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RESEARCH ARTICLE

Application of Calcorrugoscopy for Assessing Variations in Palatal Rugae Pattern among the Native Population of Riyadh Province in Saudi Arabia

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Abstract

Objectives: This study aims to analyze the palatal rugae pattern in the native population of Riyadh province in Saudi Arabia to understand whether the rugae patterns are unique to these ethnic origins and determine whether these palatal rugae patterns can be used as an adjunct aid in biometric human identification. **Methods:** A cross-sectional descriptive study was conducted among 200 participants within the age group ranging from 18 to 35. Their rugae patterns were analyzed macroscopically (Calcorrugoscopy) to record the length, shape, direction, and unification of the rugae pattern. **Findings :** It was found that females had a more significant number of palatal rugae (4.83 $\pm$ 1.05) as compared with males (4.30 $\pm$ 0.93) on the right side, while a reverse trend was seen in terms of the mean length of rugae where males (1.10$\pm$0.20) showed longer palatal rugae on the left side than females (0.97$\pm$0.17). This difference was statistically significant (p=0.001). A statistically significant difference was found between the mean length of rugae on either side of the palate (p=0.001) with longer rugae on the left side (1.04$\pm$.20) than the right side (0.97 $\pm$0.16). Furthermore, a statistically significant difference based on sex was found in straight, curved, convergent, and branched palatal rugae, in the rugae oriented towards the left side of the palate (p=0.001) and in the unification of rugae on the palate's left side (p=0.001) based on sex. **Novelty:** The natives of Riyadh had a unique characteristic of unification and lesser number of rugae compared to other ethnic groups in Saudi Arabian Population which helps in differentiating them from other ethnicity.

Keywords: Ethnic identification; Palatal rugae; Unification; Saudi Arabia

1 Introduction

Palatal rugae are mucosal folds located intraorally behind the incisive papillae on either side of the median palatine raphe. Since the palatine rugae are a stable landmark; they may also play an essential role in clinical dentistry. For example, rugae are taken as stable reference landmarks in orthodontics for the superimposition of pre-and post-treatment cephalometric tracings. They are crucial for phonetics as they provide tactile sensation for proper articulation, influence treatment plans while fabricating complete dentures, and diagnose submucosal clefts in the palate[(1)]. Moreover, trauma and chemical effects cause fewer extreme changes in palatal rugae than the remaining body parts. Other than these, palatal rugae also are helpful for forensic identification purposes in case of disfigurement following a death by drowning, plane crash, or road traffic accident. Hence, 'Palatal rugoscopy' is emerging as a potential tool for human identification obtained by inspecting the palatal rugae inside the mouth[(2)]. If unique patterns of rugae could be identified for different ethnic groups, they would identify their ethnicity.

It is interesting to know that palatal rugae only change in length throughout their lifetime, although the position remains constant up to seven days after death. There seems to be a genetic influence on how rugae patterns show sexual dimorphism and ethnic variations. Studies among Australian Aborigines, Saudi Arabians, Egyptians, Indians, Iranian, Yoruba group, and Iraqi population have reported the applicability of palatal rugae in identifying sex and population differences[(3–7)]. At the same time, many disagree that palatal rugae detect sexual dimorphism[(8–10)]. Studies in the Egyptian and Saudi populations show that these structures differed significantly even among children[(9)]. While these studies utilized palatine rugae, dimensions of the maxillary molar, and maxillary canine for personal identification and sex assessment, Syed et al. determined the sexual dimorphism of rugae patterns in a Saudi Arabian population by converting the rugae pattern into alphanumeric codes to generate scannable quick response codes[(3)].Variation in shapes, number, and length of palatal rugae have been found among many populations. For example, Kolude et al, reported that variables in forms had more discriminatory power than the rugae dimension[(7)]. Nevertheless, Fatima and Fida found no association between palatal rugae's morphological characteristics and sagittal skeletal patterns[(11)].

Variation according to sex, ethnicities, and left-right asymmetry, as well as resistance to deformation and ease of use, make palatal rugae an excellent candidate for population differentiation. Therefore, the present study aims to analyze the palatal rugae pattern in the native population of Riyadh province in Saudi Arabia in terms of the mean number of rugae, mean length of rugae, frequency of shape, location, direction, and unification of rugae based on sex and left-right asymmetry. Thus this study aims to see if the rugae patterns are unique to specific ethnic origins and if these palatal rugae patterns can be used as an adjunct to biometric human identification.

2 Materials and Methods

This cross-sectional descriptive study was conducted in Riyadh, Saudi Arabia, among patients aged between 18-35 years who visited the Outpatient Department of Zulfi College of Dental Science between 1 January 2019 and 30 June 2019. The Majmaah University Institutional Ethical Committee approved the research protocol, Saudi Arabia (I.E.C. no: 38/135), in compliance with the Helsinki Declaration (as amended in Edinburgh, 2000).

The participants explained the examination procedure and were recruited using a simple random sampling technique. A total of 200 participants within the age group ranging from 18 to 35 years with Class I malocclusion was initially recruited for the Riyadh province study. To ensure that all of the participants were from the same geographical area, extensive sociodemographic data including age, sex, ethnic origin, socioeconomic status, marital status, level of education and region of the nativity were collected. The sample size calculation was done using G Power 3.1 software using the mean and standard deviation values of rugae patterns in the male and female populations based on a similar study done by Fahmi et al. It was calculated to give 90% power at the 5% significance level [12]

Inclusion criteria included individuals a) native of Riyadh region between 18–35 years, b) the presence of Class I malocclusion, c) consented to participate, and d) both males and females. However, individuals with a previous history of maxillo-facial surgery, maxillofacial trauma, skeletal deformities, palatal asymmetry, inflammation of palatal mucosa, congenital cleft palate, high arch palate, class II and III malocclusion, allergic to impression materials were excluded from the study.

After obtaining the participants' informed consent, the maxillary dental arch impressions were made using a perforated metal stock tray using alginate impression material. To determine the validity of calcorrugoscopy, the research models generated from the impression were devoid of any air bubbles. Following this, rugae patterns were delineated using a sharp graphite pencil underhand lens magnification on every study cast, which was analyzed macroscopically (Calcorrugoscopy) according to Thomas and Kotze classification cited by Sekhon et al and Kapali et al [13]. A digital vernier caliper of 0.01 mm accuracy was used to measure the palatal rugae's dimension. All the measurements were determined by one calibrated examiner in a well-illuminated room to eliminate inter-calibration error. Intra-examiner reliability was assessed by repeating the measurement of 10 casts at an interval of two-time points. The Kappa value for Intra examiner reliability was 0.8.

Length, shape, direction, and unification of the rugae pattern were considered to classify them. The most significant dimension of each rugae was measured irrespective of its shape and graded as primary (more than 5 mm), secondary (3-5 mm), and fragmentary (2-3 mm) rugae. Rugae < 2 mm were disregarded. Primary rugae were further categorized as Type A: 5-10mm and Type B: ≥10mm. Based on their shapes, rugae were divided as a) curved: rugae were crescent shape and curved gently, b) wavy: rugae had a slight curve at the origin or termination of curved rugae, c) straight: rugae ran directly from their origin to termination, d) circular: rugae that formed from a definite continuous ring were classified as circular and, e) unification: joining of two rugae at their origin or termination. Based on rugae's branching concerning the origin, unification was further divided into diverging and converging rugae.

2.1 Statistical Analysis

The collected data were subjected to statistical analysis using S.P.S.S. version 21.0. The normality tests of Kolmogorov-Smirnov results showed that all variables do not follow a normal distribution. Therefore, non-parametric tests were applied to the data. Descriptive statistics was performed. Data were presented as mean ± standard error (S.E.). Mann-Whitney U test was used for inter-group comparison of the mean number of rugae, mean length of rugae based on sex and side. The Chi-square test was used to compare the difference in frequency of shape, location, direction, and unification of rugae based on sex and side of the palate. A calculated P value less than 0.05 was considered to be statistically significant.

3 Results

Out of the 200 participants, 132 participants completed the study. Sixty-eight participants were dropped out of the study due to the following reasons -14 participants did not give informed consent,15 participants personal data was incomplete, 16 participants had a mixed ethnic origin, 6 participants developed an allergy during impression making, 17 participants study casts were excluded for rugae assessments as void incorporation, lead to deformed dental casts. The participants' mean age was 24.09±3.32 years, out of which there were 71 males (53.8%) and 61 females (46.2%). A comparison of the mean number and length of palatal rugae on either side of the palate based on sex (Table 1). Females had a more significant number of palatal rugae (4.83 ± 1.05) as compared with males (4.30 ± 0.93) on the right side, and this difference was statistically significant (p=0.003). The left side showed no statistically significant difference based on sex (p=0.567). A reverse trend was seen in terms of the mean length of rugae, where males (1.10±0.20) showed longer palatal rugae on the left side than females (0.97±0.17), and this difference was statistically significant (p=0.001).

Comparison of mean length and the number of rugae between the right and left side palate shows a statistically significant difference between the mean size of rugae on either side of the palate (p=0.001) with longer rugae on the left side (1.04±.20) than the right side (0.97 ±0.16) Table 2. However, the mean number of rugae on the right side (4.55±1.02) and left side (4.38±0.92) showed no statistically significant difference (p=0.21). A statistically significant difference based on sex was found in straight,

Table 1. Comparison of the mean number of rugae and mean length of rugae on the right and left based on sex

Variable		Sex	N	Mean	Std. Deviation	p-value
Mean Number of Rugae	Number Right	Male	71	4.30	0.93	0.003*
		Female	61	4.83	1.05	
	Number Left	Male	71	4.43	0.96	0.567ns
		Female	61	4.32	0.87	
Mean Length of Rugae	Length Right	Male	71	0.99	0.16	.106ns
		Female	61	0.95	0.15	
	Length Left	Male	71	1.10	0.20	.001*
		Female	61	0.97	0.17	

Mann whitney U test; *p value <0.05 – statistically significant; ns- not significant

curved, convergent, and branched palatal rugae Table 3.While straight rugae were present more in males (2.73±1.38) than in females (1.70±1.16), palatal rugae with curved, convergent, and branched shapes rugae were more in females. When the frequency of the direction of rugae was assessed between males and females Table 4, it was found that there was a statistically significant difference in the rugae oriented towards the left side of the palate (p=0.001). Rugae oriented towards the right side did not show any statistically significant difference between males and females (p=0.77). The frequencies of unification (right and left side) of rugae between males and females were compared Table 5. A statistically significant difference was found in the unification of rugae on the palate's left side (p=0.001) based on sex. More cases of unification cases on the left side were reported in females, with 57.9% convergent and 42.1% divergent cases. However, there was no statistically significant difference in rugae's unification on the palate's right side (p=0.307) based on sex. More unification cases were seen among males, with 7.7 % convergent and 89.7 % divergent cases on the right side Figures 1 to 4.

Table 2. Comparison of mean length and mean number of rugae between right and left side palate

Variable	**Side**	**N**	**Mean**	**Std. Deviation**	**p value**
Mean Length of Rugae	Right	132	.9773	.16352	0.001
	Left	132	1.0433	.20013	
Mean Number of Rugae	Right	132	4.5530	1.02126	0.211
	Left	132	4.3864	.92173	

Mann whitney U test; *p value <0.05 – statistically significant; ns- not significant

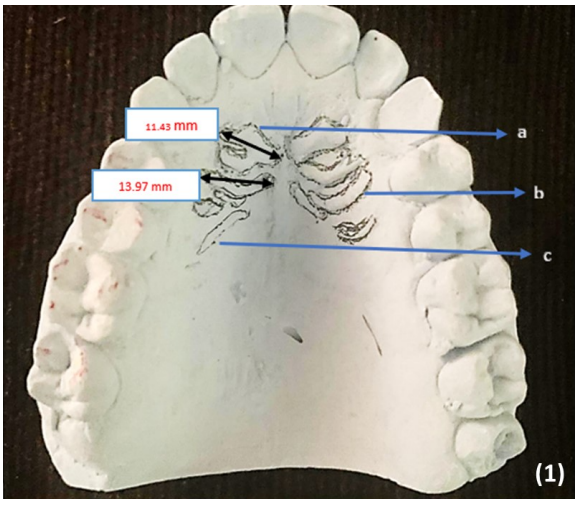

Fig 1. a-Divergent– positive direction; b-Curved-positive direction; c-Straight – negative direction

Table 3. Comparison of shape of rugae between male and female

	Sex	N	Mean	Std. Deviation	Sig. (2-tailed)
Straight	Male	71	2.7324	1.38314	0.000
	Female	61	1.7049	1.15966	
Wavy	Male	71	2.9437	1.92641	0.898
	Female	61	2.7377	1.59061	
Curved	Male	71	1.5634	1.64519	0.014
	Female	61	2.2295	1.64715	
Divergent	Male	71	1.1408	1.08622	0.051
	Female	61	1.4754	.99342	
Convergent	Male	71	.2958	.51808	0.000
	Female	61	.9508	.97342	
Circular	Male	71	.0423	.20260	0.777
	Female	61	.0328	.17956	
Branched	Male	71	.0000	.00000	0.014
	Female	61	.0820	.27659	
Absent	Male	71	.0000	.00000[a]	N/A
	Female	61	.0000	.00000[a]	

Mann whitney U test; *p value <0.05 – statistically significant; ns- not significant

Table 4. Comparison of frequency of direction of rugae between male and female

Sex		Direction Right				Total	Chi Square	p value
		Anterior	Posterior	Horizontal	A/P			
Male	N	43	21	6	1	71	1.129	0.77[ns]
	% within Sex	60.6%	29.6%	8.5%	1.4%	100.0%		
	% within Direction Right	54.4%	51.2%	60.0%	100.0%	54.2%		
Female	N	36	20	4	0	60		
	% within Sex	60.0%	33.3%	6.7%	0.0%	100.0%		
	% within Direction Right	45.6%	48.8%	40.0%	0.0%	45.8%		
Total	N	79	41	10	1	131		
	% within Sex	60.3%	31.3%	7.6%	0.8%	100.0%		
	% within Direction Right	100.0%	100.0%	100.0%	100.0%	100.0%		
		Direction Left						
Male	N	53	16	2	0	71	22.255	0.001*
	% within Sex	74.6%	22.5%	2.8%	0.0%	100.0%		
	% within DirectionLeft	67.1%	51.6%	9.5%	0	54.2%		
Female	N	26	15	19	0.0%	60		
	% within Sex	43.3%	25.0%	31.7%	0	100.0%		
	% within DirectionLeft	32.9%	48.4%	90.5%	0.0%	45.8%		
Total	N	79	31	21	0	131		
	% within Sex	60.3%	23.7%	16.0%	0.0%	100.0%		
	% within DirectionLeft	100.0%	100.0%	100.0%	0	100.0%		

*p value <0.05 – statistically significant; ns- not significant

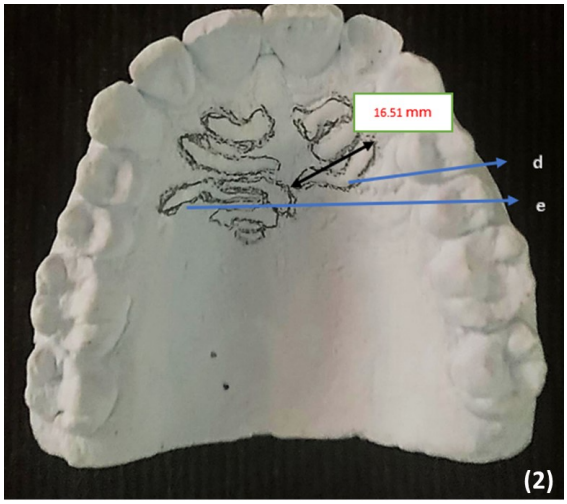

Fig 2. d-Wavy –positive direction; e-Wavy –negative direction

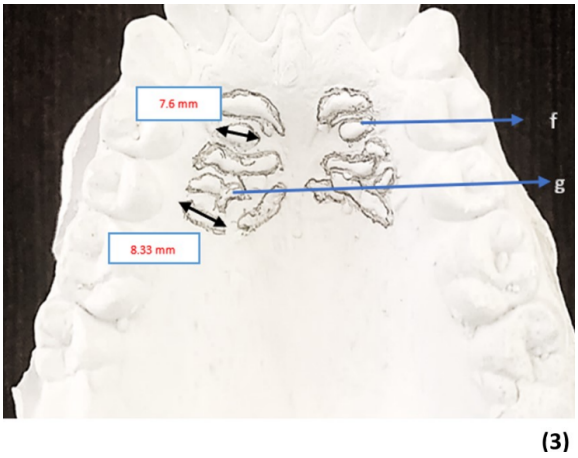

Fig 3. f-Circular; g-convergent- positive direction

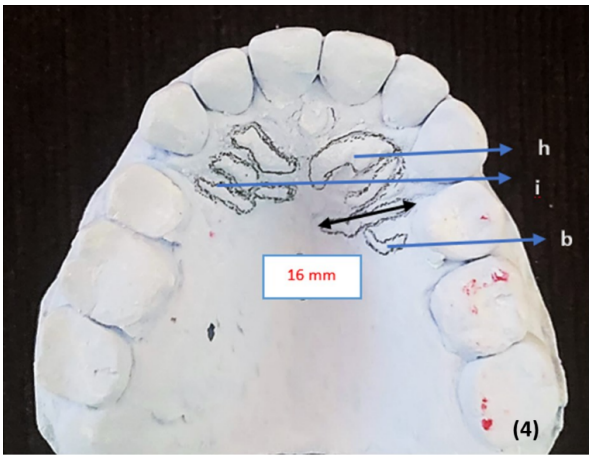

Fig 4. h-Curved-negative direction; i-Straight–positive direction.

Table 5. Comparison of frequency of unification (right) of rugae between male andfemale

Sex		Unification Right			Total	Chi Square	p value
		Diverging	Converging	Di/Co			
Male	Count	35	3	1	39	2.361	0.307ns
	% within Sex	89.7%	7.7%	2.6%	100.0%		
	% within Unification Right	61.4%	37.5%	100.0%	59.1%		
Female	Count	22	5	0	27		
	% within Sex	81.5%	18.5%	0.0%	100.0%		
	% within Unification Right	38.6%	62.5%	0.0%	40.9%		
Total	Count	57	8	1	66		
	% within Sex	86.4%	12.1%	1.5%	100.0%		
	% within Unification Right	100.0%	100.0%	100.0%	100.0%		
		Unification Left					
Male	Count	25	3	0	28	15.251	0.001**
	% within Sex	89.3%	10.7%	0.0%	100.0%		
	% within Unification Left	61.0%	12.0%	0.0%	42.4%		
Female	Count	16	22	0	38		
	% within Sex	42.1%	57.9%	0.0%	100.0%		
	% within Unification Left	39.0%	88.0%	0.0%	57.6%		
Total	Count	41	25	0	66		
	% within Sex	62.1%	37.9%	0.0%	100.0%		
	% within Unification Left	100.0%	100.0%	0.0%	100.0%		

4 Discussion

Studies reporting racial profiling based on palatal rugae for the Saudi Arabian population are scanty. This is the first study from Riyadh province that has identified a specific unification pattern on palatal rugae among Saudi natives to the best of our knowledge. In this study, casts were delineated using a pencil and analyzed macroscopically (Calcorrugoscopy) according to Thomas and Kotze classification cited by Sekhon et al. to evaluate various characteristics of palatine rugae [13]

4.1 Unification

The most significant finding of this study was identifying a specific pattern in the unification (right and left side) of rugae between males and females of the Saudi population. More unification cases were seen in females on the left side, among which 57.9% were convergent and 42.1%, divergent cases. More unification cases were seen among males, with 7.7 % convergent and 89.7 % divergent cases on the right side. We propose that the unification of rugae can be used for ethnic identification of the Saudi Arabia population. Globally, many authors have reported palatal rugae's unification as a method for identifying a person's ethnicity, although there are only a few studies from Saudi Arabia to compare.

Elmoazen and Elsherbini [4] demonstrated less common unification (3.3% diverge form and 2.1% converging form) among the Qassim population of Saudi Arabia, while the present study found an increase in unification among females on the left side (57.9% convergent and 42.1% divergent cases) and males on the right side (7.7 % convergent and 89.7 % divergent cases). Elmoazen and Elsherbini [4] used digital photographs to identify palatal rugae, whereas we employed manually delineated study casts. The plausible reason for fewer unification cases in some studies could be because rugae sometimes merge with the rest of the palate on two-dimensional photographs, leaving them undetected.

Increased prevalence of divergence rugae can be seen in a Saudi population when palatal rugae's unification was studied between Egypt and Saudi children [5]. Diverging rugae were found to be more common in Saudi children (4.84 %), indicating that genetic variances and environmental alterations occur in distinct rugae populations' patterns. Thomas and Kotze, cited by Sekhon et al. in their research in South Africa, concluded that environmental effects are unlikely to influence rugae creation and that rugae morphology is genetically monitored [13].

A specific pattern in the unification of palatal rugae based on sex was observed in our study, which is similar to a coastal population of Andra Pradesh, India [14]. However, Kapali et al. found that unification changes were infrequent in a landmark

study done among Aborigines residing at Yuendumu (Australia) and Caucasians (Australian twins and their families) using Thomas and Kotze classification[6]. In the current research, the divergent form of unification was more prevalent, contrary to Azab et al, who studied 108 patients (18-35 years) in Cairo, Egypt, and found a more convergent form of unification than diverging[9].

Another study found that Egyptians and Malaysians shared specific characteristic patterns and directions of rugae[15]. Still, sexual dimorphism was not evident in the form, orientation, and unification status of rugae among both populations. A unique trend was also observed in schoolchildren, where converging unification trends were more among boys[16]. Simultaneously, a diverging pattern was more among girls when 30 schoolchildren were examined for 8-15 years. It is possible that some but unidentified genes during embryogenesis influence the collagen fiber's orientation and control the pattern of rugae in different populations[5]. To substantiate this report's results, further research with larger sample sizes and based on genetic considerations may be required.

4.2 Bilateral Asymmetry

Another significant finding of the present study was the right and left asymmetry in the number of rugae. Females had more palatal rugae than males on the right side, while males showed longer palatal rugae on the left side than females. Several rugae vary throughout the studies reported globally. While the mean number of rugae in our study ranged between 4.30 to 4.83, most of the authors reported more rugae than this. A study by Elmomozen and Elsherbini in 2017 found a gender variation in the number of palatal rugae where the mean value for females was found to be 8.85 ± 1.41 and 9.38 ± 1.13 in males[4]. The lowest number of rugae was reported by Kim et al. among 5-18-year-old patients in Korea, and it ranged from the right side[17]. While we disregarded rugae < 2 mm, others would have included them. That could be a possible reason for significantly more rugae in some studies. One type of rugae may develop at the other's expense, thereby showing an indirect developmental relationship between the number of primary and secondary rugae[18].

Most of the rugae were oriented towards the palate's left side between males and females in the present study. A link between the wingless-type M.M.T.V. integration site family (Wnt) and regulation of the crucial aspects of cell processes during palate formation has been reported[19]. In the Wnt signaling pathway, left-right asymmetry in palatal rugae was associated with genetic variants. According to them, the most abundant rugae are wavy, curve rugae, and the bilateral asymmetry in the number of rugae due to the rs708111 A allele and rs1533767 G allele, which was found to increase the risk more than two times[20]. The presence of two risk alleles of WNT3A was also found to have a higher chance of this bilateral symmetry being present. This idea was based on the fact that genetic variants were historically associated with defects such as oral clefts in WNT11 and WNT3A[21].

4.3 Sexual dimorphism

Various studies have reported sexual dimorphism in the number of rugae[16,17]. In our study, females had a more significant number of palatal rugae than males, contrary to most earlier studies. This reflects broader palates and more extensive anthropometric cephalic measurements. However, the length of rugae was more in males in this study, therefore, the rugae length could be a differentiating factor between the sexes. A contradictory study among the Kerala population by Ashok A et al. 2020 reported no gender difference in the length and number of palatal rugae[22].

4.4 Variations in shapes

Among several cultures, differences in the shapes of rugae have been identified. We propose a significant association between the forms of rugae and ethnicity among participants of the Riyadh region. Straight rugae were more present in males than females in this sample, and curved, convergent, and branched rugae were more present in females than males. This varies from Saudi Arabia's previous findings[4]. In most studies, wavy and straight type palatal rugae were the most common form of rugae without sex variation.

A Study done in the Karachi population reported that common rugae pattern observed in males was wavy compared to curved pattern in females and they observed significant gender dimorphism in the size of secondary rugae[23]. Kolude et al. discovered that Nigeria's Yoruba community had more wavy and straight patterns while the Igbo's of the same country had more curved and circular patterns[7]. The mean incidence of the wavy, round, curve, and straight shapes of the rugae did not differ significantly between the two groups. The Igbo group had more secondary rugae than the Yoruba group, and the differences in mean occurrence were significant. There are no notable differences in the primary shape of the rugae's between Igbos and Yorubas. Rugoscopy may be useful in ethnic distinction because there were significant differences in the number of secondary

and non-classified rugae between the two classes.

4.5 Recent advances

Recent research reports various uses of palatal rugae such as the association between the pattern of primary rugae with the angle's classes of malocclusion, the applicability of palatal rugae as reference points for cast superimposition in orthodontic patients, the identification of schizophrenic patients, and gender identification [11,24–26]. Because their position is usually consistent, palatal rugae are used for identification reasons. The regional palatal vault dorsal to the third rugae and the medial two-thirds of the third rugae have been found to be stable enough for 3-dimensional (3D) digital model superimposition. The use of a three-dimensional model of the palate in personal identification has also been reported, owing to the distinctive structure of the palatal rugae. In a Korean study, when employed as an area of reference in 3D digital model superimposition during the orthodontic intervention, a fluctuation in palatal rugae numbers influenced the third primary rugae's anteroposterior position [27].

In 2021, Bragea S et al. found statistically significant relationship in the number and shape of all palatal rugae in dizygotic twins, except for the shape of the first two right rugaes, implying its role in dizygotic twin identification [28].

Recent technology has evolved with an "Identity Base", a complex information system used for personal identification by utilizing three-dimensional palatal scans in digital format and this can even be used to estimate the age of a person. Studies have shown that the stability of the palatal rugae was not affected even after the slow maxillary expansion during orthodontic treatment [29,30].

4.6 Strengths and Limitations

This is a novel study among the Saudi population, which identified a unification pattern among the natives. No previous research describes the characteristics of palatal rugae of the Riyadh population of Saudi Arabia. However, these interpretations should be made with caution as these studies had only a small sample size and further research work on larger samples. Manual tracing of palatal rugae for assessing morphological characteristics using dental casts needs to be replaced by more advanced methods such as three-dimensional scanners and computerized techniques. To improve reliability and decrease subjectivity, rugae measurements need to be done in three dimensions on a computer screen. Samples must be studied from different countries to increase the generalizability of the study. It is also recommended that the findings be checked by a more significant number of evaluators with varying levels of expertise, a larger sample size, different dental treatments such as Rapid Maxillary Expansion, and various patient categories.

5 Conclusions

On the right side, females (4.83 1.05) showed a higher number of palatal rugae (4.30 0.93) than males (4.30 0.93), demonstrating gender dimorphism. On the left side, males had longer palatal rugae than females. Males' rugae patterns were largely straight, but females' rugae patterns were mostly curved, convergent, and branching. Females had more convergent and divergent left side unifications than males, with 57.9% convergent and 47.9% divergent.

The palatal rugae pattern is unique to each individual, and its use in forensic identification has been suggested. Within the constraints of this investigation, the rugae traits discovered in this study can be classified as population-specific for the Riyadh, Saudi Arabia region. The high frequency of unifications and the lower number of rugae suggest that, in comparison to other racial groups, Riyadh residents have fewer rugae. We infer that the shape and amount of rugae in Riyadh natives assist to distinguish them from other ethnic groups. To verify our findings, however, detailed research in large samples should be conducted.

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