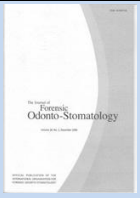

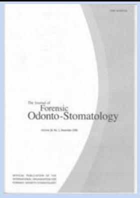

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Association Among Geometric Configurations Of Palatal Rugae

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ABSTRACT

Background: The associations between the length and morphological shape-related characteristics of palatal rugae have not been fully explored. Objective: We aimed to assess the possible association among various geometric configurations of the palatal rugae in an adult population. Materials and methods: The maxillary dental casts of 217 non-growing subjects (95 males, 122 females, mean age 25.5±7.6 years) were scanned (laser scanning system Perceptron ScanWorks® V5) and digitized for linear measurements. The casts were also surveyed for visual categorization into curved, wavy, straight and other topographical forms, along with spatial direction of the rugae and the presence of unification. The rugae were categorized as primary, secondary, and fragmentary based on their lengths (>5mm, 2-3mm, <2mm, respectively). Chi square and one-way ANOVA and post-hoc tests were used to compare the palatal rugae groupings. Results: Primary and backward-directed rugae prevailed in the total sample (84.7% and 49.3%, respectively). Wavy form was dominant among primary lengths, while straight form was associated with the shorter secondary and fragmentary groups (p=0.0042). Absence of unification was the norm (88.8%). Conclusions: Associations of length and shape characteristics among palatal rugae combine wavy patterns with increased length, and straight forms with shorter folds. These features contribute to the definition of ruga individuality in combination rather than separately.

KEYWORDS: Forensic odontology, human identification, palatal rugae, morphology, dimensions, digital models

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INTRODUCTION

Because of fingerprint-like individuality, relative temporal stability, and resistance to external physical and chemical conditions and delayed post-mortem decomposition,[1,2] the palatal rugae have stirred much research in forensic odontology and post-mortem identification.[3-5] Major work has been committed to research in extensive details the morphology and topography of these structures. Their reported stability has been recognized by orthodontic researchers who used the mucosal folds in dental cast superimposition to assess tooth movement.[6-8] In this perspective, more accurate acquisition of palatal dimensions through 3-dimensional digital scanning technology has prompted the development of more reliable digital palatal rugae superimposition techniques.[9-11]

Morphometric evaluations of the rugae have focused on dimensions (e.g. categorization on length or direct length measurements, distances between ruga bands, angulation of rugae) and shapes (e.g. types, unification).[12,13] Various conclusions have been reached from these studies regarding prevalence of types and categories, gender differences, and symmetry.[14-21] Although some findings were not concordant either because of ethnic/racial differences or sampling methodology,[20] particularly regarding the distribution of shape categories (curved, wavy, and straight), all converged on the individuality of the rugae, strengthening their potential forensic use.

While dimensions and shapes have been investigated separately, we hypothesized that they may be associated, such as curvy or wavy rugae being longer than the straight structures. Accordingly, the aim of this study was to assess possible associations between the dimensions and morphology of the palatal rugae in an adult population.

MATERIAL AND METHODS

The study sample consisted of the pre-treatment maxillary dental casts of 217 non-growing subjects (95 males, 122 females, mean age 25.5 ± 7.6 years) recruited from the database of patients treated in the orthodontic division at the American University of Beirut Medical Center. Strict criteria were followed for a- inclusion: casts deemed of high quality from a set of fully erupted permanent teeth, no posterior cross-bite, crowding <2mm, and b- exclusion: subjects with systemic disease, craniofacial anomalies, history of orthodontic treatment and/or surgical treatment involving the head and neck. The study was approved by the Institutional Review Board.

De-identification of maxillary and mandibular dental casts preceded analysis by research support personnel who were not directly involved in the project. The principal investigator (MS) performed all remaining procedures. Dental casts were scanned through the laser scanning system Perceptron (ScanWorks® V5) that included a scanning probe attached to the Cimcore Infinite 2.0 (Seven axis) CMM Arm, complemented by a point cloud handling software (IM Inspect from PolyWorks, InnovMetric Software, Quebec, Canada).

Before saving the 3-dimentsional images for subsequent analysis, they were carefully scrutinized for sufficient surface profile for all relevant anatomical structures. The saved data files were processed (through IMInspect software from PolyWorks®) to generate the polygonal model derived from the point cloud for all anatomical structures at point-to-point resolutions up to 12µm. The same software was used to measure and record the palatal rugae measurements.

The anterior (first), middle (second) and posterior (third) rugae were numbered 1, 2, and 3, respectively, and the right and left sides identified as R and L (Fig. 1). The following categorizations were generated, after Lysell[7] and Thomas and Kotze,[8] as described by Kapali et al.[21]:

1. Length, which was first estimated for each ruga then measured through correspondence with digital scans on the scanned casts: primary rugae (>5mm in length); secondary rugae (3-5mm in length) and fragmentary rugae (2-3mm in length). Rugae less than 2mm in length were discarded.
2. Ruga direction, based on the angle formed between ruga and a line perpendicular to the median palatal raphe (MPR)- (Fig. 2): forward-directed (positive angle formed with MPR perpendicular); straight (parallel to MPR perpendicular) or backward-directed (negative angle formed with MPR perpendicular).

Following direct visual inspection, the palatal rugae were drawn with a pencil, then classified (also according to Lysell[7] and Thomas and Kotze[8]). Based on shape, the rugae were stratified as (Fig. 3A): curved (simple crescent shape gently bending in the central zone of the ruga); wavy (basic serpentine shape, or presence of slight curves at ruga origin or termination); straight (runs in straight line from origin to termination); circle (forming a continuous definite ring) or non-specific (not conforming to any of the described shapes). Absent unification (ruga has one origin and one termination), the rugae were described as (Fig. 3B): diverging (immediate branching of the ruga from a common origin at the medial aspect) or converging (different origins that join in one termination at the lateral aspect).

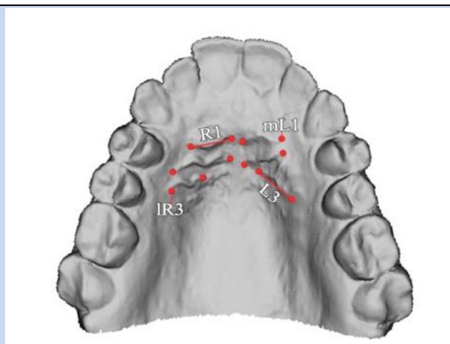

Fig. 1: Rugal digitization and linear dimensions. The most medial (m: mR1/mL1, mR2/mL2, mR3/mL3) and most lateral (l: lR1/lL1, lR2/LL2, lR3/lL3) points were digitized. The lengths of the rugae on right and left sides (R1, R2, R3, L1, L2, L3) were measured from most medial to most lateral points**.**

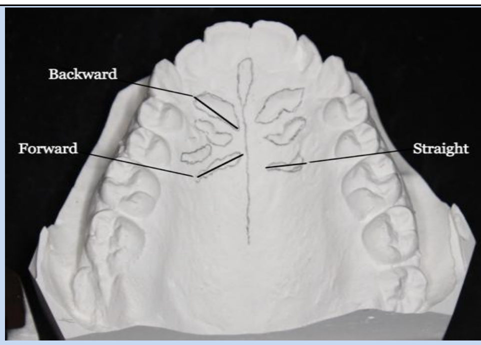

Fig. 2: Description of rugae direction

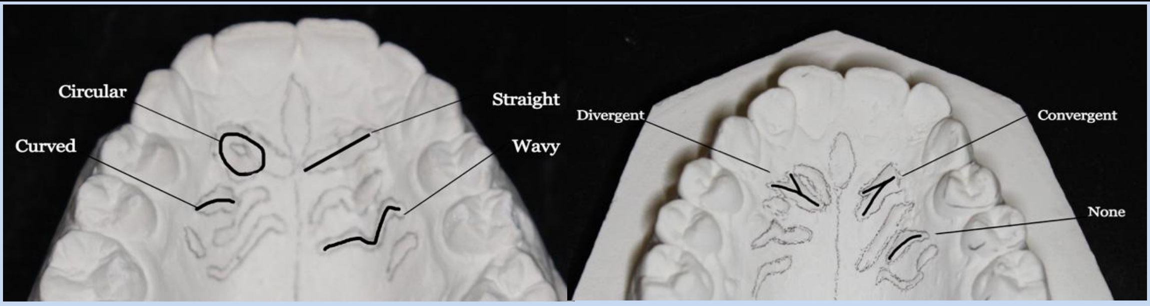

Fig. 3: Palatal rugae classified on shape (A) and unification (B)

The visual classification on length (primary, secondary, fragmentary) was compared with the digital length measures of corresponding rugae (n=350) on 50 casts through kappa statistics, resulting in a kappa coefficient equal to 0.96. Accordingly, the measurements gathered from the visual inspection were computed in the statistical analyses.

The dimensional data were computed within each classification group. Associations between shape categories (curved, wavy, straight, circular, non-specific) and length groups (primary, secondary and fragmentary) were evaluated with the chi-square test. Analyses of variance were applied to determine differences within the length subgroups. Both analyses were followed by a post-hoc analysis with Bonferroni correction to determine statistically significant comparisons.

All measurements (distances) and assessments (shapes) were repeated on 50 randomly selected dental casts at least 14 days after the initial analysis. To evaluate inter-rater reliability, similar computations were conducted on 50 randomly selected models by another investigator (RH). The repeated measures were evaluated with the two-way mixed effects intra-class correlations for absolute agreement on single measures. Data were processed using the Statistical Package for Social Sciences (IBM SPSS®, version 20.0, Armonk, NY) and Stata Statistical Software (version 11.1, College Station, TX). Statistical significance was set at 0.05.

RESULTS

The intraclass correlation coefficients gauging reliability of repeated length measurements within and between operators were high: $0.897<r<0.996$ for the intra-rater computations; $0.865<r<0.991$ for the inter-rater values. For repeated measures of the various shapes, direction and unification characteristics, the ranges were $0.892<r<0.968$ (intra-rater) and $0.875<r<0.977$ (inter-rater).

The prevalence of primary rugae was overwhelming (nearly 85%) compared to the secondary (~8%) and fragmentary (~6%) lengths. However, within each of these groups, the distribution of shape differed significantly (Table 1): nearly equal (about 1/3) curved, wavy and straight in the primary group, but greater percentages of straight in the secondary (49%) and fragmentary (~62%) groups. Within the shape groups, the wavy form was mostly associated with the primary length, the straight pattern mostly with the fragmentary then the secondary categories, whereas the curved rugae were in approximate proportions among the primary (34.5%), secondary (27.2%) and fragmentary (23.1%) types. When secondary and fragmentary forms were pooled (as the rugae shorter than 5mm) and compared with the primary group (rugae >5mm), the same conclusions were confirmed: predominant associations were between primary and wavy (to a lesser extent curved), and between shorter and straight rugae.

The prevalence of the backward-directed rugae was the highest in the primary, secondary and fragmentary groups. However, in the post-hoc test the rugae in straight direction in fragmentary groupings composed the only statistically significant association (Table 1). Unification was absent in the greatest majority of rugae (p<0.001).

Table 1. Association between rugae length categories and other morphological characteristics, according to Thomas and Kotze classification (n =1674)

	1		2		3		A		4	B	
	Primary		Secondary		Fragmentary		Chi-square		< 5 mm	Chi-Square	
	n 1419	% 84.8	n 151	% 9	n 104	% 6.2			n 255	% 15.2	
	n (%)		(n (%)		n (%)		χ^2	*p*	n (%)	χ^2	*p*
Shape											
Curved n=554 (33.1%)	489 (34.5)		41 (27.2)		24 (23.1)		65.81	<0.001	65 (25.5)	60.5	<0.001Ŧ
Wavy n=545 (32.6%)	494 (34.8)*		36 (23.8)		15 (14.4)*				51 (20)*		
Straight n=564 (33.7%)	425 (30)*		74 (49)*		65 (62.5)*				139 (54.5)*		
Circular n=10 (0.6%)	10 (0.7)		0 (0)		0 (0.0)				0 (0.0)		
Nonspecific n=1 (0.06%)	1 (0.1)		0 (0)		0 (0.0)				0 (0.0)		
Direction											
Forward n=299 (17.9%)	249 (17.5)		28 (18.5)		22 (21.2)		9.561	0.049	50 (19.6)	5.13	0.077
Straight n=549 (32.8%)	481 (33.9)		48 (31.8)		20 (19.2)*				68 (26.7)		
Backward n=826 (49.3%)	689 (48.6)		75 (49.7)		62 (59.6)				137 (53.7)		
Unification											
Absent n=1487 (88.8%)	1234 (87)*		149 (98.7)*		104 (10)*		32.86	<0.001	253 (99.2)*	32.74	<0.001Ŧ
Divergent n=157 (9.4%)	155 (10.9)*		2 (1.3)*		0 (0)*				2 (0.8)*		
Convergent n=30 (1.8%)	30 (2.1)		0 (0)		0 (0)				0 (0)		

*statistically significant after Bonferroni correction; Ŧ Fisher's Exact Test
A- Chi-square test for associations among variables in columns 1, 2, 3.
B- Chi-square test for associations between variables in column 1 (primary rugae) and column 2 (combined secondary and fragmentary rugae from columns 2 and 3).

In a comparison of the lengths in the various shapes within the largest group of primary rugae, the wavy form was the longest on average (11.17+2.59 mm), followed by the curved (10.04+2.34 mm) then the straight configurations (9.75+2.39

mm); statistically significant differences were noted between the wavy and both curved and straight folds (Table 2).

The multiple regression showing associations between rugae form and other morphological features revealed that the variables rugae length, direction and unification collectively were significantly associated with rugae shape ($p<0.001$)-Table 3. However, these morphological features only differentiated the wavy from the curved form; all comparisons between the straight and curved patterns were not significant ($p>0.05$). The following equation describes the relative log odds of rugae being wavy compared to them being curved:

$$\text{Ln}\frac{p\,(wavy)}{p\,(curved)} = -1.516 + 0.188\,length - 0.132 straight - 0.937 backward - 0.601 divergent - 0.819\,convergent$$

Increasing length was positively associated with greater likelihood of wavy rather than curved patterns, controlling for both rugae direction and the presence of unification ($p<0.001$). The odds of wavy rugae compared to curved decrease in backward rugae compared to forward direction rugae ($p<0.001$), and in divergent rugae compared to rugae without unification ($p=0.009$).

Table 2. Comparison of rugae length among the various shapes within the primary rugae (>5mm) group

Shape	n	Mean	SD	Curved vs Wavy	Curved vs Straight	Wavy vs Straight
Curved	427	10.04	2.34			
Wavy	389	11.17	2.59	<0.001*	0.306	<0.001*
Straight	344	9.75	2.39			

*Statistically significant, p<0.01

DISCUSSION

We report associations heretofore not clearly identified in the rich literature available on palatal rugae:

1. the paramount majority of rugae (nearly 85%) are primary (>5mm in length), as also reported in prior studies[14]; however, they were equally distributed among curved, wavy and straight in our sample. This disparity may be related to either the populations studied or methodological differences.
2. Wavy forms prevailed among the primary rugae; straight patterns are predominant in the lesser groups of secondary and fragmentary forms, understandably reflecting the fact that shorter rugae have less curves or waves.

   This novel contribution may relate to the specifics of the studied sample, or possibly generalized through various populations, thus possibly related to more genetic influence. Focused research is needed in this perspective.
3. Backward-directed rugae are most prevalent among all length categories of rugae.
4. Rugae are more likely to be curved if backward directed and if without unification.

Previous studies did not evaluate the associations between direction and length, thus investigations in other populations may provide a basis for future comparisons.

These observations essentially underscore the association of form and length, and form and direction, despite the prevalence of variability of arrangements among mainly the 3 first rugae. Accordingly, individuality may be summed up in the relationship between shape and length, rather than each of these features separately. Several rugoscopy studies have pointed out the prevalence of primary rugae length

Table 3. Multiple logistic regression showing associations between shape and other morphological features, according to Thomas and Kotze classification (n = 1160)

Shape	Coef.	Std. Err.	95% CI	*p* value
Curved	(base outcome)			
Wavy				
Constant	-1.516	0.360	[-2.221; -0.811]	<0.001**
Length	0.188	0.030	[0.129; 0.246]	<0.001**
Direction (*Forward*)				
Straight	-0.132	0.210	[-0.544; 0.280]	0.529
Backward	-0.937	0.203	[-1.335; -0.538]	<0.001**
Unification (*Absent)*				
Divergent	-0.601	0.231	[-1.054; -0.148]	0.009**
Convergent	-0.819	0.553	[-1.904; 0.265]	0.139
Straight				
Constant	0.398	0.357	[-0.300; 1.097]	0.264
Length	-0.485	0.031	[-0.108; 0.012]	0.114
Direction (*Forward*)				
Straight	0.023	0.230	[-0.427; 0.473]	0.920
Backward	-0.182	0.215	[-0.603; 0.239]	0.396
Unification (*Absent)*				
Divergent	-0.286	0.215	[-0.707; 0.135]	0.183
Convergent	-0.226	0.465	[-1.137; 0.685]	0.626
LR Chi^2 (10)	115.87			
Prob > Chi^2	<0.001**			
Pseudo R^2	0.0456			

Notes. Coef. = regression coefficient; Std. Err. = standard error;
LR Chi^2(*x*) refers to the Likelihood ratio Chi-square test statistic and associated degrees of freedom.
(Base): refers to the base outcome all other categories are compared to
*Statistically significant at $p \leq 0.05$; **Statistically significant at $p < 0.01$

and wavy shape.[15,21] Our findings are similar on the frequency of primary length, but the shape forms in our population were similar (Table 1). While the reported frequencies seem to be independent trends, our data disclose an association between primary and wavy. It is quite possible that the association would have been found in those previous studies had it been tested. In addition, the forward direction was found to be predominant by other investigators,[15] different from our observing a higher rate of backward direction (Table 1), which was also associated with the curved shape (Table 3). It may be argued that the actual length of curved and wavy rugae is greater than the measured value, as digital measurements were between the medial and lateral points of each fold. This observation may yield a difference in interpretation if the straight bands were longer than the curved and wavy. However, straight configurations were shorter than the other two varieties.

Regarding potential similarities between curved and wavy rugae if stretched out, it would be unlikely that the curved rugae are longer, because they essentially have one curve or wave as opposed to repetitive curves in the wavy form.
The association between dimension and form was confirmed by the multiple regression analysis, reflecting again a certain order of arrangement rather than a confusing array of random variations. Palatal rugae exist to provide a biologic function. Indeed, the rugae are involved physiologically in oral swallowing, enhancing the relationship between food and taste receptors in the dorsal surface of the tongue;[22] they also participate in speech as well as suction in children.[13] We propose that the mechanical advantage provided by the PR is increased friction for the function of the opposing tongue. Research is needed to sort out whether these functions contribute an environmental developmental component to the final disposition of the rugae bands. The predictive value of the multiple regression would underscore the strong genetic role in determining the ruga phenotype.

In summary, the study of associations among geometric configurations proved to be of relevant outcome and forensic significance, as it yielded important knowledge that seems logical, such as the link between straight and short rugae and longer wavy patterns. However, a basic limitation lies in the potential for generalization across populations. The results may be specific to the studied adult group, and would require validation at younger ages and across other geographic, racial and ethnic entities. In addition, the direct manual approach we used prolongs the process of investigation. With the improvements in mouth scanning digital technology, the collection of rugal data should provide faster and readily three-dimensional records.

Molecular forensics, when available, defy the usage of morphological methods such as palatal rugae, which obviously have not risen to routine forensic and medico-legal assessment. Nevertheless, rugoscopy must be explored fully because of its potential need when conventional records (dental, fingerprints) are not available or of limited value.

CONCLUSION

Primary, back directed, and lack of unification are the predominant features of palatal rugae, despite the endless combinations of these features with the main shape characteristics: curved, wavy and straight. These three forms were nearly equal in our population, but the wavy form prevailed in association with the primary longer rugae; the straight configuration dominated in the shorter secondary and fragmentary groups. Accordingly, far from the negation of order in the arrangement of palatal rugae, a scheme of organization appears to emerge from the association of shape and length features. The multiple combinations of the geometric variables bestow a unique fingerprint forensic value to these folds.

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