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Morphological Variations of the Cusp of Carabelli in Permanent Maxillary First Molars and Their Correlation with Caries Risk in the Peshawar Population

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ABSTRACT

The Cusp of Carabelli is a common non-metric morphological trait of permanent maxillary first molars. Although its anthropological significance is well recognized, its clinical relevance in relation to dental caries remains controversial, with limited regional data from Khyber Pakhtunkhwa. **Objectives:** To determine the prevalence and morphological patterns of the Cusp of Carabelli and evaluate their association with caries risk in a young population of Peshawar. **Methods:** A descriptive cross-sectional study was conducted at the Dental Outpatient Department of Khyber College of Dentistry, Peshawar. A total of 103 participants aged ≥12 years were examined using non-probability consecutive sampling. The Cusp of Carabelli was assessed on teeth 16 and 26 using the ASUDAS/Dahlberg classification (Types 0–6). Caries experience was recorded using the DMFT index. Oral hygiene behaviors were obtained through a structured questionnaire. Data were analyzed using descriptive statistics, chi-square, independent t-test, and Pearson correlation. **Results:** The Cusp of Carabelli was present in 62.1% of participants, with a mean severity score of 1.47 ± 1.41. The mean DMFT score was 4.48 ± 2.42, and 53.4% were classified as high caries risk. No significant associations were observed between Carabelli morphology, side expression, or severity score and caries experience ($p>0.05$). Oral hygiene behaviors also showed no significant association with caries risk. **Conclusions:** The Cusp of Carabelli is common in the studied population; however, its presence and morphology do not significantly influence caries risk and should be regarded primarily as a normal anatomical variation.

INTRODUCTION

The Cusp of Carabelli is a well-recognized non-metric morphological trait located on the palatal surface of permanent maxillary first molars and is understood to represent genetic and developmental dental variation rather than a functional anatomical feature. This trait exhibits a wide spectrum of expression, from minor pits and grooves to distinct, well-developed cusps, reflecting its complex ontogeny and multifactorial genetic influences [1, 2]. Morphological dental traits such as the Cusp of Carabelli have long served as important markers in dental anthropology, forensic science, and human population studies, demonstrating variations in expression among different ethnic and regional groups worldwide [3, 4]. Systematic meta-analyses indicate that the prevalence of the Cusp of Carabelli in permanent maxillary first molars globally hovers around 59%, although individual studies report broad variation depending on population characteristics and grading systems used [5]. European

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populations generally show higher expression frequencies, whereas Asian and African populations display intermediate to lower rates, highlighting marked inter-ethnic variability [6, 7]. Within the South Asian context, including Pakistan, published prevalence estimates for this trait vary considerably. A recent study using ASUDAS criteria found the Cusp of Carabelli in 46.5% of maxillary first molars in a Lahore population, with morphological types ranging from shallow grooves to pronounced cusps [3]. Hospital-based research from Peshawar Dental Hospital reported a 39.3% prevalence in a Peshawar population and noted associated caries in the Carabelli groove in 17.7% of cases, although no significant gender differences were observed [8]. Another local investigation in Multan identified the trait in 53.75% of patients, reinforcing the notion of regional variation within Pakistan itself [9]. These findings suggest that underlying genetic heterogeneity and environmental factors may influence trait distribution across Pakistani subpopulations. Despite its long-standing use in anthropological research, the clinical implications of the Cusp of Carabelli, particularly in caries etiology, remain unclear. Some recent studies indicate that deeper or more pronounced expressions of the trait may create retentive niches conducive to plaque accumulation and subsequent caries development, especially in the grooves at the mesiolingual surface of first molars [10]. However, other regional studies have contradicted this association, reporting no significant relationship between Carabelli morphology and overall caries experience when controlling for behavioral and hygiene factors [11, 12]. This inconsistency suggests that the trait's impact on caries risk might be conditional on a complex interplay with oral hygiene behaviors, dietary patterns, fluoride exposure, and socioeconomic determinants, rather than a direct causal factor in isolation. Furthermore, interstudy differences in methodology, particularly grading systems for Carabelli expression (e.g., ASUDAS) and criteria for caries assessment, have contributed to the lack of consensus. These methodological disparities complicate cross-population comparisons, as some studies restrict analyses to the presence/absence of the trait, while others incorporate detailed morphological scoring [5, 13].

Given the high burden of dental caries in many low- and middle-income contexts and the scarcity of robust dental morphologic data from Khyber Pakhtunkhwa, region-specific research is essential. Understanding whether morphological variants like the Cusp of Carabelli contribute to increased caries susceptibility beyond established risk factors can inform targeted preventive strategies in local public dental health initiatives. This study aimed to determine the prevalence and morphological patterns of the Cusp of Carabelli and evaluate their association with caries risk in a young population of Peshawar.

METHODS

This descriptive cross-sectional study was conducted from 26 September to 26 November 2025 at the Dental Outpatient Department (OPD) of Khyber College of Dentistry, Peshawar. Ethical approval was obtained from the Institutional Ethics Committee of Khyber College of Dentistry (Reference No. 110/ADR/KCD), and written informed consent was obtained from all participants before enrollment. The sample size comprised 103 participants and was calculated using the standard cross-sectional formula $n = (Z^2 \times P \times (1–P)) / d^2$, where $Z = 1.96$ (95% confidence), P was based on previously reported regional prevalence [14], and d was set between 0.08 and 0.10. To compensate for possible non-responses and improve precision, a final sample size of 103 was included. A non-probability consecutive sampling technique was employed. Demographic information, including age, gender, residence, and socioeconomic status, was collected through a structured interviewer-administered questionnaire at the time of clinical examination. Oral hygiene practices such as brushing frequency, fluoride toothpaste use, and snack frequency were recorded using the same questionnaire. Participants aged 12 years and above with fully erupted permanent maxillary first molars and intact crown morphology were included. Participants were excluded if maxillary first molars were grossly carious, fractured, hypoplastic, restored with full-coverage crowns, orthodontically altered, or if any systemic or developmental condition known to affect tooth formation was present. Intra-oral examination was performed under ambient clinical lighting using a disposable mouth mirror and periodontal probe. Both maxillary first molars (teeth 16 and 26) were examined. The Cusp of Carabelli was assessed using the Arizona State University Dental Anthropology System (ASUDAS) / Dahlberg classification [15], which categorizes the trait on a scale from Type 0 (absence of the cusp) to Type 6 (well-developed prominent cusp). Types 1–2 represent pits and shallow depressions, Types 3–4 represent grooves and small cusps, and Types 5–6 represent moderately to well-developed cusps. Side expression (unilateral/bilateral) was also recorded. Caries experience was assessed using the DMFT index (Decayed, Missing, Filled Teeth) according to the World Health Organization (WHO) Oral Health Surveys criteria Basic Methods (5th edition), which provides standardized criteria for epidemiological recording of dental caries [16]. To ensure reliability, all examinations were performed by a single calibrated examiner. Intra-examiner reliability was assessed on a subset of participants before data collection, and consistent scoring

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was achieved. Data were analyzed using IBM SPSS version 26.0. Descriptive statistics were used to summarize demographic, oral hygiene, and morphological variables. Chi-square tests were applied to assess associations between categorical variables. An independent samples t-test was used to compare mean DMFT scores between groups with and without the Cusp of Carabelli. Pearson's correlation coefficient was used to evaluate the relationship between Carabelli severity scores and DMFT values. A p-value ≤ 0.05 was considered statistically significant.

RESULTS

The mean age of the participants was 18.49 ± 3.05 years, with the majority (60.2%) belonging to the 17–21-year age group. Females comprised 56.3% of the sample, and 57.3% were urban residents. With respect to oral hygiene practices, 38.8% brushed once daily, 33.0% brushed twice daily, and 28.2% brushed irregularly, while 78.6% reported using fluoride toothpaste. The demographic and behavioral characteristics of the study participants are summarized in table 1.

Table 1: Frequency of Demographic, Oral Hygiene, and Dietary Characteristics (n=103)

Variables	Category	n (%)
Age (Years)	Mean ± SD	18.49 ± 3.05
Age Groups	12–16	22 (21.4%)
	17–21	62 (60.2%)
	>21	19 (18.4%)
Gender	Male	45 (43.7%)
	Female	58 (56.3%)
Residence	Urban	59 (57.3%)
	Rural	44 (42.7%)
Socioeconomic Status	Low	31 (30.1%)
	Middle	54 (52.4%)
	High	18 (17.5%)
Brushing Frequency	Once daily	40 (38.8%)
	Twice daily	34 (33.0%)
	Irregular	29 (28.2%)
Fluoride Toothpaste	Yes	81 (78.6%)
	No	22 (21.4%)
Snack Frequency	<1/day	24 (23.3%)
	1–2/day	51 (49.5%)
	≥3/day	28 (27.2%)

The study demonstrates the prevalence and morphological expression of the Cusp of Carabelli. The cusp was present in 62.1% of participants, with 58.3% showing bilateral expression. The mean severity score was 1.47 ± 1.41, indicating predominantly mild expression. The most frequent morphology was Type 0 (37.9%), followed by Type 1 (12.6%) and Type 5 (12.6%), as shown in table 2.

Table 2: Tooth-Related Findings and Morphology of the Cusp of Carabelli

Variables	Category	n (%)
Tooth Examined	16	50 (48.5%)
	26	53 (51.5%)
Side Expression	Bilateral	60 (58.3%)
	Unilateral	43 (41.7%)
Presence of CC	Present	64 (62.1%)
	Absent	39 (37.9%)
Severity Score	Mean ± SD	1.47 ± 1.41
Morphology	Type 0	39 (37.9%)
	Type 1	13 (12.6%)
	Type 2	9 (8.7%)
	Type 3	8 (7.8%)
	Type 4	8 (7.8%)
	Type 5	13 (12.6%)
	Type 6	13 (12.6%)

Results summarize the overall caries experience of the study participants using the DMFT index and its association with the Cusp of Carabelli. The mean DMFT score was 4.48 ± 2.42, with the decayed component contributing the largest share (2.87 ± 2.09), indicating an overall moderate caries burden. More than half of the participants (53.4%) were classified as having high caries risk, while 24.3% and 22.3% were categorized as low and moderate risk, respectively. Comparison of mean DMFT scores between individuals with and without the Cusp of Carabelli showed no statistically significant difference (p=0.529), and severity score did not correlate with DMFT (r=0.001, p=0.996), indicating that Carabelli morphology did not influence caries experience, as shown in table 3.

Table 3: Caries Status, Risk Distribution, and Association with Cusp of Carabelli (n=103)

Variables	Category / Statistic	Mean ± SD / n (%)	p-value
DMFT Components	Decayed (D)	2.87 ± 2.09	–
	Missing (M)	0.12 ± 0.40	
	Filled (F)	1.49 ± 1.15	
	Total DMFT	4.48 ± 2.42	
Caries Risk Categories	Low	25 (24.3%)	–
	Moderate	23 (22.3%)	
	High	55 (53.4%)	
Mean DMFT by CC Presence	CC Present	4.59 ± 2.40	0.529
	CC Absent	4.28 ± 2.47	
Correlation Analysis	Severity Score vs DMFT	r = 0.001	0.996

The study demonstrates the association between Carabelli morphology, side expression, and caries risk. A higher proportion of individuals with the Cusp of Carabelli had high caries risk (56.3%) than those without it (48.7%); however, this difference was not statistically significant (p=0.714). Similarly, bilateral (53.3%) and unilateral (53.5%) expressions showed comparable high-risk proportions,

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with no significant association between side expression and caries risk (p=0.318). Furthermore, different Carabelli morphological types did not demonstrate statistically significant variation in caries risk categories (p=0.693), indicating that Carabelli morphology did not influence caries susceptibility in this population, as shown in table 4.

Table 4: Association of Carabelli Features with Caries Risk (n=103)

Features	Category	High, n (%)	Low, n (%)	Moderate, n (%)	Total	χ^2 (Cramer's V)	p-value
CC Presence	Present	36 (56.3%)	14 (21.9%)	14 (21.9%)	64	0.673	0.714
	Absent	19 (48.7%)	11 (28.2%)	9 (23.1%)	39		
Side Expression	Bilateral	32 (53.3%)	12 (20.0%)	16 (26.7%)	60	0.149	0.318
	Unilateral	23 (53.5%)	13 (30.2%)	7 (16.3%)	43		
CC Morphological Type	Type 0	19 (48.7%)	11 (28.2%)	9 (23.1%)	39	9.121	0.693
	Type 1	7 (53.8%)	4 (30.8%)	2 (15.4%)	13		
	Type 2	3 (33.3%)	2 (22.2%)	4 (44.4%)	9		
	Type 3	4 (50.0%)	2 (25.0%)	2 (25.0%)	8		
	Type 4	5 (62.5%)	2 (25.0%)	1 (12.5%)	8		
	Type 5	10 (76.9%)	0 (0.0%)	3 (23.1%)	13		
	Type 6	7 (53.8%)	4 (30.8%)	2 (15.4%)	13		

The results present the relationship between oral hygiene behaviors and caries risk categories. Although higher proportions of high caries risk were observed among participants who brushed twice daily (64.7%) and those consuming ≥3 snacks per day (64.3%), brushing frequency (p=0.566), fluoride toothpaste use (p=0.920), and snack frequency (p=0.184) did not show statistically significant associations with caries risk. These findings indicate that oral hygiene behaviors were not independent predictors of caries susceptibility in this study population, as shown in table 5.

Table 5: Association of Oral Hygiene Behaviors with Caries Risk (n=103)

Behaviors	Category	High, n (%)	Low, n (%)	Moderate, n (%)	p-value
Brushing Frequency	Twice Daily	22 (64.7%)	7 (20.6%)	5 (14.7%)	0.566
	Once Daily	19 (47.5%)	10 (25.0%)	11 (27.5%)	
	Occasionally	14 (48.3%)	8 (27.6%)	7 (24.1%)	
Fluoride Toothpaste Use	Yes	44 (54.3%)	19 (23.5%)	18 (22.2%)	0.920
	No	11 (50.0%)	6 (27.3%)	5 (22.7%)	
Snack Frequency	<1/Day	9 (37.5%)	10 (41.7%)	5 (20.8%)	0.184
	1–2/Day	28 (54.9%)	10 (19.6%)	13 (25.5%)	
	≥3/Day	18 (64.3%)	5 (17.9%)	5 (17.9%)	

Scatter plot showing no correlation between CC severity and DMFT (r=0.001, p=0.996). Evidence suggests no significant relationship, as the point distribution lacks a clear linear pattern, and the trendline is almost flat. This aligns with the results from the cusp severity and caries experience correlation test (r=0.001; p=0.996), which showed no statistically significant correlation between cusp severity and caries experience (Figure 1).

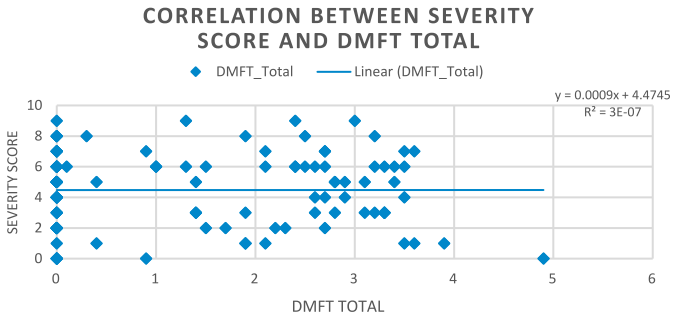

Figure 1: Correlation Between Severity Score and DMFT Total

DISCUSSION

The present study demonstrated a high prevalence of the Cusp of Carabelli (62.1%) among permanent maxillary first molars in the Peshawar population, with predominantly mild morphological expressions, and found no statistically significant association between Carabelli morphology and caries experience. These findings are consistent with recent international and regional literature. A global systematic review and meta-analysis by Kotsanos *et al.* reported an overall prevalence of approximately 59%, confirming that Carabelli expression is common worldwide but highly variable across populations [4]. Comparable results were observed in Pakistan, where Shahbaz *et al.* reported a prevalence of 46.5% using ASUDAS classification in Lahore [3], while Khan *et al.* from Peshawar and Qamar *et al.* from Multan documented similarly moderate to high frequencies of the trait [17, 18]. Studies from neighboring regions further support these findings. Zichao *et al.* in China documented moderate prevalence rates and substantial inter-individual variation [19]. German orthodontic research also emphasized the genetic basis and bilateral nature of Carabelli expression [20], reinforcing that this trait primarily reflects inherited crown morphology rather than pathological change.

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Importantly, the absence of a significant association between Carabelli morphology and caries experience in the present study aligns with multiple regional and international investigations. Zichao *et al.* in Peshawar [19] and Matti *et al.* in Iraq [6] similarly reported that Carabelli expression did not independently predict dental caries when oral hygiene behaviors and other confounders were considered. These observations suggest that Carabelli morphology alone does not constitute a clinically meaningful caries risk factor. Conversely, a few studies have reported slightly increased caries susceptibility in deeper Carabelli groove types, particularly in the Bangladeshi population [21] and in a cohort study by Bhavyaa *et al.* [22]. However, these studies also noted that the observed associations were modest and strongly influenced by oral hygiene practices, dietary habits, and fluoride exposure. The predominance of shallow, easily cleanable Carabelli expressions and relatively high fluoride toothpaste use in the present cohort may explain the lack of association observed. Overall, the current findings support the growing body of evidence that regards the Cusp of Carabelli as a genetically determined non-metric dental trait with limited independent clinical relevance in caries etiology. While its documentation remains valuable for anthropological, forensic, and population studies, its role as a predictive indicator for dental caries appears minimal.

This study was conducted in a single city with a limited sample, which may not represent the wider population. Additionally, the cross-sectional design and focus on mild Carabelli expressions limited assessment of potential effects of extreme morphologies on caries risk. Future longitudinal investigations with larger sample sizes are warranted to elucidate whether pronounced morphological expressions may contribute to caries development under varying behavioral and environmental conditions.

CONCLUSIONS

The present study demonstrates that the Cusp of Carabelli is a prevalent morphological feature of permanent maxillary first molars among young individuals in Peshawar, predominantly expressed in mild forms. Despite a moderate overall caries burden in the study population, no statistically significant associations were identified between Carabelli presence, side expression, morphological type, or severity score and caries risk or DMFT values. These findings indicate that Carabelli morphology does not independently influence dental caries susceptibility and should be regarded primarily as a normal anatomical variation rather than a clinical risk indicator.

Authors' Contribution

Conceptualization: FD
Methodology: FD, MAK
Formal analysis: SUF, AS, NI, AK, MAK
Writing and Drafting: FD, SUF, AS, NI, AK
Review and Editing: FD, SUF, AS, NI, AK, MAK

All authors approved the final manuscript and take responsibility for the integrity of the work.

Conflicts of Interest

All the authors declare no conflict of interest.

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