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ORIGINAL ARTICLE

First Permanent Molars as Indicators of Paediatric Oral Health: A Cross-Sectional Study of Visible Occlusal Plaque, Caries Experience and Treatment Need

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ABSTRACT

Introduction: First permanent molars (FPMs) are highly susceptible to plaque accumulation and dental caries due to their early eruption and complex occlusal morphology. This study aimed to investigate the associations between visible occlusal plaque, dental caries status, treatment needs, oral hygiene and age in schoolchildren.

Methods: This cross-sectional study included 329 children aged 5–12 years from a public school. Intraoral examinations assessed dental caries experience using the Decayed, Missing and Filled Teeth (DMFT) and decayed and filled teeth (dft) indices, oral hygiene using the Simplified Oral Hygiene Index (OHI-S), including the Debris Index-Simplified (DI-S) and Calculus Index-Simplified (CI-S), plaque accumulation using the Visible Occlusal Plaque Index (VOPI) and treatment needs using the Treatment Need Index (TNI). Multinomial logistic regression and Kendall's tau correlation analyses were performed to evaluate associations among the study variables.

Results: The mean age of the participants was 7.47 ± 1.56 years. The mean dft and DMFT scores were 5.29 ± 3.37 and 1.17 ± 1.49, respectively. The prevalence of untreated visible cavitated carious lesions was higher in mandibular FPMs (41.8% in left FPMs and 40.7% in right FPMs) than in maxillary FPMs (32.0% in left FPMs and 29.5% in right FPMs). Higher OHI-S scores were consistently associated with higher VOPI categories across all FPMs, particularly for VOPI 2 and VOPI 3 categories (OR range: 9.75–33.52; all $p < 0.001$). Higher DMFT scores were also significantly associated with higher VOPI categories in multiple regression models ($p = 0.018$ to $p < 0.001$). Significant positive correlations were observed between VOPI, OHI-S and TNI scores (all $p < 0.001$). Regression models demonstrated moderate explanatory performance, with Nagelkerke R^2 values ranging from 40.7% to 47.8%.

Conclusion: Visible occlusal plaque in FPMs was associated with poorer oral hygiene, higher caries experience and increased treatment needs in schoolchildren. These findings highlight the importance of preventive strategies and effective plaque control measures for improving paediatric oral health outcomes.

1 | Introduction

Despite considerable advances in dental care and preventive strategies, dental caries remains one of the most prevalent chronic diseases worldwide, particularly among children, substantially affecting their general health and quality of life. This condition is associated with pain, infection and difficulties in essential daily activities such as eating, speaking and

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learning [1–3]. The World Health Organization (WHO) recognises dental caries as the most common disease globally, affecting 60%–90% of school-aged children in developed countries [4, 5].

Globally, approximately 2 billion individuals are affected by dental caries in permanent teeth, highlighting the substantial public health burden of this condition [5]. First permanent molars (FPMs) are particularly susceptible to dental caries because of their early eruption at around 6 years of age and their essential role in the dental arch [6, 7]. During the eruption phase, immature enamel increases susceptibility to demineralisation and plaque retention [8]. This vulnerability is further exacerbated by children's limited ability to maintain effective oral hygiene, often resulting in inadequate plaque removal and increased caries prevalence [9, 10]. Untreated caries in FPMs may lead to severe complications, including extractions, endodontic treatment, apical pathology and disturbances affecting adjacent teeth. Therefore, preserving FPMs is critical not only for maintaining mastication and occlusion but also for supporting long-term oral health outcomes in children [11].

Occlusal plaque plays a major role in the initiation and progression of dental caries, particularly in permanent molars, which are inherently more vulnerable because of their complex occlusal morphology and posterior location [12]. Plaque accumulation on these surfaces is strongly associated with inadequate oral hygiene and increased caries risk, often resulting in the need for preventive or restorative interventions [13]. Previous studies have demonstrated that visible occlusal plaque is associated with increased occlusal caries activity and may serve as a clinically relevant indicator of oral hygiene status and caries susceptibility [12, 14–16]. However, although the Visible Occlusal Plaque Index (VOPI) has previously been investigated primarily in relation to occlusal caries activity, limited information is available regarding its relationship with broader clinical parameters, including oral hygiene status, treatment needs and tooth-specific distribution patterns in schoolchildren. In addition, comprehensive evaluations integrating VOPI, oral hygiene indices, caries experience and treatment need assessments within the same paediatric population remain scarce.

Therefore, this study aimed to investigate the relationships between visible occlusal plaque, dental caries status and treatment needs in FPMs, as well as the associations among oral hygiene status, caries experience and age in schoolchildren aged 5–12 years. By focusing on FPMs, this study sought to provide a more comprehensive understanding of plaque-related oral health patterns in children and to contribute to the development of targeted preventive strategies in paediatric dentistry. The null hypothesis was that there would be no statistically significant differences in visible occlusal plaque scores among FPMs according to caries experience, treatment needs, tooth location (maxilla or mandible), right–left distribution, oral hygiene status and age.

2 | Study Population and Methodology

2.1 | Ethical Approval and Consent

This study was conducted in accordance with the principles outlined in the Helsinki Declaration and following the guidelines of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement. Ethical approval for the study was obtained from the Clinical Research Ethics Committee of the School of Dentistry, Marmara University, on 23.02.2023, with protocol number 2023-131. All necessary permissions regarding the study were obtained from the relevant institutions and official authorities prior to data collection. Given that the study population consisted of children, who are considered a vulnerable population in clinical research, particular attention was paid to ethical considerations throughout the study process. The study procedures were explained to the participating children in an age-appropriate language by the researchers and assent was obtained from children who agreed to participate. In addition, written informed consent was obtained from the parents or legal guardians of all participating children before enrolment in the study. The study was not preregistered and no publicly accessible study protocol was available prior to data collection.

2.2 | Study Population

This cross-sectional study was conducted at a public school in İstanbul, Türkiye, including both kindergarten and primary school students. A school-based convenience sampling approach was used because access to participants was limited to the selected school during the study period, allowing the recruitment of eligible children within the available educational setting. A total of 372 children aged 5–12 years from kindergarten and 1st, 2nd, 3rd and 4th grades were invited to participate in the study. All children within the eligible age range attending these educational levels during the study period were considered for participation.

2.3 | Sample Size Calculation

A priori sample size calculation was performed based on a previous study evaluating the association between the VOPI and occlusal caries lesion activity [16]. In that study, thick/heavy occlusal plaque accumulation (VOPI scores 2–3) was significantly associated with active non-cavitated occlusal lesions, with an odds ratio (OR) of 2.3. Based on this reference effect size, the expected proportions were estimated as 11.9% for the lower plaque group and 23.7% for the higher plaque group, corresponding to an effect size of Cohen's $h = 0.31$. Using a two-sided alpha level of 0.05 and 80% statistical power, the minimum required sample size was calculated as 322 participants.

2.4 | Data Collection

The data collection schedule was established in January 2024. Following this planning phase, an examiner training and calibration procedure was conducted before the main data collection. Two paediatric dentists were trained using the diagnostic criteria and scoring systems applied in the study, including Decayed, Missing and Filled Teeth (DMFT) and decayed and filled teeth (dft) indices, Simplified Oral Hygiene Index (OHI-S), VOPI and Treatment Need Index (TNI). Calibration was performed on 20 randomly selected children who were not included in the final study sample. During the calibration

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session, both examiners independently assessed the same children under the same examination conditions. The examiners recorded their findings independently and were blinded to each other's scores during the calibration process. To evaluate intra-examiner reliability, the same 20 children were re-examined 1 month later using the same clinical criteria. During the reassessment phase, the examiners were blinded to their previous recordings. Inter-examiner reliability was assessed by comparing the scores recorded by the two examiners, whereas intra-examiner reliability was assessed by comparing the first and second examinations for each examiner. Intraclass correlation coefficients (ICCs) were calculated for continuous or score-based indices, including DMFT/dft and OHI-S, while weighted kappa statistics were used for ordinal indices, including VOPI and TNI. Before the calibration process, ICC values ≥ 0.75 and weighted kappa values ≥ 0.80 were predefined as indicating acceptable agreement. Calibration was considered satisfactory only when these predetermined thresholds were achieved. Actual data collection was subsequently conducted between February and March 2024 by the calibrated paediatric dentists through intraoral examinations.

2.5 | Inclusion Criteria

Children were considered eligible for participation if they met the following criteria: (1) provision of written informed consent by parents or legal guardians and assent from the participating child; (2) adequate cooperation to permit intraoral examination procedures; (3) presence of at least one fully erupted FPM; (4) absence of erupted permanent second molars; and (5) absence of systemic diseases or medical conditions requiring long-term medication use.

2.6 | Exclusion Criteria

Children were excluded if they did not meet the eligibility criteria or if clinical examination could not be completed reliably. Specifically, exclusion criteria included: (1) refusal to participate or absence of parental/legal guardian consent and child assent; (2) inadequate cooperation during intraoral examinations; (3) absence of fully erupted FPMs; (4) presence of erupted permanent second molars; and (5) presence of systemic diseases or medical conditions requiring long-term medication use.

The exclusion of children with erupted permanent second molars was applied to obtain a more developmentally homogeneous study population and to minimise potential variability related to differences in posterior dentition development, eruption stage and occlusal conditions that could influence plaque accumulation and caries patterns in FPMs.

2.7 | Assessment of Dental Caries Status

Clinical examinations were conducted in the classroom setting under natural lighting conditions, with the child seated on a stool and the examiner positioned behind the participant on a chair. To enhance examination consistency, all assessments were performed by the calibrated examiners in the same school environment during regular school hours, between 10:00 a.m. and 2:00 p.m., under comparable field conditions. Oral examinations were performed using a flat-surface mouth mirror (#5) and natural light for visual inspection. A standard dental probe (#PCP11) was used to support clinical examination when necessary, while a periodontal probe (#PCPUNC15) with millimetre markings was used for oral hygiene assessments.

Dental caries experience was evaluated using the DMFT/dft indices. Caries assessment was based solely on clinically visible cavitated lesions detected during intraoral examination and non-cavitated enamel lesions were not included in the D/d component of the indices. Radiographic examinations were not performed. Within the DMFT/dft indices, the decayed component (D/d) included teeth with untreated visible cavitated carious lesions. The missing component (M/m) included teeth extracted due to dental caries, whereas the filled component (F/f) included teeth restored because of previous caries experience. Caries experience prevalence was defined as a DMFT/dft score greater than zero. In addition, the prevalence of untreated decayed teeth ($D/d > 0$), missing teeth due to caries ($M/m > 0$) and filled teeth ($F/f > 0$) was also determined separately using the same approach [17].

2.8 | Assessment of Oral Hygiene and Visible Occlusal Plaque

Children's oral hygiene status was assessed using the OHI-S, which is calculated by combining the simplified debris index (DI-S) and the simplified calculus index (CI-S). To determine the OHI-S score, six tooth surfaces were examined, selected from four posterior teeth and two anterior teeth (for primary dentition: buccal surfaces of teeth #54, #61 and #64 and lingual surfaces of teeth #82, #75 and #85; for permanent dentition: buccal surfaces of teeth #11, #16, #26 and #31 and lingual surfaces of teeth #36 and #46). For the DI-S, Score 0 indicated 'no debris or stain present'; Score 1 indicated 'soft debris covering not more than one-third of the tooth surface, or the presence of extrinsic stains without other debris regardless of the surface area covered'; Score 2 indicated 'soft debris covering more than one-third but no more than two-thirds of the exposed tooth surface'; and Score 3 indicated 'soft debris covering more than two-thirds of the exposed tooth surface.' For the CI-S, Score 0 indicated 'no calculus present'; Score 1 indicated 'supragingival calculus covering not more than one-third of the exposed tooth surface'; Score 2 indicated 'supragingival calculus covering more than one-third but not more than two-thirds of the exposed tooth surface or the presence of individual flecks of subgingival calculus around the cervical portion of the tooth'; and Score 3 indicated 'supragingival calculus covering more than two-thirds of the exposed tooth surface or a continuous heavy band of subgingival calculus around the cervical portion of the tooth'. The cumulative debris and calculus scores recorded from the buccal and lingual/palatal surfaces of the selected teeth were averaged by dividing the total score by the number of examined surfaces, resulting in the DI-S and CI-S scores for each participant. The OHI-S score was subsequently calculated as the sum of the DI-S and CI-S scores. Lower OHI-S scores indicated better

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oral hygiene status. According to standard classification criteria, OHI-S scores were categorised as good (0–1.2), moderate (1.3–3.0) and poor (3.1–6.0) [18].

The occlusal surfaces of fully erupted FPMs were examined for visible plaque accumulation using the VOPI. This index was used to identify and categorise plaque accumulation on occlusal surfaces. The VOPI criteria were defined as follows: Score 0 indicated 'no visible plaque identified when carefully running a dental probe on the groove-fossa system'; Score 1 indicated 'thin plaque: hardly detectable plaque restricted to the groove-fossa system and identified by carefully running a dental probe on the groove-fossa system'; Score 2 indicated 'thick plaque: easily detectable plaque on the groove-fossa system identifiable with the naked eye'; and Score 3 indicated 'heavy plaque: occlusal surfaces partially or totally covered with heavy plaque accumulation identifiable with the naked eye'. The VOPI provides a clinically relevant assessment of plaque control and plaque accumulation patterns associated with caries risk [12, 16]. This index was applied during the intraoral examination as part of the comprehensive assessment of the children's oral health status [19].

2.9 | Assessment of Treatment Needs

Dental treatment needs were assessed using the TNI, which categorises treatment requirements according to the urgency and type of dental treatment needed, regardless of the underlying condition, such as dental caries, trauma, or periodontal disease. The TNI provides useful information for oral health assessment and treatment planning. The index was originally developed and applied in paediatric populations by Mann et al. [20], supporting its applicability in paediatric oral health research. The index includes seven treatment categories. Code 0 indicates 'no treatment needed'; Code 1 indicates 'preventive treatment (topical fluoride applications, etc.) needed'; Code 2 indicates 'fissure sealants needed'; Code 3 indicates 'initial conservative restorations (one-surface restorations, preventive resin restorations, etc.) needed'; Code 4 indicates 'moderate conservative restorations (one- or two-surface restorations, etc.) needed'; Code 5 indicates 'advanced conservative restorations (three- or more-surface restorations, stainless steel crowns, etc.) needed'; and code 6 indicates 'radical treatment (endodontic, prosthetic, and/or surgical procedures, etc.) needed.' For each participant, the number and percentage of teeth within each treatment category were recorded [20].

2.10 | Outcome Measures

The primary outcome of the present study was the VOPI score of FPMs. VOPI was selected as the primary outcome because the main objective of the study was to investigate the relationship between visible occlusal plaque accumulation and oral health–related parameters in FPMs.

Secondary outcomes included oral hygiene status assessed using the OHI-S, caries experience assessed using the DMFT/dft indices, and treatment needs assessed using the TNI. In addition, the associations between VOPI scores and age, oral hygiene status, caries experience, treatment needs and FPM-specific clinical characteristics were evaluated as secondary outcomes.

2.11 | Statistical Analysis

Descriptive statistics, including counts, percentages, mean, standard deviation, median, minimum and maximum values, were calculated. Normality of data distribution was assessed using the Shapiro–Wilk test, and homogeneity of variances was evaluated using the Levene test. For comparisons between two independent groups, the independent samples *t*-test was used when parametric assumptions were satisfied; otherwise, the Mann–Whitney *U* test was applied. The Kruskal–Wallis test was used for comparisons among three or more independent groups that did not demonstrate normal distribution. When significant differences were identified, Bonferroni-adjusted post hoc analyses were performed to determine the source of the differences between groups. The Pearson chi-square test was used to evaluate associations between categorical variables when the expected cell count assumption was satisfied (expected value > 5), whereas Fisher's exact test was applied when this assumption was not met. Multinomial logistic regression analysis was performed to model the relationships between categorical dependent variables and independent variables. Separate regression models were constructed for each FPM; therefore, each participant contributed only one observation to each model. The selection of variables for the regression models was based on clinical relevance and statistical considerations. OHI-S, DMFT and age were included as explanatory variables. Multicollinearity among the explanatory variables was assessed using variance inflation factor (VIF) values, and no evidence of problematic multicollinearity was identified (all VIF values < 5). No missing data were identified for the analysed variables; therefore, no imputation procedures were required. ORs with 95% confidence intervals (95% CIs) were reported for regression analyses, and model explanatory performance was evaluated using Nagelkerke R^2 values. Kendall's tau correlation analysis was used to examine associations between ordinal and continuous variables. A *p*-value of < 0.05 was considered statistically significant. All statistical analyses were performed using IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA).

3 | Results

The examiner calibration procedure demonstrated high intra-examiner reliability for the quantitative clinical indices, with ICC values ranging from 0.897 to 0.924. Inter-examiner reliability was also excellent, with ICC values ranging from 0.978 to 0.988. For the ordinal indices, weighted kappa analyses demonstrated strong to excellent agreement for both VOPI and TNI assessments. The intra-examiner weighted kappa values ranged from 0.842 to 0.891, whereas the inter-examiner weighted kappa values ranged from 0.903 to 0.947. These findings indicated that the clinical examination procedures and scoring systems used in the study showed high reproducibility and consistency prior to the main data collection phase.

Participant recruitment and inclusion are summarised in Figure 1. Of the 372 children initially assessed for eligibility,

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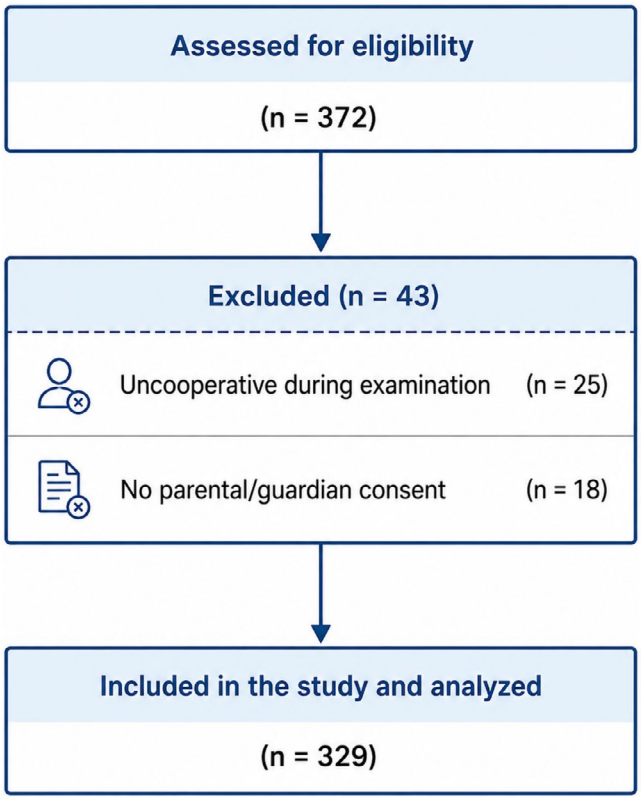


FIGURE 1 | Participant flow diagram showing eligibility assessment, exclusions, and final inclusion in the study (*n*, number).

329 met the inclusion criteria, resulting in a participation rate of 88.4%. Among the 43 excluded children, 25 were uncooperative during the examination, and 18 lacked parental or guardian consent. The gender distribution was nearly balanced, with 152 boys and 177 girls, and the mean age of the participants was 7.47 ± 1.56 years (range: 5–12 years). The prevalence of untreated visible cavitated carious lesions in the study population was 93.3%, based on the presence of at least one clinically visible untreated cavitated lesion detected during oral examination.

This study analysed a total of 1118 FPMs, including 280 mandibular right FPMs, 282 mandibular left FPMs, 278 maxillary right FPMs, and 278 maxillary left FPMs. Among the mandibular FPMs, untreated visible cavitated carious lesions were identified in 114 (40.7%) mandibular right FPMs and 118 (41.8%) mandibular left FPMs, while fillings were present in 13 (4.6%) and 14 (5.0%) teeth, respectively. In the maxillary arch, untreated visible cavitated carious lesions were detected in 82 (29.5%) maxillary right FPMs and 89 (32.0%) maxillary left FPMs, whereas fillings were observed in 11 (4.0%) and 8 (2.9%) teeth, respectively.

The distribution of VOPI scores among FPMs demonstrated that Score 1 (thin plaque) was the most common category, observed in 38.5% of maxillary right FPMs, 39.6% of maxillary left FPMs, 42.6% of mandibular left FPMs and 41.4% of mandibular right FPMs. Score 2 (thick plaque) was identified in 27.3% of maxillary right FPMs, 27.0% of maxillary left FPMs, 27.3% of mandibular left FPMs and 27.1% of mandibular right FPMs. Score 0 (no visible plaque) was observed in 26.3% of maxillary right FPMs, 24.8% of maxillary left FPMs, 22.3% of mandibular left FPMs and 23.6% of mandibular right FPMs. Score 3 (heavy plaque accumulation) was the least prevalent category, detected in 7.9% of maxillary right FPMs, 8.6% of maxillary left FPMs, 7.8% of mandibular left FPMs and 7.9% of mandibular right FPMs. Fisher's exact test demonstrated no statistically significant association between VOPI scores and the presence of untreated visible cavitated carious lesions or fillings in FPMs ($p > 0.05$).

The mean OHI-S score among the participants was 1.18 ± 0.71, with 66.6% classified as having good oral hygiene, 33.1% as moderate and only 0.3% as poor. Table 1 summarises the distribution of OHI-S scores according to gender and age groups. A statistically significant difference in OHI-S scores was identified among the age groups ($p < 0.05$), whereas no significant difference was observed between genders ($p > 0.05$). Statistical analyses using the Mann–Whitney *U* and Kruskal–Wallis tests demonstrated significant differences among age groups, and Bonferroni-adjusted post hoc analyses revealed significantly higher OHI-S scores in the 11–12 age group compared with the 5–6, 7–8 and 9–10 age groups ($p < 0.001$, $p < 0.001$ and $p = 0.002$, respectively). Furthermore, Fisher's exact test demonstrated a significant association between age group and categorical OHI-S classification ($p < 0.05$). Most participants in the 7–8 age group were classified as having good oral hygiene, whereas participants in the 11–12 age group were predominantly classified as having moderate oral hygiene.

Statistically significant associations were found between VOPI scores and categorical OHI-S scores for maxillary right FPMs, maxillary left FPMs, mandibular left FPMs and mandibular right FPMs ($p < 0.05$). Higher VOPI scores were generally associated with poorer oral hygiene status (Table 2).

The TNI scores demonstrated that most cases for all FPMs were categorised as Score 2, indicating preventive or minor restorative treatment needs: maxillary right FPMs (67.5%), maxillary left FPMs (64.3%), mandibular right FPMs (52.4%) and mandibular left FPMs (51.1%). TNI Score 3 accounted for 25.4% to 32.8% of cases across the evaluated teeth. Higher-complexity treatment needs (combined Scores 4, 5 and 6) were relatively uncommon, comprising 7.1% for maxillary right FPMs, 8.6% for maxillary left FPMs, 17.2% for mandibular left FPMs and 14.7% for mandibular right FPMs.

Statistically significant associations were also identified between VOPI and TNI scores across all tooth groups ($p < 0.05$). Higher VOPI scores were associated with higher TNI scores (Table 3).

Kendall's tau correlation analysis was performed to examine the relationships between OHI-S scores and VOPI and TNI scores. Statistically significant, positive and moderate correlations were identified between OHI-S scores and VOPI scores for maxillary right FPMs, maxillary left FPMs, mandibular left FPMs and mandibular right FPMs ($p < 0.05$; correlation coefficients: 0.520, 0.513, 0.451 and 0.476, respectively). In addition, statistically significant positive but weak correlations were observed between OHI-S scores and TNI scores for maxillary right FPMs, maxillary left FPMs, mandibular left FPMs and mandibular right FPMs ($p < 0.05$; correlation coefficients: 0.189, 0.213, 0.229 and 0.230, respectively) (Table 4).

Multinomial logistic regression analysis was performed to examine the associations of OHI-S, DMFT and age with the VOPI

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TABLE 1 | Distribution and statistical comparison of OHI-S scores by gender and age groups.

		OHI-S scores (numerised)				OHI-S scores (categorised)					
		Min.–Max.	Mean ± SD (median)	Test statistic	*p*	Good	Moderate	Poor	Test statistic	*p*
						N (%)	*N* (%)	*N* (%)		
Age	Ages 5–6	0–2.16	0.93 ± 0.76 (1)	24.194	<0.001[a,b]	29 (76.3)	9 (23.7)	0	22.046	<0.001[a,d]
	Ages 7–8	0–2.6	1.05 ± 0.62 (1)			84 (74.3)	29 (25.7)	0		
	Ages 9–10	0–3	1.23 ± 0.69 (1)			97 (64.2)	54 (35.8)	0		
	Ages 11–12	0–4	1.80 ± 0.81 (2)			9 (33.3)	17 (63.0)	1 (3.7)		
Gender	Boys	0–4	1.18 ± 0.76 (1)	−0.409	0.682[c]	101 (66.4)	50 (32.9)	1 (0.7)	1.108	0.800[d]
	Girls	0–3	1.18 ± 0.67 (1)			118 (66.7)	59 (33.3)	0		
Total		0–4	1.18 ± 0.71 (1)			219 (66.6)	109 (33.1)	1 (0.3)		

Abbreviations: Max, maximum; Min, minimum; *N*, number; OHI-S, simplified oral hygiene index; SD, standard deviation.

[a]$p < 0.05$ is considered statistically significant.

[b]Kruskal–Wallis test.

[c]Mann–Whitney *U* test.

[d]Fisher's Exact tests.

scores of maxillary right FPMs, maxillary left FPMs, mandibular left FPMs and mandibular right FPMs, using score '0' as the reference category. Significant associations of OHI-S, DMFT and age with VOPI scores were identified for maxillary right FPMs, maxillary left FPMs and mandibular left FPMs, whereas only OHI-S and DMFT were significantly associated with VOPI scores in mandibular right FPMs. The Nagelkerke R^2 values ranged from 40.7% to 47.8%, while classification accuracies ranged between 57.1% and 57.9%, indicating moderate explanatory capacity and modest classification performance of the models (Table 5).

4 | Discussion

First permanent molars serve as key indicators of oral health due to their early eruption, complex morphology and essential roles in occlusion and mastication [21]. Their complex occlusal anatomy, characterised by deep pits and fissures, makes them particularly prone to plaque accumulation and caries development [22, 23]. Since FPMs erupt earlier than other permanent teeth, they are exposed to cariogenic challenges for longer periods, especially during the eruption phase when immature enamel is more susceptible to demineralisation [24, 25]. A substantial proportion of dental caries in children occurs on occlusal surfaces, with FPMs representing some of the most vulnerable teeth during the mixed dentition period [14, 26]. These characteristics emphasise the importance of preventive strategies specifically targeting FPMs during childhood.

The primary objective of this study was to investigate the associations among visible occlusal plaque, oral hygiene status, caries experience, treatment needs and age in school-aged children. The findings demonstrated significant associations between VOPI scores and oral hygiene status, caries experience, treatment needs and age. However, despite the established role of plaque accumulation in caries aetiology, no statistically significant association was identified between VOPI scores and the presence of untreated visible cavitated carious lesions or fillings in FPMs. This finding should be interpreted cautiously and may reflect the multifactorial and cumulative nature of dental caries. While VOPI represents a site-specific assessment of current occlusal plaque accumulation, the presence of cavitated lesions and fillings may reflect previous disease experience and long-term oral health behaviours rather than plaque accumulation at a single examination time point. In addition, the cross-sectional design limits the ability to evaluate temporal relationships between plaque accumulation and caries development. Consequently, the null hypothesis was partially rejected, as statistically significant associations were identified for several evaluated variables but not for the presence of untreated visible cavitated carious lesions or fillings. The observed associations between VOPI and OHI-S scores may also be expected to some extent, as both indices reflect oral hygiene conditions, although VOPI provides a localised occlusal surface assessment whereas OHI-S reflects general oral hygiene status. From a clinical perspective, these findings suggest that visible occlusal plaque accumulation on FPMs may serve as a practical and easily applicable indicator of broader oral hygiene status in school-aged children. Therefore, rapid visual assessment of occlusal plaque during routine dental examinations may help identify children who could benefit from intensified preventive measures and oral hygiene instruction.

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TABLE 2 | Distribution and relationships of VOPI scores by OHI-S scores.

OHI-S scores (categorised)	0			1			2			3			Test statistic	*p*
	n	%	%V.	*n*	%	%V.	*n*	%	%V.	*n*	%	%V.		
VOPI scores of maxillary right FPMs														
Good	62	34.3	84.9	92	50.8	86.0	24	13.3	31.6	3	1.7	13.6	98.727	< 0.001*
Moderate	11	11.5	15.1	15	15.6	14.0	51	53.1	67.1	19	19.8	86.4		
Poor	0	0	0	0	0	0	1	100.0	1.3	0	0	0		
VOPI scores of maxillary left FPMs														
Good	57	31.7	82.6	97	53.9	88.2	24	13.3	32.0	2	1.1	8.3	108.988	< 0.001*
Moderate	12	12.4	17.4	13	13.4	11.8	50	51.5	66.7	22	22.7	91.7		
Poor	0	0	0	0	0.0	0	1	100.0	1.3	0	0.0	0.0		
VOPI scores of mandibular left FPMs														
Good	51	28.0	81.0	101	55.5	84.2	28	15.4	36.4	2	1.1	9.1	86.503	< 0.001*
Moderate	12	12.1	19.0	19	19.2	15.8	48	48.5	62.3	20	20.2	90.9		
Poor	0	0	0	0	0	0	1	100.0	1.3	0	0	0		
VOPI scores of mandibular right FPMs														
Good	55	30.2	83.3	99	54.4	85.3	26	14.3	34.2	2	1.1	9.1	95.411	< 0.001*
Moderate	11	11.3	16.7	17	17.5	14.7	49	50.5	64.5	20	20.6	90.9		
Poor	0	0	0	0	0.0	0	1	100.0	1.3	0	0	0		

Abbreviations: FPMs, first permanent molars; Max, maximum; Min, minimum; *n*, number; OHI-S, simplified oral hygiene index; VOPI, visible occlusal plaque index.
*$p < 0.05$ is considered statistically significant, Fisher's Exact test.

Collectively, these findings support the importance of monitoring plaque accumulation patterns in FPMs and reinforce the need for preventive approaches tailored to children during critical stages of dental development.

The results of this study demonstrated that the 11–12 age group exhibited poorer oral hygiene status compared with the 5–6, 7–8 and 9–10 age groups, suggesting an association between increasing age and less favourable oral hygiene conditions. As children grow and permanent teeth erupt, maintaining effective oral hygiene may become more challenging, particularly with the emergence of FPMs and other posterior teeth that are more difficult to access during brushing [27]. Moreover, older children often assume greater responsibility for their oral hygiene routines, whereas younger children may receive more direct parental supervision and assistance. Reduced parental involvement, combined with inconsistent brushing practices and inadequate oral hygiene behaviours, may contribute to increased plaque accumulation in older age groups. Previous studies have similarly emphasised the importance of parental involvement in maintaining oral hygiene among younger children [28–30]. This finding highlights the importance of maintaining parental engagement and reinforcing oral hygiene education during late childhood, particularly during the eruption and maturation period of FPMs. Targeted preventive programmes directed towards older school-aged children may help reduce age-related deterioration in oral hygiene status and support the long-term preservation of permanent dentition.

Study findings also demonstrated that mandibular right and left FPMs exhibited higher rates of untreated visible cavitated carious lesions and fillings compared with their maxillary counterparts. This difference may be associated with anatomical variations, particularly the deeper grooves and fissures commonly observed in mandibular molars, which may facilitate plaque retention and increase susceptibility to caries development [14]. Additionally, mandibular molars may be more difficult to clean effectively because of their posterior location and limited accessibility during routine brushing procedures. Similar findings were reported in a 5-year observational study by Zhu et al. [31], which demonstrated a higher prevalence of caries in mandibular FPMs compared with maxillary FPMs. Although the present study was not designed to directly investigate the mechanisms underlying these differences, the findings suggest that mandibular FPMs may warrant particular attention during routine preventive care. Clinically, early fissure sealant application, regular monitoring and reinforced oral hygiene instruction may be especially important for preserving the long-term health of these teeth.

Regression analyses demonstrated significant associations between higher VOPI scores and higher OHI-S and DMFT scores across all FPM groups. These findings suggest that increased occlusal plaque accumulation may reflect broader patterns of poorer oral hygiene and greater cumulative caries experience in children. Previous studies have similarly emphasised the relationship between plaque accumulation and caries-related outcomes in FPMs. Nazir et al. [32] reported that caries affecting FPMs was associated with increased caries involvement in other permanent teeth. Quaglio et al. [33] observed that FPMs with visible plaque demonstrated greater caries susceptibility, whereas Zenkner et al. [34] found that teeth with heavy plaque accumulation showed higher

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TABLE 3 | Distribution and relationships of VOPI scores by TNI scores.

		VOPI scores													
		0			1			2			3			Test statistics	*p*
	TNI	*n*	%	%V.	*n*	%	%V.	*n*	%	%V.	*n*	%	%V.		
Maxillary right FPMs	2	56	30.9	87.5	80	44.2	75.5	39	21.5	51.3	6	3.3	27.3	49.299	< 0.001*
	3	6	8.8	9.4	22	32.4	20.8	31	45.6	40.8	9	13.2	40.9		
	4	2	14.3	3.1	3	21.4	2.8	5	35.7	6.6	4	28.6	18.2		
	5	0	0.0	0.0	1	25.0	0.9	1	25.0	1.3	2	50.0	9.1		
	6	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	1	100.0	4.5		
Maxillary left FPMs	2	53	30.6	86.9	78	45.1	71.6	38	22.0	50.7	4	2.3	16.7	53.698	< 0.001*
	3	6	8.2	9.8	24	32.9	22.0	30	41.1	40.0	13	17.8	54.2		
	4	2	14.3	3.3	3	21.4	2.8	5	35.7	6.7	4	28.6	16.7		
	5	0	0.0	0.0	4	50.0	3.7	2	25.0	2.7	2	25.0	8.3		
	6	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	1	100.0	4.2		
Mandibular left FPMs	2	46	32.9	82.1	66	47.1	55.5	27	19.3	35.1	1	0.7	4.5	62.963	< 0.001*
	3	7	8.0	12.5	36	41.4	30.3	32	36.8	41.6	12	13.8	54.5		
	4	3	11.5	5.4	12	46.2	10.1	7	26.9	9.1	4	15.4	18.2		
	5	0	0.0	0.0	5	27.8	4.2	10	55.6	13.0	3	16.7	13.6		
	6	0	0.0	0.0	0	0.0	0.0	1	33.3	1.3	2	66.7	9.1		
Mandibular right FPMs	2	48	33.8	81.4	65	45.8	57.0	25	17.6	32.9	4	2.8	18.2	57.419	< 0.001*
	3	10	11.2	16.9	32	36.0	28.1	36	40.4	47.4	11	12.4	50.0		
	4	1	4.0	1.7	15	60.0	13.2	6	24.0	7.9	3	12.0	13.6		
	5	0	0.0	0.0	2	15.4	1.8	7	53.8	9.2	4	30.8	18.2		
	6	0	0.0	0.0	0	0.0	0.0	2	100.0	2.6	0	0.0	0.0		

Abbreviations: %, row percentage; FPMs, First permanent molars; *n*, number; TNI, treatment need index; %V., Column Percentage for VOPI; VOPI, visible occlusal plaque index.
*$p < 0.05$ is considered statistically significant, Pearson chi-square test.

TABLE 4 | Correlation analysis of OHI-S scores with VOPI and TNI scores for first permanent molars.

			VOPI scores	TNI scores
OHI-S scores (numerical)	Maxillary right FPMs	*r*	0.520	0.189
		p	< 0.001*	< 0.001*
	Maxillary left FPMs	*r*	0.513	0.213
		p	< 0.001*	< 0001*
	Mandibular left FPMs	*r*	0.451	0.229
		p	< 0.001*	< 0.001*
	Mandibular right FPMs	*r*	0.476	0.230
		p	< 0.001*	< 0.001*

Abbreviations: FPMs, first permanent molars; OHI-S, simplified oral hygiene index; TNI, treatment need index; VOPI, visible occlusal plaque index.
*$p < 0.05$ is considered statistically significant, *r*: correlation coefficient, Kendall's Tau correlation.

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TABLE 5 | Detailed summary of multivariable regression analysis predicting VOPI scores by FPMs.

		Maxillary right FPMs					Maxillary left FPMs					Mandibular left FPMs					Mandibular right FPMs				
					95% Confidence interval					95% Confidence interval					95% Confidence interval					95% Confidence interval	
		β	*p*-value	OR	Lower bound	Upper bound	*β*	*p*	OR	Lower bound	Upper bound	*β*	*p*	OR	Lower bound	Upper bound	*β*	*p*	OR	Lower bound	Upper bound
VOPI 1	Intercept	−2.714	0.013*				−1.862	0.085				−1.776	0.104				−0.520	0.106			
	OHI-S	0.930	0.003*	2.535	1.359	4.729	0.725	0.018*	2.064	1.130	3.772	0.840	0.005*	2.316	1.283	4.178	0.855	0.006*	2.352	1.284	4.309
	DMFT	0.149	0.193	1.160	0.927	1.452	0.202	0.082	1.223	0.975	1.535	0.228	0.064	1.256	0.987	1.599	0.266	0.016*	1.305	1.051	1.619
	Age	0.279	0.051	1.322	0.999	1.750	0.193	0.172	1.213	0.919	1.602	0.188	0.192	1.207	0.910	1.602					
VOPI 2	Intercept	−7.727	<0.001*				−7.487	<0.001*				−6.265	<0.001*				−3.660	<0.001*			
	OHI-S	2.885	<0.001*	17.907	7.787	41.177	2.650	<0.001*	14.147	6.348	31.530	2.277	<0.001*	9.750	4.623	20.562	2.532	<0.001*	12.579	5.833	27.125
	DMFT	0.451	0.001*	1.570	1.204	2.047	0.401	0.003*	1.493	1.146	1.944	0.418	0.003*	1.519	1.157	1.993	0.502	<0.001*	1.652	1.289	2.116
	Age	0.459	0.011*	1.582	1.112	2.251	0.482	0.006*	1.619	1.147	2.286	0.410	0.018*	1.507	1.072	2.117					
VOPI 3	Intercept	−13.288	<0.001*				−13.132	<0.001*				−11.655	<0.001*				−6.968	<0.001*			
	OHI-S	3.512	<0.001*	33.517	11.205	100.252	3.419	<0.001*	30.548	10.364	90.044	2.823	<0.001*	16.826	6.058	46.735	3.040	<0.001*	20.906	7.702	56.744
	DMFT	0.865	<0.001*	2.375	1.552	3.637	0.911	<0.001*	2.486	1.612	3.833	1.114	<0.001*	3.048	1.859	4.996	0.881	<0.001*	2.414	1.657	3.516
	Age	0.672	0.016*	1.958	1.132	3.387	0.652	0.018*	1.920	1.121	3.288	0.510	0.071	1.666	0.957	2.898					
R^2		0.487					0.478					0.434					0.407				
CA		57.6					57.9					57.8					57.1				

Abbreviations: *β*, standardised regression coefficient; CA, classification accuracy; DMFT, decayed, missing and filled teeth index; FPMs, first permanent molars; OHI-S, simplified oral hygiene index; OR, odds ratio; VOPI, visible occlusal plaque index.
*$p < 0.05$ is considered statistically significant.

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odds of caries occurrence compared with teeth exhibiting minimal plaque accumulation. Nevertheless, these findings should be interpreted cautiously, as differences in study design, plaque assessment timing, diagnostic criteria and evaluated clinical outcomes may influence the observed associations. Clinically, these findings suggest that rapid visual assessment of occlusal plaque on FPMs may provide useful supplementary information regarding a child's overall oral hygiene status and cumulative caries burden. Such assessments may help clinicians identify children who could benefit from intensified preventive care, individualised oral hygiene instruction and more frequent follow-up visits.

The high plaque accumulation observed on FPMs in this study may reflect challenges in maintaining effective oral hygiene during the eruption period [14]. Age was significantly associated with VOPI scores for maxillary right and left FPMs and mandibular left FPMs, but not for mandibular right FPMs. Although the reason for this asymmetrical finding remains unclear, anatomical variations, differences in tooth accessibility and individual oral hygiene behaviours may contribute to variations in plaque accumulation patterns among FPMs. Previous studies have reported that children often focus brushing on more easily accessible tooth surfaces, potentially leaving posterior molars more vulnerable to plaque retention and caries-related conditions [9]. These findings highlight the importance of individualised preventive approaches and further investigation of behavioural and anatomical factors associated with plaque accumulation in FPMs.

These findings underscore the importance of considering anatomical and behavioral factors when designing paediatric oral health interventions. Educational programmes emphasising effective brushing techniques for posterior and less accessible teeth may help improve plaque control in children. In addition, the findings highlight the importance of targeted preventive approaches for FPMs during critical stages of eruption and oral development.

This study contributes to the limited literature regarding the VOPI and its application in paediatric dentistry. Previous studies have largely focused on general plaque indices, whereas occlusal surface–specific plaque assessments remain relatively limited despite the susceptibility of these surfaces to plaque retention and caries-related conditions. By integrating regression and correlation analyses, the present study provides additional insight into the relationships among occlusal plaque accumulation, oral hygiene status, treatment needs and caries experience in children.

The study, however, has several limitations that should be considered when interpreting the findings. First, the cross-sectional design does not permit causal inferences regarding the associations between plaque accumulation, oral hygiene status, caries experience and treatment needs. Additionally, because plaque accumulation was assessed at a single time point, the findings may not fully reflect the dynamic nature of oral hygiene behaviours and plaque accumulation patterns over time. Second, the study included children across a relatively wide age range (5–12 years), which may have introduced developmental heterogeneity related to dentition stage, eruption status, oral hygiene behaviours, brushing ability and the degree of parental involvement in daily oral care. Third, clinical examinations were performed under natural classroom lighting conditions without radiographic assessment. Although this approach facilitated field-based examinations in a school setting, it may have affected diagnostic standardisation and reduced the sensitivity of caries detection, particularly for interproximal lesions or lesions beneath existing restorations that were not clinically visible. Consequently, some teeth may have been misclassified with respect to their true caries status, potentially leading to an underestimation of caries prevalence and weakening the observed associations involving caries-related variables. In addition, information regarding the timing of examinations relative to toothbrushing or food consumption was not recorded. Therefore, variation in recent oral hygiene practices or dietary intake may have influenced plaque scores and should be considered when interpreting the findings. Although separate tooth-specific regression models were constructed to avoid intra-subject clustering within each model, findings involving multiple FPMs should still be interpreted with awareness of shared child-level biological and behavioural characteristics. Furthermore, although the study population was sufficient for statistical analysis, participants were recruited using a convenience sampling approach from a single public school. This sampling strategy may have introduced selection bias and limited the representativeness of the study population. Consequently, the findings should be interpreted with caution when generalising the results to children from different geographic regions, socioeconomic backgrounds, or educational settings. Future longitudinal and multicentre studies incorporating radiographic evaluation and more diverse paediatric populations are warranted to further clarify the relationships among occlusal plaque accumulation, oral hygiene, caries experience and treatment needs in children.

5 | Conclusion

Within the limitations of this cross-sectional study, visible occlusal plaque accumulation in FPMs was significantly associated with oral hygiene status, treatment needs, age and caries experience in schoolchildren. Although significant associations were identified between VOPI scores and oral hygiene–related parameters, no statistically significant direct association was observed between VOPI scores and the presence of untreated visible cavitated carious lesions or fillings in FPMs. Mandibular FPMs demonstrated higher frequencies of untreated visible cavitated carious lesions and fillings compared with maxillary FPMs. These findings may reflect differences in plaque retention patterns and oral hygiene challenges associated with posterior teeth, although the underlying anatomical and behavioural mechanisms were not directly evaluated in the present study. Overall, the findings support the clinical relevance of monitoring plaque accumulation patterns in FPMs and emphasise the importance of preventive oral health strategies during childhood.

6 | Clinical Relevance

6.1 | Scientific Rationale for the Study

First permanent molars are highly susceptible to plaque accumulation and caries during eruption, yet occlusal plaque–specific assessments in children remain limited.

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6.2 | Principal Findings

Visible occlusal plaque scores were significantly associated with oral hygiene status, treatment needs, age and caries experience in schoolchildren, with mandibular FPMs demonstrating higher frequencies of untreated visible cavitated carious lesions and fillings.

6.3 | Practical Implications

VOPI may serve as a simple chairside tool for monitoring occlusal plaque accumulation in children during routine dental examinations and school-based preventive programmes. Early identification of plaque-retentive FPMs may support targeted oral hygiene education, preventive interventions and individualised follow-up strategies by paediatric dentists and dental hygienists.

Author Contributions

Ecem Akbeyaz Şivet: conceptualisation, investigation, methodology, data curation, formal analysis, writing – original draft, supervision. **Berkant Sezer:** conceptualisation, methodology, formal analysis, writing – original draft, writing – review and editing, supervision. **Neslihan Atmaca:** conceptualisation, investigation, methodology, data curation. **Betül Kargül:** conceptualisation, methodology, supervision. **Narmin Huseynova:** investigation, data curation.

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The authors have nothing to report.

Ethics Statement

Ethical approval for the study was obtained from the Clinical Research Ethics Committee of the School of Dentistry, Marmara University, on 23.02.2023, with protocol number 2023-131.

Consent

The study procedures were explained to the participating children in an age-appropriate language by the researchers and assent was obtained from children who agreed to participate. In addition, written informed consent was obtained from the parents or legal guardians of all participating children before enrolment in the study.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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