children. Intraclass correlation coefficient (ICC) was used to assess examiner agreement [25], requiring both inter-examiner and intra-examiner Kappa values to reach above 0.80. During the formal survey period, 5% of samples were randomly selected weekly for re-examination by another examiner to monitor the stability of examination quality. Data entry was performed using EpiData 3.1 software with double entry, and inconsistent data were verified by consulting original records.

2.6 Statistical Analysis

Data analysis was performed using IBM SPSS Statistics 25.0 software, following Field's statistical analysis guidelines [26]. Descriptive statistics were used to summarize study population characteristics. After normality testing, continuous variables were expressed as mean ± standard deviation or median (interquartile range), and categorical variables were expressed as frequencies and percentages. Prevalence rates and their 95% confidence intervals were calculated using the Wilson score method. In univariate analysis, chi-square test was used for between-group comparisons of categorical variables, and independent samples t-test or Mann-Whitney U test was used for continuous variables.

For age-related trends in caries prevalence, considering the physiological transition from primary to permanent dentition, both linear trend test and quadratic trend test were performed to identify potential non-linear patterns. The Cochran-Armitage trend test was used for linear trends, while polynomial contrasts in chi-square analysis were employed to detect quadratic (U-shaped or inverted U-shaped) trends. Age groups were analyzed both as categorical variables (for between-group comparisons using chi-square test) and as ordinal variables (for trend analysis) to comprehensively assess the relationship between age and caries occurrence.

Correlations among the three oral diseases were analyzed using Spearman correlation analysis. Multivariate analysis employed binary logistic regression, with the presence of dental caries, gingivitis, and malocclusion as dependent variables. Variables with $P<0.1$ in univariate analysis were included in the model, using backward stepwise method for variable selection. For the caries prediction model, age was entered both as a linear term and a quadratic term to account for the observed non-linear relationship. Model fit was assessed using the Hosmer-Lemeshow test, and the area under the receiver operating characteristic curve (AUC) was calculated to evaluate the model's predictive ability. All statistical tests were two-tailed, with $P<0.05$ considered statistically significant.

RESULTS

3.1 Baseline Characteristics of Study Subjects

This study included 502 school-aged children with a mean age of 8.9±1.8 years, comprising 263 boys (52.4%) and 239 girls (47.6%). The demographic characteristics and oral health behaviors of the study subjects are shown in Table 2. Most children (68.1%) brushed their teeth twice daily, but only 15.7% used dental floss. Regarding dietary habits, 34.5% of children consumed sweets daily, and 26.9% consumed carbonated beverages more than 3 times per week. Notably, only 23.3% of children had undergone an oral examination in the past year.

Table 2. Demographic characteristics and oral health behaviors of the study population (n=502)

Characteristics	n (%) or mean ± SD
Demographic variables	
Age (years)	8.9 ± 1.8
Gender	
- Male	263 (52.4)
- Female	239 (47.6)
Family monthly income (CNY)	

- <5,000	146 (29.1)
- 5,000-10,000	218 (43.4)
- >10,000	138 (27.5)
Parental education level	
- Primary/Middle school	124 (24.7)
- High school	197 (39.2)
- College or above	181 (36.1)
Oral hygiene habits	
Toothbrushing frequency	
- <1 time/day	45 (9.0)
- 1 time/day	115 (22.9)
- 2 times/day	342 (68.1)
Use of dental floss	
- Never	423 (84.3)
- Occasionally/Regular	79 (15.7)
Oral Hygiene Index (OHI-S)	
- Good (0-1.2)	142 (28.3)
- Fair (1.3-3.0)	287 (57.2)
- Poor (3.1-6.0)	73 (14.5)
Regular dental check-up	
- Yes	117 (23.3)
- No	385 (76.7)
Dietary habits	
Sweet snack consumption	
- Rarely	157 (31.3)
- 1-2 times/week	172 (34.2)
- Daily	173 (34.5)
Carbonated beverage intake	
- Never/Rarely	183 (36.5)
- 1-2 times/week	184 (36.6)
- ≥3 times/week	135 (26.9)

3.2 Oral Disease Prevalence

The overall prevalence rates of dental caries in the study population were 45.4% (95% CI: 41.1-49.8), gingivitis were 48.6% (95% CI: 44.2-53.0), and malocclusion were 68.3% (95% CI: 64.1-72.3), respectively, with specific distributions shown in Table 3. Caries prevalence exhibited a non-linear inverted U-shaped pattern: 52.7% (6-8 years), 39.7% (9-10 years), and 44.4% (11-12 years) (P=0.018 for quadratic trend; P=0.523 for linear trend). This pattern reflects dentition transition: high early prevalence from primary tooth caries, mid-age decline from physiological exfoliation, and subsequent increase from early permanent tooth caries accumulation.

Girls had higher caries prevalence (47.7%) than boys (43.3%), though not statistically significant (P=0.352). Regarding severity, mild caries (D1-D2) accounted for 58.6% and moderate-to-severe (D3-D4) for 41.4%, highlighting early intervention importance.

Gingivitis prevalence showed no statistically significant difference among age groups (P=0.187), with prevalence rates fluctuating between 45.5%-51.0% across age groups, suggesting that gingivitis may develop at an early age and persist. Boys had higher prevalence (52.9%) than girls (43.9%) (P=0.025), with this 9 percentage point gender difference being more pronounced than for caries. In terms of severity distribution, mild gingivitis accounted for 62.7% of affected children, moderate for 28.3%, and severe for only 9.0%, indicating that most gingivitis cases were still at a reversible stage. Malocclusion distribution was relatively uniform across age groups (65.5%-70.6%), suggesting it may be primarily determined by genetic and early developmental factors. Angle Class I accounted for 47.2%, Class II for 38.5%, and Class III for 14.3%. According to DAI scores, mild malocclusion accounted for 52.8%, moderate for 31.5%, and severe for 15.7%, with nearly half of children's malocclusions requiring clinical intervention.

Table 3. Prevalence and severity distribution of dental caries, gingivitis, and malocclusion by age and gender

Variables	Dental Caries	Gingivitis	Malocclusion
	n (%) [95% CI]	n (%) [95% CI]	n (%) [95% CI]
Overall prevalence	228 (45.4) [41.1-49.8]	244 (48.6) [44.2-53.0]	343 (68.3) [64.1-72.3]
Age groups			
6-8 years (n=165)	87 (52.7) [44.9-60.4]	75 (45.5) [37.8-53.3]	108 (65.5) [57.7-72.6]
9-10 years (n=184)	73 (39.7) [32.7-47.1]	91 (49.5) [42.1-56.8]	127 (69.0) [61.9-75.5]
11-12 years (n=153)	68 (44.4) [36.5-52.6]	78 (51.0) [42.9-59.0]	108 (70.6) [62.7-77.6]
P-value*	0.018† / 0.523‡	0.187	0.346
Gender			
Male (n=263)	114 (43.3) [37.4-49.4]	139 (52.9) [46.7-59.0]	176 (66.9) [60.9-72.5]
Female (n=239)	114 (47.7) [41.3-54.2]	105 (43.9) [37.6-50.4]	167 (69.9) [63.7-75.6]

P-value*	0.352	0.025	0.285
Severity distribution			
Mild	134 (58.8)	153 (62.7)	181 (52.8)
Moderate	61 (26.8)	69 (28.3)	108 (31.5)
Severe	33 (14.5)	22 (9.0)	54 (15.7)

*Note: *Chi-square test; †P-value for quadratic trend test; ‡P-value for linear trend test*

3.3 Comorbidity Patterns of the Three Diseases

Table 4 presents the comorbidity patterns of the three oral diseases. Only 75 children (14.9%) had no oral diseases, while 119 children (23.7%) had all three diseases simultaneously, a high comorbidity rate rarely reported in domestic and international literature. Among single diseases, malocclusion alone was most common (23.1%), followed by gingivitis alone (4.6%) and dental caries alone (3.8%), a distribution pattern consistent with the overall prevalence rates of the three diseases.

Analysis of two-disease comorbidities showed that gingivitis combined with malocclusion had the highest proportion (11.9%), followed by dental caries combined with malocclusion (9.6%) and dental caries combined with gingivitis (8.4%). Relative risk analysis indicated an incremental relationship between disease number and health risk: RR values for single diseases ranged from 1.18-1.92, RR values for two-disease comorbidities ranged from 2.08-2.31, while the RR value for three-disease comorbidity reached as high as 3.51 (95% CI: 2.84-4.34). This incremental pattern suggests possible mutual facilitation among diseases rather than simple additive effects. Further analysis revealed that children with all three diseases generally had poor oral hygiene habits and unhealthy dietary habits, suggesting that unhealthy lifestyle may be the common foundation for multiple disease comorbidity.

Stratified analysis by age groups revealed distinct comorbidity patterns. In the 6-8 years group, the three-disease comorbidity rate was particularly high (28.5%), primarily driven by the high prevalence of primary tooth caries combined with malocclusion and gingivitis. In the 9-10 years transitional group, the comorbidity rate decreased to 21.2%, reflecting the temporary reduction in caries burden during primary tooth exfoliation. The 11-12 years group showed a rebound to 21.6%, indicating the re-establishment of disease comorbidity patterns in permanent dentition. This age-dependent variation in comorbidity underscores the dynamic nature of oral disease interactions during dentition transition.

Table 4. Comorbidity patterns of dental caries, gingivitis, and malocclusion among school children

Disease Pattern	n (%)	Relative Risk (95% CI)*
No disease	75 (14.9)	Reference
Single disease		
- Caries only	19 (3.8)	1.18 (0.71-1.96)
- Gingivitis only	23 (4.6)	1.35 (0.86-2.12)
- Malocclusion only	116 (23.1)	1.92 (1.49-2.48)
Two diseases		
- Caries + Gingivitis	42 (8.4)	2.08 (1.51-2.87)
- Caries + Malocclusion	48 (9.6)	2.25 (1.66-3.05)
- Gingivitis + Malocclusion	60 (11.9)	2.31 (1.73-3.09)
Three diseases		
- Caries + Gingivitis + Malocclusion	119 (23.7)	3.51 (2.84-4.34)
Age-stratified comorbidity†		
6-8 years (n=165)	47 (28.5)	-
9-10 years (n=184)	39 (21.2)	-
11-12 years (n=153)	33 (21.6)	-

*Note: *Relative risk compared to children with no disease; †Three-disease comorbidity only*

3.4 Correlation Analysis Results

The correlation analysis among the three oral diseases is shown in Figure 2. Spearman correlation analysis revealed a moderate positive correlation between dental caries and gingivitis (r=0.342, P < 0.001), a weak positive correlation between dental caries and malocclusion (r=0.268, P < 0.001), and a weak positive correlation between gingivitis and malocclusion (r=0.231, P < 0.001). The Venn diagram visually illustrates the overlapping distribution of diseases, with the three-disease comorbidity region accounting for the largest proportion (23.7%), suggesting that these three diseases may share common risk factors or have mutually promoting effects.

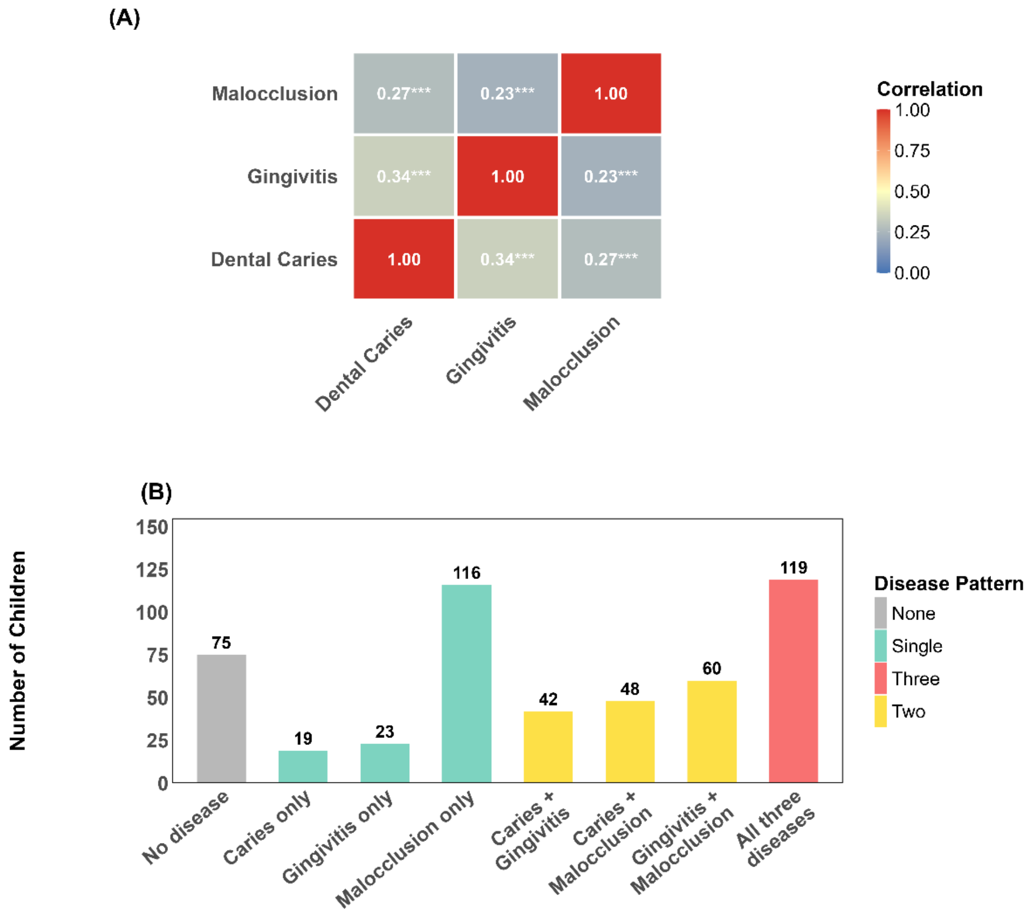

Figure 2. Correlation analysis and comorbidity patterns of oral diseases. (A) Correlation Matrix of Oral Diseases. (B) Distribution of Disease Comorbidity Patterns.

Multivariate Logistic regression analysis identified independent risk factors associated with the three oral diseases, with results shown in Table 5. For dental caries, daily sweet food consumption (OR=2.14, 95% CI: 1.43-3.21), tooth brushing frequency <2 times/day (OR=1.87, 95% CI: 1.26-2.78), and lower family income (OR=1.65, 95% CI: 1.08-2.52) were the main risk factors. Age showed a complex non-linear relationship with caries occurrence; when entered as a quadratic term in the model, it demonstrated statistical significance (P=0.031 for the quadratic term), reflecting the inverted U-shaped pattern observed in prevalence rates across age groups. Risk factors for gingivitis included male gender (OR=1.58, 95% CI: 1.09-2.29), not using dental floss (OR=2.23, 95% CI: 1.31-3.79), and carbonated beverage consumption ≥3 times/week (OR=1.76, 95% CI: 1.15-2.69). Malocclusion was associated with increasing age (OR=1.24, 95% CI: 1.07-1.43) and history of thumb-sucking habits (OR=2.87, 95% CI: 1.68-4.91). All models had Hosmer-Lemeshow test P values >0.05, indicating good model fit.

Table 5. Multivariate logistic regression analysis of risk factors for dental caries, gingivitis, and malocclusion

Variables	β	SE	OR (95% CI)	Wald χ^2	P-value
Dental Caries					
Daily sweet food consumption	0.761	0.207	2.14 (1.43-3.21)	13.52	<0.001
Tooth brushing frequency <2 times/day	0.626	0.203	1.87 (1.26-2.78)	9.51	0.002
Lower family income	0.501	0.218	1.65 (1.08-2.52)	5.28	0.021
Age (linear term, per year)	0.077	0.070	1.08 (0.94-1.24)	1.21	0.142
Age^2 (quadratic term)	-0.117	0.054	0.89 (0.81-0.98)	4.69	0.031
Constant	-1.234	0.456	-	7.31	0.007
Gingivitis					
Not using dental floss	0.802	0.272	2.23 (1.31-3.79)	8.71	0.003
Carbonated beverage consumption ≥3/week	0.565	0.217	1.76 (1.15-2.69)	6.78	0.009
Male gender	0.458	0.190	1.58 (1.09-2.29)	5.81	0.016
Age (per year)	0.058	0.064	1.06 (0.93-1.20)	0.82	0.382
Constant	-1.567	0.389	-	16.23	<0.001
Malocclusion					
History of thumb-sucking habits	1.054	0.274	2.87 (1.68-4.91)	14.81	<0.001
Age (per year)	0.215	0.074	1.24 (1.07-1.43)	8.44	0.004

Lower family income	0.166	0.245	1.18 (0.73-1.91)	0.46	0.498
Constant	-0.892	0.401	-	4.95	0.026

Model fit statistics:

- *Dental Caries: Hosmer-Lemeshow $\chi^2 = 6.34$, $df = 8$, $P = 0.609$; AUC = 0.723*
- *Gingivitis: Hosmer-Lemeshow $\chi^2 = 8.12$, $df = 8$, $P = 0.421$; AUC = 0.687*
- *Malocclusion: Hosmer-Lemeshow $\chi^2 = 5.89$, $df = 8$, $P = 0.660$; AUC = 0.645*

Note: OR, odds ratio; CI, confidence interval; SE, standard error; AUC, area under the receiver operating characteristic curve. For dental caries, age was entered both as a linear term and a quadratic term to account for the observed non-linear (inverted U-shaped) relationship with prevalence across age groups.

The forest plot of major risk factors is shown in Figure 3, visually demonstrating the strength of association between various factors and the three oral diseases. Among all risk factors, thumb-sucking habits had the greatest impact on malocclusion (OR=2.87), followed by not using dental floss on gingivitis (OR=2.23) and daily sweet food consumption on dental caries (OR=2.14). These findings provide important evidence for developing targeted prevention strategies.

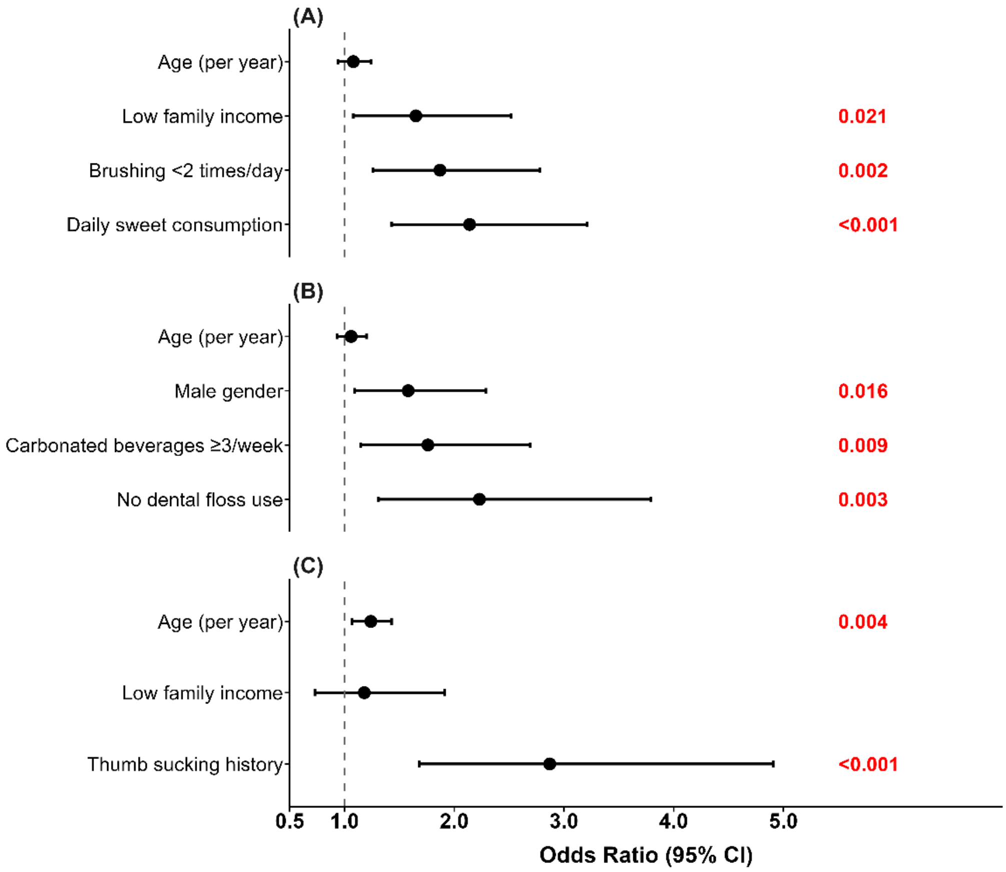

Figure 3. Forest plot of adjusted odds ratios for risk factors associated with oral diseases. (A) Forest Plot of Risk Factors for Dental Caries. (B) Forest Plot of Risk Factors for Gingivitis. (C) Forest Plot of Risk Factors for Malocclusion.

DISCUSSION

This study systematically evaluated the prevalence and interrelationships of dental caries, gingivitis, and malocclusion through a cross-sectional survey of 502 school-age children. The study found prevalence rates of 45.4%, 48.6%, and 68.3% for the three oral diseases respectively, with significant correlations among them. These findings provide new evidence for understanding complex interactions among pediatric oral diseases.

The study revealed distinct age and gender patterns in oral disease prevalence. Dental caries exhibited an inverted U-shaped pattern: 52.7% (6-8 years), 39.7% (9-10 years), and 44.4% (11-12 years), reflecting dentition transition rather than simple disease accumulation.

The elevated early prevalence (6-8 years, 52.7%) is primarily attributable to primary tooth caries, which are more susceptible due to thinner enamel, larger pulp chambers, and higher mineral porosity, combined with less developed oral hygiene skills and higher consumption frequencies of cariogenic foods. The mid-age decline (9-10 years, 39.7%) results from physiological exfoliation of carious primary teeth during mixed dentition. However, this decline does not indicate true oral health improvement but merely reflects dentition replacement, underscoring the need to distinguish apparent from actual improvements when interpreting age-related caries trends. The subsequent increase (11-12 years, 44.4%) is concerning, demonstrating early caries accumulation in newly erupted permanent teeth during their vulnerable post-eruptive maturation phase when enamel is incompletely mineralized [21]. This pattern aligns with the "window of infectivity" concept [27], suggesting critical periods when the oral environment is particularly conducive to cariogenic bacteria establishment. The relatively high prevalence suggests inadequate preventive measures implementation, including insufficient fluoride exposure, lack of pit and fissure sealants, and suboptimal oral hygiene practices, supporting intensified preventive efforts when permanent molars are newly erupted and most vulnerable.

Girls had higher caries prevalence than boys (47.7% vs 43.3%), though the difference was not statistically significant (P=0.352), potentially related to earlier tooth eruption, hormonal changes, and dietary preferences. Boys had higher gingivitis prevalence (52.9% vs 43.9%), reflecting gender differences in oral hygiene behaviors. The malocclusion prevalence in this study (68.3%) was similar to results from De Ridder et al.'s systematic review, which showed malocclusion prevalence in healthy children and adolescents globally ranged from 56%-73% [28]. However, the caries prevalence in this study was slightly lower than Balachandran and Janakiram's meta-analysis results for 8-15 year-old Indian children (47.6%), a difference possibly related to regional variations in dietary habits, oral healthcare levels, and socioeconomic factors [29]. The relatively lower caries prevalence (45.4%) observed in our study compared to some previous reports may reflect recent improvements in oral health prevention programs in Guangzhou, including school-based fluoride mouth rinse programs implemented since 2020, increased accessibility to dental services in urban areas, and enhanced oral health awareness among urban families through community health education initiatives. Additionally, the higher socioeconomic status of families in urban Guangzhou compared to rural areas may contribute to better access to preventive dental care and healthier dietary choices.

Particularly noteworthy is that 23.7% of children had all three diseases simultaneously, a high comorbidity rate rarely reported in previous studies. Compared to single diseases, children with all three diseases had a relative risk ratio as high as 3.51, suggesting possible synergistic effects among the diseases. This high comorbidity not only increases treatment complexity but may also have cumulative negative impacts on children's growth and development, nutritional status, and psychological health. Only 14.9% of children were completely free of oral diseases, a proportion far below ideal conditions, reflecting the severe challenges currently facing pediatric oral health promotion efforts.

Age-stratified analysis of comorbidity patterns revealed distinct trends. The three-disease comorbidity rate was highest in the 6-8 years group (28.5%), driven primarily by the high prevalence of primary tooth caries combined with malocclusion and gingivitis. The rate decreased to 21.2% in the 9-10 years transitional group, reflecting the temporary reduction in caries burden during primary tooth exfoliation. The 11-12 years group showed a rebound to 21.6%, indicating the re-establishment of disease comorbidity patterns in permanent dentition. This age-dependent variation underscores the dynamic nature of oral disease interactions during dentition transition and emphasizes the need for age-specific integrated prevention strategies.

The moderate positive correlation between dental caries and gingivitis (r=0.342) reflects a common pathophysiological basis. Dental caries is closely related to oral microecological imbalance [30], and local inflammatory responses may alter gingival crevicular fluid composition, creating favorable conditions for periodontal pathogen colonization. Oral microbiome changes following caries treatment may simultaneously improve gingival health [31].

This study found daily sweet consumption to be a major risk factor for dental caries (OR=2.14), while frequent carbonated beverage intake was associated with gingivitis (OR=1.76). This difference suggests that although the two diseases share common microbiological foundations, their triggering factors may differ. The acidity of carbonated beverages not only directly erodes teeth but their chemical irritation of gingival tissues may be an independent factor causing gingivitis. Saliva, as an important regulatory factor in the oral environment, may simultaneously affect both diseases through changes in its flow rate, buffering capacity, and antimicrobial components. Tian et al.'s research showed that comprehensive caries treatment can alter supragingival microbiome composition in the short term, providing microbiological evidence for the interaction between these two diseases [32].

Notably, age demonstrated a significant non-linear (quadratic) relationship with caries occurrence (P=0.031 for quadratic term), confirming the inverted U-shaped prevalence pattern observed in our descriptive analysis. This finding has important methodological implications, suggesting that future epidemiological studies should consider non-linear age effects when examining caries in populations undergoing dentition transition, as different stages of dental development present distinct risk profiles [21].

The mechanisms linking malocclusion with dental caries and gingivitis are more complex. This study found weak positive correlations between malocclusion and both dental caries (r=0.268) and gingivitis (r=0.231), consistent with Singh and Purohit's systematic review results, which found associations between malocclusion and dental caries in permanent dentition children and adolescents, though association strength varied by malocclusion type [33]. Lucchese et al.'s systematic review indicated that removable orthodontic appliances alter oral microbial community structure, potentially increasing risks for dental caries and gingivitis [34]. In this study, thumb-sucking was the strongest risk factor for malocclusion (OR=2.87), emphasizing the importance of early intervention for harmful oral habits. Anterior crowding (31.5%) and deep overbite (24.2%) were the most common malocclusion manifestations in this study; these characteristics may increase risks for other oral diseases by affecting oral hygiene effectiveness. Koizumi et al.'s research found that craniofacial morphology can serve as a predictor of caries risk in orthodontic patients, with specific craniofacial structures potentially increasing caries susceptibility by affecting saliva flow and self-cleaning action [35].

The age-specific patterns have important implications for preventive strategy design. For the 6-8 years group with high primary tooth caries (52.7%), interventions should prioritize primary tooth preservation through topical fluoride applications, atraumatic restorative treatment, and intensive parental education[36]. During the 9-10 years transitional period, despite apparent prevalence decline (39.7%), timely pit and fissure sealant application on newly erupting permanent molars remains critical, as sealants can prevent approximately 80% of cavities in sealed teeth [21]. For the 11-12 years group showing caries re-elevation (44.4%), comprehensive approaches including sealants for remaining unsealed teeth, fluoride supplementation, dietary counseling, and age-appropriate oral hygiene instruction are needed [21, 37].

From a public health perspective, only 23.3% of children underwent regular oral examinations, far below developed country levels. Systematic reviews demonstrate that school-based oral health programs, particularly peer-led interventions and culturally-adapted education, can effectively improve children's oral health in resource-limited settings [38, 39]. Comprehensive interventions addressing multiple diseases simultaneously have proven more effective than single-disease approaches [15, 40], supporting integrated prevention strategies combining oral health education, regular screening, fluoride application, and dietary guidance.

Regarding preventive measures, this study found inadequate brushing frequency as a risk factor for dental caries, while not using dental floss was associated with gingivitis. Clark et al.'s research on fluoride application in primary care provides evidence-based support for caries prevention [36]. Alqalaleef et al.'s systematic review on silver diamine fluoride as a caries preventive and arrest agent emphasizes the importance of combining mechanical plaque control with chemical prevention [41]. Munteanu et al.'s review on professionally applied fluorides for preventing dental caries in children and adolescents further supports strategies combining multiple preventive measures [37]. Based on this evidence, implementing comprehensive intervention programs at the school level is recommended, including oral health education, regular screening, fluoride application, and dietary guidance.

This study has several notable strengths. The use of standardized clinical assessment methods and strict quality control measures ensured data reliability, with inter-examiner Kappa values reaching above 0.80. Simultaneous assessment of three oral diseases and their interrelationships provides valuable information for understanding overall oral disease patterns. Our identification of non-linear age-related patterns in caries prevalence provides new insights into the natural history of dental caries during dentition transition. Adequate sample size with reasonable representativeness gives the results good generalizability.

This study has limitations. The cross-sectional design cannot determine causal relationships; observed correlations may be influenced by unmeasured confounding factors. The study was conducted only in urban areas, limiting generalizability to rural populations. Self-reported oral hygiene and dietary habits are subject to recall and social desirability bias. Additionally, oral health-related quality of life was not assessed, preventing comprehensive evaluation of disease impact on children's wellbeing.

Future research should employ longitudinal cohort designs to clarify causal relationships and natural history among the three oral diseases, particularly following children through the mixed dentition period (ages 6-12) to confirm the dynamic patterns of caries prevalence we observed and identify critical periods for preventive intervention. Multi-center studies are needed to improve sample representativeness, particularly including rural children and those from different socioeconomic backgrounds. For assessment methods, considering objective biomarkers (such as salivary microbiome analysis) could more accurately evaluate disease risk. Developing and validating oral health risk prediction models for Chinese children will help identify high-risk populations and implement precision prevention. Designing and evaluating school-based comprehensive oral health intervention programs with cost-effectiveness analysis will provide important evidence for policy-making. Given the non-linear age-disease relationships we identified, future epidemiological studies should routinely consider non-linear analytical approaches when examining age effects in populations undergoing dentition transition. This methodological consideration may improve the accuracy of prevalence estimates and risk predictions.

CONCLUSION

This cross-sectional study of 502 school-aged children revealed high prevalence and significant interrelationships among dental caries, gingivitis, and malocclusion. Notably, caries exhibited an inverted U-shaped age pattern (52.7% at 6-8 years, 39.7% at 9-10 years, 44.4% at 11-12 years), reflecting primary-to-permanent dentition transition. Moderate caries-gingivitis correlation (r=0.342) and weak correlations with malocclusion were confirmed. Major risk factors included daily sweet consumption, inadequate oral hygiene, and harmful oral habits. Age demonstrated significant quadratic relationship with caries (P=0.031), confirming non-linear patterns during dentition transition. These findings emphasize implementing comprehensive, age-specific prevention strategies: primary tooth preservation (6-8 years), timely sealants (9-10 years), and comprehensive permanent tooth protection (11-12 years). School-based programs integrating oral health education, regular screening, and individualized interventions for high-risk children are recommended. Future longitudinal studies should clarify causal relationships and evaluate long-term intervention effectiveness.

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