

Evaluation of Palatal Rugae Patterns and Their Relationship with Dental Malocclusion, Craniofacial Growth Pattern, And Gender in the Malappuram Population: A Cross-Sectional Study

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Abstract—Palatal rugae are stable anatomical structures that develop early in intrauterine life and retain their morphology throughout life. Their stability and relationship with craniofacial development make them potentially useful supplementary markers in forensic identification and orthodontic assessment. This cross-sectional study evaluated the association of palatal rugae morphology with Angle's malocclusion, craniofacial growth pattern, and gender. A total of 150 pretreatment dental stone casts, equally distributed among Class I, Class II, and Class III malocclusion groups, were assessed. Maxillary impressions were obtained using alginate, and casts were prepared using orthodontic stone. Palatal rugae were delineated and evaluated for number, length, pattern, and orientation by visual inspection and linear measurement using digital vernier calipers. Significant differences in palatal rugae characteristics were observed according to malocclusion, gender, and growth pattern. Females demonstrated a greater number of rugae and significantly longer first and second left rugae, whereas males showed a significantly longer third left ruga. Class I malocclusion was predominantly associated with straight and irregular rugae, Class II with wavy and forking patterns, and Class III with anteriorly directed and elongated rugae. Subjects with a horizontal growth pattern had a greater number of rugae and longer first and second left rugae, whereas those with a vertical growth pattern showed a longer third left ruga. These findings indicate that palatal rugae exhibit morphological variations associated with gender, malocclusion, and craniofacial growth pattern. Their relative stability and individual variation support their potential use as supplementary markers in orthodontic assessment and forensic identification.

Index Terms—Palatal rugae; rugoscopy; Angle's malocclusion; craniofacial growth pattern; sexual dimorphism; forensic dentistry

I. INTRODUCTION

Palatal rugae are irregular mucosal ridges located in the anterior region of the hard palate. They develop during early intrauterine life and remain relatively stable throughout life. Their distinctive morphology, resistance to postnatal changes, and protection by surrounding oral structures make them useful in forensic identification and orthodontic applications.^{1,2} In orthodontics, palatal rugae can serve as stable anatomical landmarks for dental cast superimposition and assessment of anteroposterior tooth movement.³ The development and spatial patterning of palatal rugae are regulated by complex epithelial–mesenchymal interactions and molecular signaling pathways during craniofacial morphogenesis.^{4,5} Since craniofacial growth and dental occlusion share common developmental pathways, variations in rugae morphology may be associated with different malocclusion types and craniofacial growth patterns. Previous studies have reported associations between palatal rugae characteristics and Angle's classes of malocclusion, although the findings have not been completely consistent.^{6,7} Malocclusion is a common oral health condition with a substantial genetic and environmental contribution. Early recognition of dentoskeletal variations facilitates timely orthodontic intervention and may reduce treatment complexity. Given their early development and relative stability, palatal rugae may provide supplementary morphological information for

evaluating dentoskeletal relationships in addition to their established forensic applications.^{1,2}

Studies have also suggested an association between palatal rugae morphology and craniofacial growth pattern. In particular, research conducted in a South Indian population demonstrated differences in palatal rugae characteristics among subjects with different craniofacial growth patterns.⁸ However, evidence from Kerala, particularly the Malappuram population, remains limited.

Therefore, the present study aimed to evaluate the association of palatal rugae morphology with Angle's classes of malocclusion, craniofacial growth pattern, and gender among individuals from the Malappuram district of Kerala, India.

II. MATERIALS AND METHODS

STUDY DESIGN AND SAMPLE

A cross-sectional study was conducted on 150 pretreatment dental stone casts selected from the records of patients aged 12–30 years. The sample consisted of 50 casts each from Angle's Class I, Class II, and Class III malocclusion groups. All casts satisfied the predefined eligibility criteria.

INCLUSION CRITERIA

- Age between 12 and 30 years.
- Permanent dentition with fully erupted first molars.
- Well-established molar relationship.

EXCLUSION CRITERIA

- Previous orthodontic or prosthodontic treatment.
- History of maxillofacial or plastic surgery.
- History of craniofacial trauma.
- Congenital craniofacial anomalies.
- Missing, grossly decayed, or impacted teeth.

CAST PREPARATION AND PALATAL RUGAE ASSESSMENT

Maxillary dental casts were prepared from alginate impressions using ISO Type 3 orthodontic dental stone. Palatal rugae were delineated on the casts using a 0.5-mm HB mechanical pencil, and the medial and distal limits of each ruga were marked. The number, pattern, and orientation of palatal rugae were assessed by visual inspection. The lengths of the three anterior-most primary rugae measuring ≥ 5 mm were recorded using a digital vernier caliper with an accuracy of 0.01 mm.

STATISTICAL ANALYSIS

Statistical analysis was performed using SPSS version 26.0. Differences among the three malocclusion groups were assessed using one-way analysis of variance followed by the Bonferroni post hoc test. Independent t-tests were used for comparisons according to gender and craniofacial growth pattern, and chi-square tests were used for categorical variables. Statistical significance was set at $p < 0.05$.

III. RESULTS

A total of 150 pretreatment dental casts were analyzed, comprising 50 casts each from Angle's Class I, Class II, and Class III malocclusion groups.

MALOCCLUSION

Significant differences were observed in the number and length of palatal rugae among the three malocclusion groups (Table 1; Figure 1). Class III subjects exhibited the lowest number of rugae on the right side but the highest number on the left side ($p < 0.001$). The first, second, and third rugae on the right side and the first and third rugae on the left side were significantly longer in Class III subjects ($p < 0.001$). No significant difference was observed in the length of the second left ruga ($p = 0.800$).

GENDER

Significant sexual dimorphism was observed in palatal rugae characteristics (Table 2; Figure 2). Females had a significantly greater number of rugae on both sides than males ($p < 0.05$). Females also exhibited significantly longer first and second rugae on the left side, whereas males demonstrated a significantly longer third left ruga. No significant gender differences were observed in the lengths of the right-sided rugae.

CRANIOFACIAL GROWTH PATTERN

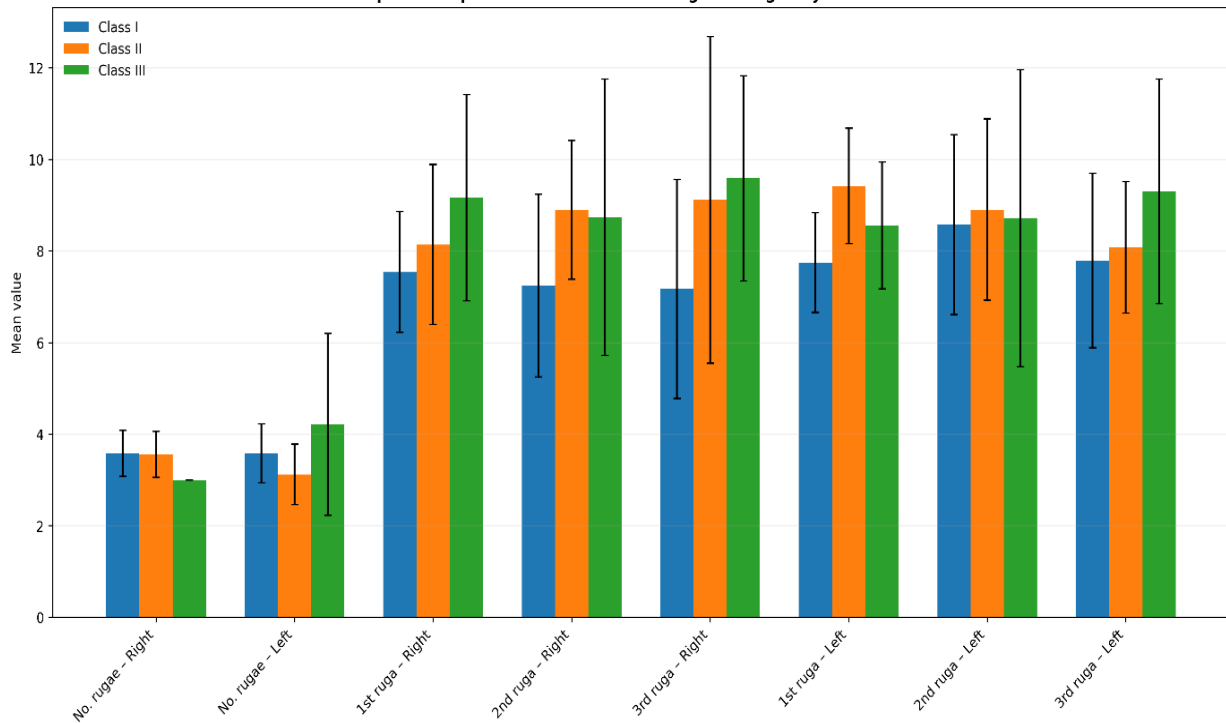
Subjects with a horizontal growth pattern had significantly more rugae on both sides than those with a vertical growth pattern ($p < 0.05$) (Table 3; Figure 3). The first and second left rugae were significantly longer in horizontal growers, whereas the third left ruga was significantly longer in vertical growers ($p < 0.001$). No significant differences were observed in the lengths of the right-sided rugae.

Overall, palatal rugae morphology demonstrated significant associations with Angle's malocclusion, gender, and craniofacial growth pattern.

Table 1. Comparison of Number and Length of Rugae by Malocclusion

Variable	Class I	Mean	SD	Test statistic	p value
No. rugae - Right	Class I	3.58	0.499	32.520	<0.001
No. rugae - Right	Class II	3.56	0.501	32.520	<0.001
No. rugae - Right	Class III	3	0	32.520	<0.001
No. rugae - Left	Class I	3.58	0.6418	9.444	<0.001
No. rugae - Left	Class II	3.12	0.659	9.444	<0.001
No. rugae - Left	Class III	4.214	1.9865	9.444	<0.001
1st ruga - Right	Class I	7.545	1.3193	10.171	<0.001
1st ruga - Right	Class II	8.1394	1.7477	10.171	<0.001
1st ruga - Right	Class III	9.162	2.2517	10.171	<0.001
2nd ruga - Right	Class I	7.2426	1.9934	8.154	<0.001
2nd ruga - Right	Class II	8.9	1.5144	8.154	<0.001
2nd ruga - Right	Class III	8.736	3.0125	8.154	<0.001
3rd ruga - Right	Class I	7.1692	2.3928	10.503	<0.001
3rd ruga - Right	Class II	9.1164	3.5643	10.503	<0.001
3rd ruga - Right	Class III	9.586	2.2413	10.503	<0.001
1st ruga - Left	Class I	7.744	1.0916	22.350	<0.001
1st ruga - Left	Class II	9.4186	1.2621	22.350	<0.001
1st ruga - Left	Class III	8.556	1.3864	22.350	<0.001
2nd ruga - Left	Class I	8.5752	1.9668	0.223	0.800
2nd ruga - Left	Class II	8.9042	1.9774	0.223	0.800
2nd ruga - Left	Class III	8.718	3.2435	0.223	0.800
3rd ruga - Left	Class I	7.79	1.901	8.044	<0.001
3rd ruga - Left	Class II	8.08	1.436	8.044	<0.001
3rd ruga - Left	Class III	9.3	2.452	8.044	<0.001

Table 1. Comparison of the Number and Length of Palatal Rugae According to Malocclusion

Graph 1. Comparison of Number and Length of Rugae by Malocclusion

Graph 1. Comparison of the Number and Length of Palatal Rugae According to Malocclusion

Table 2. Comparison of Number and Length of Rugae by Gender

Variable	Male	Mean	SD	Test statistic	p value
No. rugae – Right	Male	3.28	0.452	-2.134	0.034
No. rugae – Right	Female	3.45	0.5	-2.134	0.034
No. rugae – Left	Male	3.0984	0.5974	-4.342	<0.001
No. rugae – Left	Female	4.0079	1.5581	-4.342	<0.001
1st ruga – Right	Male	8.3887	2.3678	0.561	0.576
1st ruga – Right	Female	8.2091	1.5548	0.561	0.576
2nd ruga – Right	Male	8.0689	3.2886	-0.959	0.339
2nd ruga – Right	Female	8.4464	1.4346	-0.959	0.339
3rd ruga – Right	Male	8.5284	3.1336	-0.325	0.745
3rd ruga – Right	Female	8.6893	2.8669	-0.325	0.745
1st ruga – Left	Male	8.2167	0.9108	-2.590	0.011
1st ruga – Left	Female	8.817	1.6443	-2.590	0.011
2nd ruga – Left	Male	7.4457	1.2129	-5.878	<0.001
2nd ruga – Left	Female	9.6144	2.6987	-5.878	<0.001
3rd ruga – Left	Male	8.84	2.35	2.349	0.020
3rd ruga – Left	Female	8.04	1.758	2.349	0.020

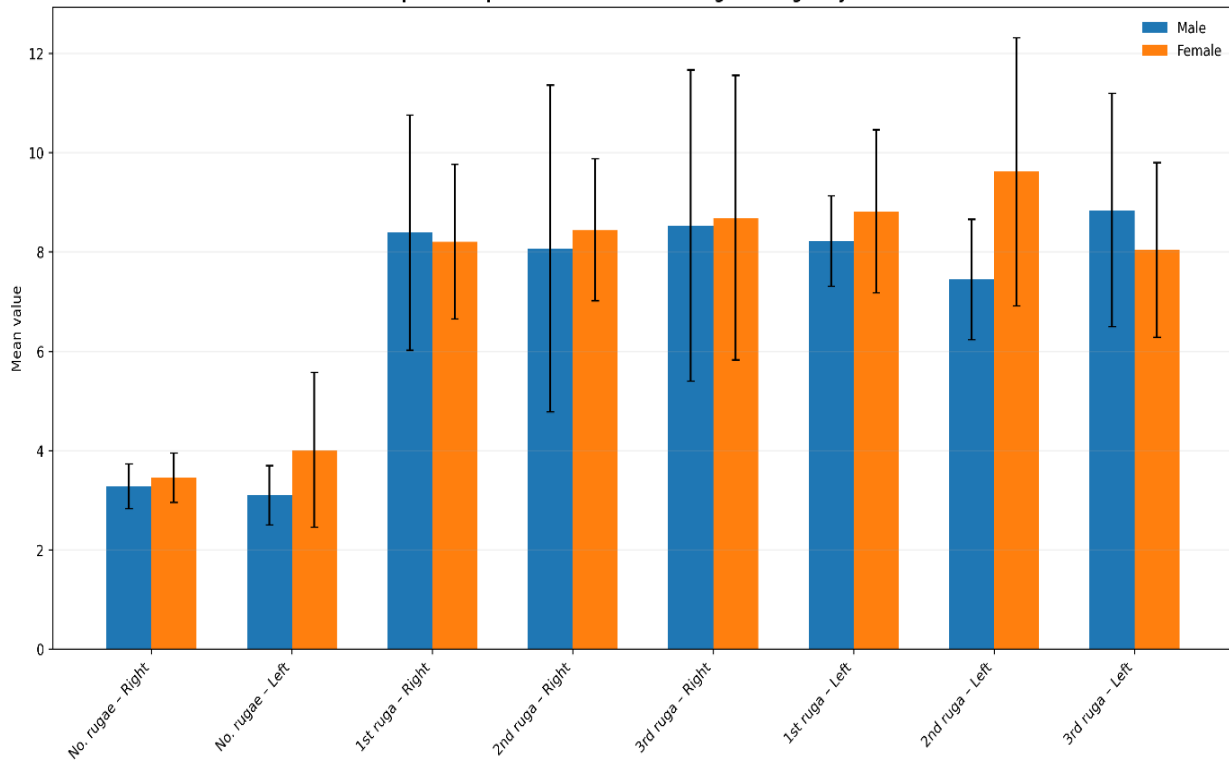
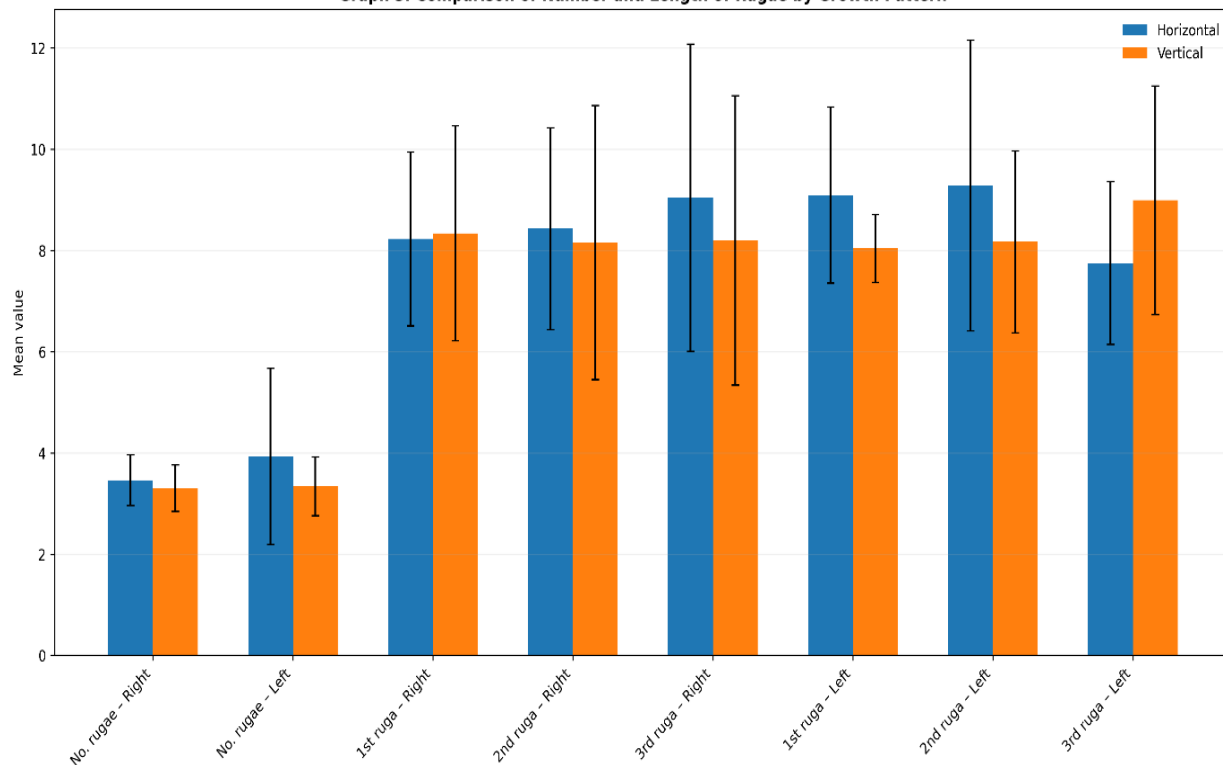
Table 2. Comparison of the Number and Length of Palatal Rugae According to Gender**Graph 2. Comparison of Number and Length of Rugae by Gender****Graph 2. Comparison of the Number and Length of Palatal Rugae According to Gender**

Table 3. Comparison of Number and Length of Rugae by Growth Pattern

Variable	Horizontal	Mean	SD	Test statistic	p value
No. rugae - Right	Horizontal	3.46	0.502	2.075	0.040
No. rugae - Right	Vertical	3.3	0.46	2.075	0.040
No. rugae - Left	Horizontal	3.9303	1.7408	2.781	0.006
No. rugae - Left	Vertical	3.3378	0.58	2.781	0.006
1st ruga - Right	Horizontal	8.2275	1.7174	-0.352	0.725
1st ruga - Right	Vertical	8.3382	2.1217	-0.352	0.725
2nd ruga - Right	Horizontal	8.4267	1.9936	0.700	0.485
2nd ruga - Right	Vertical	8.1554	2.7054	0.700	0.485
3rd ruga - Right	Horizontal	9.0389	3.0335	1.747	0.083
3rd ruga - Right	Vertical	8.1976	2.8591	1.747	0.083
1st ruga - Left	Horizontal	9.0928	1.7363	4.877	<0.001
1st ruga - Left	Vertical	8.0389	0.6724	4.877	<0.001
2nd ruga - Left	Horizontal	9.2814	2.8708	2.838	0.005
2nd ruga - Left	Vertical	8.1686	1.7935	2.838	0.005
3rd ruga - Left	Horizontal	7.75	1.609	-3.846	<0.001
3rd ruga - Left	Vertical	8.99	2.261	-3.846	<0.001

Table 3. Comparison of the Number and Length of Palatal Rugae According to Craniofacial Growth Pattern**Graph 3. Comparison of Number and Length of Rugae by Growth Pattern****Graph 3. Comparison of the Number and Length of Palatal Rugae According to Craniofacial Growth Pattern**

IV. DISCUSSION

The present study evaluated the association between palatal rugae morphology and gender, Angle's malocclusion, and craniofacial growth pattern in 150 subjects. Significant variations were observed in the number and length of palatal rugae across the studied groups. These findings support the potential utility of palatal rugae as stable anatomical landmarks in orthodontic assessment and as supplementary features in forensic identification.¹⁻³

Significant sexual dimorphism was observed in the present study. Females exhibited a greater number of rugae on both sides and significantly longer first and second rugae on the left side, whereas males demonstrated a longer third left ruga. Previous studies have investigated sex-related differences in palatal rugae morphology, although the findings have not been consistent across populations.² Such variations may reflect differences in population characteristics, genetic background, sample composition, and methods used for rugae classification and measurement. The relative stability and individuality of palatal rugae have been emphasized in forensic identification studies.^{1,2}

Distinct differences in rugae characteristics were also observed among the malocclusion groups. Class I subjects were predominantly associated with straight and irregular rugae, Class II subjects with wavy and forking patterns, and Class III subjects with longer and more anteriorly directed rugae. Previous investigations have demonstrated associations between palatal rugae number, pattern, length, and orientation and Angle's classes of malocclusion.^{6,7} Differences among studies may be related to population characteristics, sample size, age distribution, classification criteria, and methodological variations in the assessment of rugae morphology.

The association between palatal rugae and craniofacial growth pattern is of particular interest because palatal development is closely related to craniofacial morphogenesis. Experimental studies have demonstrated that molecular signaling pathways, including Sonic hedgehog signaling, play important roles in the morphogenesis and spatial patterning of palatal rugae.^{4,5} In the present study, subjects with a horizontal growth pattern exhibited a greater number of rugae on both sides and longer first and second left rugae, whereas the third left ruga was longer in

subjects with a vertical growth pattern. These findings suggest that differences in rugae morphology may accompany variations in craniofacial growth, although the underlying biological mechanisms require further investigation.

The clinical relevance of palatal rugae is supported by their relative stability during orthodontic treatment. Their use as reference structures for the assessment of anteroposterior tooth movement and dental cast analysis has previously been described.³ Palatal rugae have also been recognized as potentially useful anatomical landmarks in clinical and forensic applications.^{1,2} However, although the present findings demonstrate statistically significant associations, palatal rugae should be regarded as supplementary rather than independent diagnostic markers. Their morphology may be influenced by population-specific factors and developmental variation, and the observed associations do not establish a causal relationship with malocclusion or craniofacial growth pattern.

The forensic relevance of palatal rugae is related to their individual variation, relative stability, and protection by surrounding oral structures. These characteristics make them potentially useful as supplementary features in human identification.^{1,2} Nevertheless, palatal-rugae analysis should complement, rather than replace, established identification methods such as dental records, fingerprints, and DNA analysis.

The study has certain limitations. The cross-sectional design prevents assessment of temporal changes or causal relationships. In addition, the study was conducted at a single institution and included a population from one geographic region, which may limit the generalizability of the findings. Assessment was performed on dental casts, and three-dimensional changes in palatal morphology could not be evaluated. Future multicenter longitudinal studies involving larger and ethnically diverse populations, together with three-dimensional imaging and standardized classification methods, may provide further evidence regarding the diagnostic and forensic significance of palatal rugae.

Overall, the findings indicate that palatal rugae demonstrate measurable variations according to gender, malocclusion, and craniofacial growth pattern. Their relative stability, individuality, and accessibility support their potential role as adjunctive anatomical

markers in orthodontic assessment and forensic identification.

V. CONCLUSION

The present study demonstrated significant associations between palatal rugae characteristics and gender, Angle's malocclusion, and craniofacial growth pattern. Females exhibited a greater number of rugae and significant differences in the lengths of selected left-sided rugae, while Class III subjects demonstrated distinct variations in rugae number and length. Horizontal and vertical growth patterns were also associated with differences in rugae number and selected rugae lengths.

These findings suggest that palatal rugae may serve as useful supplementary anatomical markers in orthodontic assessment and forensic identification. However, their diagnostic value should be interpreted in conjunction with established clinical and radiographic parameters. Further multicenter longitudinal studies using standardized three-dimensional assessment methods are warranted to validate these associations.

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