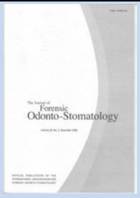

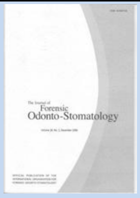

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Sex Prediction From Morphometric Palatal Rugae Measures

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The authors declare that they have no conflict of interest.

ABSTRACT

Background: While abundant research has been conducted on palatal rugae (PR), the literature pertaining to the sex dimorphism of the palatal rugae and their use for sex prediction is inconclusive. Moreover, palatal rugae have been classified into categories based on length, shape, direction and unification but accurate rugal morphometric linear and angular measurements have not yet been reported. Objective: The aims of this study were to -1- assess the dimensions and bilateral symmetry of the first three palatal rugae in an adult population and -2- explore sex dimorphism and the ability to predict sex from palatal rugae measurements. Materials and methods: The maxillary dental casts of 252 non-growing subjects (119 males, 130 females, mean age 25.6 ± 7.7 years) were scanned using a laser system (Perceptron ScanWorks® V5). Angular and linear transverse and anteroposteior measures of the first three palatal rugae were recorded. Independent samples t-tests and paired samples t-tests were used to test for side related differences and sex dimorphism. Multiple logistic regression was employed to model sex using associated palatal rugae measures. Results: Palatal rugae exhibited lateral asymmetry in the majority of bilateral measures. Males presented with larger values for 9 out of 28 parameters. Four linear rugae measurements and one angular measurement together correctly classified 71.4% of the subjects in their true gender. Conclusions: Morphometric palatal rugae measurements demonstrated promising usefulness in sex prediction. Recording morphometric linear and angular measures is recommended as an adjunct to the commonly used classification based on the shapes of rugae.

KEYWORDS: Palatal rugae, forensic odontology, sex prediction, human identification

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INTRODUCTION

A specific part of the palate, the area containing the palatal rugae, has been shown to be of significant value to forensic odontology and medicolegal identification processes.[1,2] Also known as plicae palatinae transversae, these structures are a series of transverse folds of palatal mucosa that are located in the anterior region of the palate on either side of the median palatal raphe and behind the incisive papilla.[3] Although prevalent conventional forensic methods to rely on fingerprints, DNA and dental records, the uniqueness and immutability of the palatal rugae,[1-6] their reported sex dimorphism[7,8] and their apparent ethnic specificity[9,10] promote their use in instances where fingerprints are not available (fires, decomposition and massive trauma) and when conventional dental records are of limited value (because of edentulism or significant changes in dental work since last record).

To date, the vast majority of studies assessing the palatal rugae have been based on various classification systems based on characteristics such as length, shape, direction and/or other specific features such as the presence of unification or divergence.[11-13] Such classifications bestow simplicity characterization and summation, but the diversity of criteria used across different methods represents an obstacle to meaningful comparisons. For example, Lysell classifies rugae $\geq$ 5 mm in length into primary rugae, whereas Thomas and Kotze[14] (1983) define 5mm-long rugae as secondary and only longer rugae as primary. While Thomas and Kotze[14] identify four major rugae shapes (curved, wavy, straight and circular), the classification by Trobo comprises six patterns, Basauri lists seven patterns, and dos Santos describes ten.[11,14]

Accordingly, using the actual morphometric dimensions of the palatal rugae yields accurate data comparable across different studies and different populations. The aim of this study is to assess the dimensions and bilateral symmetry of the first three palatal rugae in an adult population and to explore sex dimorphism and the ability to predict sex from morphometric palatal rugae measurements. While presumably similar to other Caucasian populations, this is the first study of palatal rugae in the Lebanese population, thus amenable to comparisons with Mediterranean, Near Eastern and other populations.

MATERIAL AND METHODS

The study sample consisted of the pre-treatment orthodontic records of 252 non-growing subjects (119 males, 130 females, mean age 25.6 ± 7.7 years) recruited from the database of patients treated in the orthodontic division at the American University of Beirut Medical Center. Inclusion criteria were: age > 16 years for females and age > 18 years for males; complete set of fully erupted permanent dentition (excluding third molars); presence of high quality pre-treatment dental cast; absence of posterior cross-bite as evaluated on dental casts. Subjects with systemic disease, craniofacial anomalies, history of orthodontic treatment and/or surgical treatment involving the head and neck were excluded. This retrospective investigation was approved by the Institutional Review Board.

Maxillary and mandibular dental casts were de-identified by research support personnel not directly involved in the research. All remaining procedures were carried out by the principal investigator (M.S.). Dental casts were scanned using the laser scanning system Perceptron (ScanWorks® V5), which consists of a scanning probe attached to the Cimcore Infinite 2.0 (Seven axis) CMM Arm and is complemented by a point cloud handling software, IMInspect from PolyWorks® (InnovMetric Software, Quebec, Canada).

Each resultant three-dimensional image was carefully scrutinized to assess the acquisition of sufficient surface profile for all relevant anatomical structures before saving for subsequent analysis.

Saved data files were processed using IMInspect software from PolyWorks® to generate the polygonal model derived from the point cloud for all anatomical structures present in the model, at point-to-point resolutions up to 12µm. The same software was used to measure and record all palatal rugae measurements.

The first three palatal rugae, anterior, middle and posterior rugae were numbered 1, 2, and 3, respectively, and the right and left sides identified as R and L. The most medial (m: mR1/mL1, mR2/mL2, mR3/mL3) and most lateral (l: lR1/lL1, lR2/LL2, lR3/lL3) points were digitized (Fig. 1). The median palatal plane (MPP) was constructed through the median palatal raphe and the following measurements were then computed (Fig. 2):

- length of the rugae on right and left sides (R1, R2, R3, L1, L2, L3), from most medial to most lateral points.
- transverse distances between bilateral rugae points: transverse perpendicular distances between medial (Tm1, Tm2, Tm3) and lateral (Tl1, Tl2, Tl3) points.
- anteroposterior (AP) distances between opposing medial (m) and lateral (l) right (R) and left (L) rugae points: APmR-1/2 and APmR-2/3 between the medial right points and APlR-1/2 and APlR-2/3 between the lateral right rugae points. The same was measured on the left side (APmL-1/2, APmL-2/3, APlL-1/2 and APlL-2/3).
- rugae divergence angles: outer lR3-IP-lL3 (RDA-out), and inner mR3-IP-mL3 (RDA-in).
- rugae angles: formed by the MPP and a line joining the medial and lateral points of each rugae on the right (AngR1/MPP, AngR2/MPP, AngR3/MPP) and left (AngL1/MPP, AngL2/MPP, AngL3/MPP) sides.

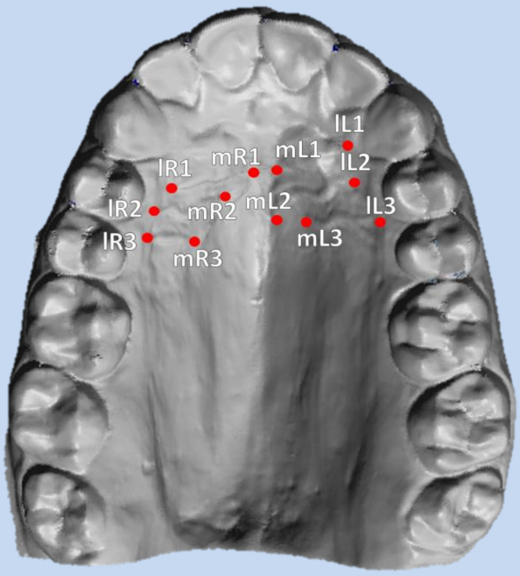

Fig. 1: The anterior, middle and posterior rugae are numbered 1, 2, and 3, respectively. The right and left sides are identified as R and L. Medial (m) and lateral (l) points are digitized. Definitions are detailed in text

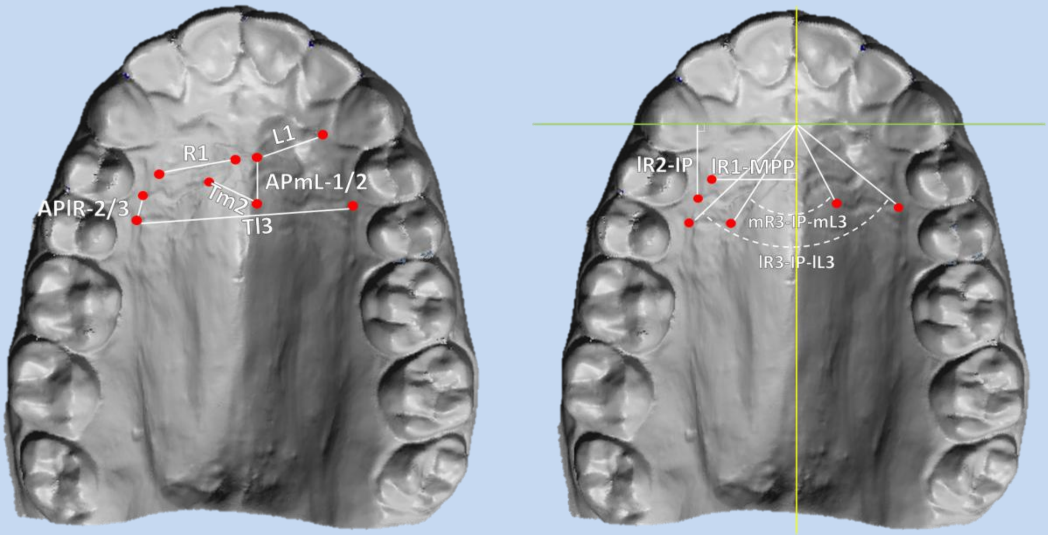

Fig. 2: Linear and angular rugal measurements (refer to text for details)

Independent samples t-tests were used to evaluate differences among palatal rugae dimensions between males and females and paired samples t-tests were used to compare right and left measures in the overall sample and in males and females separately. Rugae dimensions associated with sex at $p < 0.20$ were explored as predictors of sex in the multivariate analysis which was conducted using multiple logistic regressions.

To assess intra-observer reliability, all measurements were repeated on 50 randomly selected casts at least 14 days after the initial assessment. The repeated measures were evaluated with the two-way mixed effects intra-class correlations for absolute agreement on single measures. In addition, measurements on 50 randomly selected models were repeated by another investigator (R.H.) to evaluate inter-rater reliability.

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 correlations ranged between 0.897 and 0.991 for intra and inter-rater reliability, demonstrating high correspondence.

The third rugae were on average the longest on either side of the palate (10.37 ± 2.91 on the right, 11.25 ± 2.96 on the left; **Table 1**) and also the farthest away from each other (Tm3 = 8.06 ± 3.41 mm compared to 6.41 ± 2.63 and 3.56 ± 1.70 for the second and first rugae, respectively). Medial separation between opposing rugae exhibited wide variability, ranging between 0.71 and 10.19 mm for the first rugae; 1.71 - 12.81 mm for the second rugae and 1.68 - 17.35 mm for the third. Anteroposteriorly, the mean distance between any two opposing rugae points ranged between 4.1 ± 1.89 mm and 5.61 ± 2.32, the separation between the 2^{nd} and 3^{rd} rugae points generally being greater than that between the 1^{st} and 2^{nd}, except for the lateral rugae points on the right side of the palate (APlR-1/2= 5.8 ± 2.72 mm and APlR-2/3= 5.61 ± 2.66 mm). Anteroposterior distances between rugae points were similarly widespread, minimum values ranging between 0.56 and

1.1 mm and maximum values ranging between 8.82 and 16.49 mm.

Angular measurements of the palatal rugae were even more widespread and displayed large standard deviations. Mean outer and inner rugae divergence angles were 99.11 ± 16.32 and 39.91 ± 19.91 degrees, respectively. Average angular measurements to the MMP ranged between 61.13 ± 15.74 and 93.86 ± 26.79 degrees, but individual measures were as low 18.65 degrees for AngR1 and as high as 171.23 degrees for AngR3.

The majority of bilateral measures displayed right/left asymmetry in the overall sample (**Table 2**) and in the male (**Table 3**) and female (**Table 4**) subsamples separately. In the overall sample, only second rugae length and the anteroposterior distance between 2nd and 3rd medial and lateral rugae points showed no significant side-related differences. The first and third rugae were on average 0.78 ± 2.09 and 0.88 ± 3.61 mm longer on the left side (p < 0.001); the anteroposterior distance between the first and second rugae points was 0.51 ± 2.26 mm greater on the left medially, but it was larger on the right laterally (1.4 ± 3.34 mm, p < 0.001). The angles formed by all three rugae and the MPP were statistically significantly larger on the right side, the difference ranging between 9.51 ± 10.93 degrees for the first rugae and 25.41 ± 28.91 degrees for the third rugae (p < 0.001).
A similar situation was present in the male subset (Table 3) with the exception that third rugae length and the antero-posterior distance between the medial points of the first and second rugae did not display any right-left differences (p > 0.05). A larger number of variable exhibited asymmetry in females compared to males. The same differences observed in the overall sample were also displayed by the female subset (Table 4), with an additional statistically significant right-left difference in the anteroposterior distance between the second and third lateral rugae points (p = 0.004).

Nine out of the 28 assessed palatal rugae measures exhibited male-female differences, measurements being larger in males (**Table 5**). The second and third rugae were on average 0.73 ± 0.32 and 1.11 ± 0.36 mm longer in males than in females, respectively (p = 0.024 and p = 0.002, respectively) but there were no statistically significant differences in the lengths of any of the remaining rugae. TLL3 was the only additional transverse measure that differed between genders, the separation being on average 1.53 ± 0.44 mm larger in males. All medial anteroposterior distances between opposing rugae were similarly greater in males, the mean difference ranging between 0.6 ± 0.21 and 0.86 ± 0.26 mm (p ≤ 0.005). Laterally, only the distance between the 2nd and 3rd left rugae was larger in males (p = 0.011). As for the angular measures, only AngR1/MPP was statistically significantly larger in males (mean difference = 5.98 ± 2.50; p = 0.018).

In multivariate analysis, 5 variables significantly predicted sex and correctly classified subjects in 71.4% of instances (X^2 (3) = 44.18; p < 0.001; Tjur's R^2 = 0.169; **Table 6**). The four linear measurements (R3, APmR-1/2, APmR-2/3 and APlL-2/3) were negatively associated with being female (regression coefficients ranging between -0.13 and -0.24). With every 1 mm increase in any of these four measurements, the odds of being female is multiplied by a value ranging between 0.785 (CI: 0.667-0.991) and 0.880 (CI: 0.802-0.967). Conversely, the only angular measurement predicting sex (AngL3/MPP, p = 0.013) was positively associated with being female, the odds multiplied by 1.022 (CI: 1.005-1.040) with every degree increase in AngL3/MPP.

A simpler method of sex prediction was explored, employing multivariate models by using right side variables or left side variables separately (*data not shown*). These explorations produced models with inferior characteristics (lower percent correctly predicted and lower R^2 values) and were therefore rejected.

Table 1. Descriptive statistics for palatal rugae dimensions (n = 252)

	Mean	SD	Min.	Max.
R1	9.60	1.80	4.44	14.85
R2	10.12	2.55	4.39	17.10
R3	10.37	2.91	4.18	18.25
L1	10.38	1.85	4.46	16.53
L2	10.21	2.75	3.53	17.25
L3	11.25	2.96	4.33	20.51
Tm1	3.56	1.70	0.71	10.19
Tm2	6.41	2.63	1.71	12.81
Tm3	8.06	3.41	1.68	17.35
Tl1	19.09	2.75	9.44	28.43
Tl2	21.07	3.05	9.61	30.88
Tl3	22.64	3.59	9.32	34.15
APmR-1/2	4.10	1.89	0.64	8.82
APmR-2/3	5.12	2.09	0.56	10.50
APmL-1/2	4.62	1.70	0.82	10.28
APmL-2/3	5.08	1.94	0.68	11.02
APlR-1/2	5.80	2.72	0.28	15.19
APlR-2/3	5.61	2.66	1.10	16.49
APlL-1/2	4.40	2.20	0.67	12.68
APlL-2/3	5.29	2.32	0.68	13.01
RDA-out	99.11	16.32	54.13	150.41
RDA-in	39.91	19.91	2.98	107.49
AngR1/MMP	70.64	19.71	18.65	142.23
AngR2/MMP	84.18	23.28	34.44	148.91
AngR3/MMP	93.86	26.79	40.06	171.23
AngL1/MMP	61.13	15.74	14.62	108.61
AngL2/MMP	63.48	18.60	25.45	123.68
AngL3/MMP	68.46	18.55	28.41	158.08

Notes. Linear measures recorded in millimeters; angular measures recorded in degrees; SD: standard deviation; Min.: minimum; Max.: maximum.

DISCUSSION

Using features that are unique to an individual is key in post-mortem identification. The present study focuses on the uniqueness and immutability of the palatal rugae,[2,4-6] their apparent ethnic specificity,[9,10,15] and particularly on their reported gender dimorphism.[7,8,16] These characteristics are valuable in instances where fingerprints are not available (fires, decomposition and massive trauma)[17] and when conventional dental records are of limited value (because of edentulism or significant changes in dental work since last record.[18] Moreover, with the common usage of mouth scanners providing instant imaging, their use would be facilitated.

Table 2. Differences in palatal rugae dimensions between right and left sides (n = 252)

	Right	Left	Paired difference		
	Mean (SD)	Mean (SD)	Mean (SD)	t	*p* value^Ŧ
(R/L)1	9.60 (1.80)	10.38 (1.85)	-0.78 (2.09)	-5.93	<0.001**
(R/L)2	10.12 (2.55)	10.21 (2.75)	-0.09 (3.19)	-0.43	0.667
(R/L)3	10.37 (2.91)	11.25 (2.96)	-0.88 (3.61)	-3.89	<0.001**
APm(R/L)-1/2	4.10 (1.89)	4.62 (1.70)	-0.51 (2.26)	-3.62	<0.001**
APm(R/L)-2/3	5.12 (2.09)	5.08 (1.94)	0.04 (2.58)	0.25	0.807
APl(R/L)-1/2	5.80 (2.72)	4.40 (2.20)	1.40 (3.34)	6.64	<0.001**
APl(R/L)-2/3	5.61 (2.68)	5.29 (2.32)	0.32 (3.51)	1.44	0.152
Ang(R/L)1/MPP	70.64 (19.71)	61.13 (15.74)	9.51 (19.93)	7.58	<0.001**
Ang(R/L)2/MPP	84.18 (23.28)	63.48 (18.60)	20.69 (22.99)	14.29	<0.001**
Ang(R/L)3/MPP	93.86 (26.79)	68.46 (18.55)	25.41 (28.91)	13.95	<0.001**

Notes. Linear measures recorded in millimeters; angular measures recorded in degrees; SD: standard deviation; Ŧ*p* values from paired t-test at 251 degrees of freedom; *statistically significant at $p < 0.05$; **statistically significant at $p < 0.01$.

Table 3. Differences in palatal rugae dimensions between right and left sides in male subjects (n = 119)

	Right	Left	Paired difference		
	Mean (SD)	Mean (SD)	Mean (SD)	t	*p* value^Ŧ
(R/L)1	9.58 (1.80)	10.61 (1.80)	-1.03 (2.19)	-5.14	<0.001**
(R/L)2	10.50 (2.69)	10.22 (2.66)	0.28 (3.13)	0.98	0.331
(R/L)3	10.95 (2.88)	11.44 (2.98)	-0.49 (3.57)	-1.50	0.137
APm(R/L)-1/2	4.53 (2.02)	4.93 (1.76)	-0.40 (2.28)	-1.94	0.055
APm(R/L)-2/3	5.57 (2.17)	5.44 (1.84)	0.12 (2.42)	0.54	0.593
APl(R/L)-1/2	5.65 (2.46)	4.39 (2.14)	1.26 (2.99)	4.49	<0.001**
APl(R/L)-2/3	5.36 (2.43)	5.68 (2.34)	-0.32 (3.40)	-1.04	0.303
Ang(R/L)1/MPP	73.80 (22.11)	61.88 (15.54)	11.92 (19.45)	6.69	<0.001**
Ang(R/L)2/MPP	84.75 (25.29)	62.23 (19.70)	22.52 (20.61)	11.92	<0.001**
Ang(R/L)3/MPP	91.62 (27.13)	66.73 (18.77)	24.89 (29.10)	9.33	<0.001**

Notes. Linear measures recorded in millimeters; angular measures recorded in degrees; SD: standard deviation; Ŧp values from paired t-test at 118 degrees of freedom; *statistically significant at $p < 0.05$; **statistically significant at $p < 0.01$.

Specifically on sex identification, the gold-standard method remains DNA analysis. Rugoscopy figures among the morphological methods that evaluate structures that may vary within their environment over time. While odontometric evaluations have been used for sex differentiation (mesiodistal[19,20] and buccolingual[21] dimensions of teeth, tooth morphology,[22] mean canine index,[23,24] earlier studies on palatal rugae focused on their number (greater in males)[15] and patterns.[25]

Table 4. Differences in palatal rugae dimensions between right and left sides in female subjects (n = 133)

	Right	Left	Paired difference		
	Mean (SD)	Mean (SD)	Mean (SD)	t	*p* value^{Ŧ}
(R/L)1	9.62 (1.81)	10.18 (1.87)	-0.56 (1.98)	-3.25	0.001**
(R/L)2	9.78 (2.37)	10.19 (2.83)	-0.41 (3.21)	-1.49	0.139
(R/L)3	9.84 (2.86)	11.07 (2.94)	-1.23 (3.62)	-3.94	<0.001**
APm(R/L)-1/2	3.72 (1.67)	4.33 (1.59)	-0.61 (2.24)	-3.16	0.002**
APm(R/L)-2/3	4.71 (1.93)	4.74 (1.98)	-0.03 (2.72)	-0.13	0.896
APl(R/L)-1/2	5.93 (2.93)	4.41 (2.26)	1.52 (3.62)	4.83	<0.001**
APl(R/L)-2/3	5.83 (2.83)	4.94 (2.26)	0.89 (3.51)	2.92	0.004**
Ang(R/L)1/MPP	67.81 (16.86)	60.46 (15.95)	7.36 (20.17)	4.21	<0.001**
Ang(R/L)2/MPP	83.66 (21.52)	64.60 (17.55)	19.05 (24.89)	8.83	<0.001**
Ang(R/L)3/MPP	95.86 (26.42)	70.00 (18.29)	25.87 (28.83)	10.35	<0.001**

Notes. Linear measures recorded in millimeters; angular measures recorded in degrees; SD: standard deviation; ^{Ŧ}p values from paired t-test at 132 degrees of freedom; *statistically significant at $p < 0.05$; **statistically significant at $p < 0.01$.

This study contributes components of palatal rugae related to gender differences that have not been reported earlier. Although only the lengths of the tight second and third palatal rugae differed significantly between males and females, the lengths of all remaining rugae were consistently greater in males to varying extents (but were not statistically significant). Medial separation between rugae on opposite sides of the palate did not differ between genders for any of the assessed rugae, suggesting a close transverse association between the MPP and rugae origin points irrespective of gender. Sex differences were also predominant in anteroposterior distances between opposing rugae, especially at the medial end where all comparisons were statistically significant.

While it is difficult to compare our numeric data with the predominantly descriptive data from previous studies, signs of larger palatal rugae measurements in males seem to also be present in previous studies. Jain and Jain[26] reported a statistically significant lower number of fragmented rugae (< 3 mm) and larger number of primary rugae (5-10 mm) in males compared to females; Fawzi et al.[27] obtained similar results in a study conducted in Saudi Arabia. In a different assessment, Babu et al.[28] also reported gender disparity: a larger (though not statistically significant) mean number of primary rugae in males and larger mean numbers of secondary and tertiary rugae in females.

Our data indicated that females had less of the longer and more of the shorter rugae, and an average rugae length smaller than in males. Other authors have found no differences in mean numbers of primary and/or other rugae categorized on length,[11,29,30] but the divergence in results probably relates to the classification in other studies into three broad categories compared to our direct measurements. In a recent study, Alani et al. measured the length of the 3rd rugae on 82 dental casts and also found no statistically significant differences between males and females although mean length was 0.93 mm greater in males.[31]

Table 5. Distribution of palatal rugae dimensions by sex (n = 252)

	Males (n = 119)	Females (n = 133)	Difference		
	Mean (SD)	Mean (SD)	Mean (SE)	t	*p* value^Ŧ
R1	9.58 (1.80)	9.62 (1.81)	-0.04 (0.23)	-0.16	0.871
R2	10.50 (2.69)	9.78 (2.37)	0.73 (0.32)	2.28	0.024*
R3	10.95 (2.88)	9.84 (2.86)	1.11 (0.36)	3.08	0.002**
L1	10.61 (1.80)	10.18 (1.87)	0.43 (0.23)	1.87	0.062
L2	10.22 (2.66)	10.19 (2.83)	0.03 (0.35)	0.09	0.929
L3	11.44 (2.98)	11.08 (2.94)	0.37 (0.37)	0.99	0.324
Tm1	3.56 (1.77)	3.56 (1.65)	0.00 (0.22)	0.02	0.983
Tm2	6.52 (2.78)	6.32 (2.49)	0.20 (0.33)	0.60	0.551
Tm3	8.42 (3.76)	7.73 (3.05)	0.69 (0.43)	1.62	0.107
Tl1	19.43 (2.82)	18.78 (2.66)	0.65 (0.35)	1.89	0.060
Tl2	21.37 (3.16)	20.79 (2.94)	0.59 (0.38)	1.53	0.128
Tl3	23.44 (3.47)	21.91 (3.56)	1.53 (0.44)	3.45	0.001**
APmR-1/2	4.53 (2.03)	3.72 (1.67)	0.81 (0.23)	3.47	0.001**
APmR-2/3	5.57 (2.17)	4.71 (1.93)	0.86 (0.26)	3.31	0.001**
APmL-1/2	4.93 (1.76)	4.33 (1.59)	0.60 (0.21)	2.84	0.005**
APmL-2/3	5.45 (1.84)	4.74 (1.98)	0.71 (0.24)	2.92	0.004**
APlR-1/2	5.66 (2.46)	5.93 (2.93)	-0.27 (0.34)	-0.79	0.430
APlR-2/3	5.36 (2.43)	5.84 (2.83)	-0.47 (0.33)	-1.43	0.155
APlL-1/2	4.40 (2.14)	4.41 (2.26)	-0.01 (0.28)	-0.05	0.960
APlL-2/3	5.69 (2.34)	4.94 (2.26)	0.74 (0.29)	2.56	0.011*
RDA-out	98.65 (16.22)	99.52 (16.45)	-0.87 (2.06)	-0.42	0.674
RDA-in	38.47 (19.8)	41.20 (20.00)	-2.72 (2.51)	-1.09	0.279
AngR1/MMP	73.80 (22.11)	67.82 (16.86)	5.98 (2.50)	2.39	0.018*
AngR2/MMP	84.75 (25.19)	83.66 (21.52)	1.10 (2.94)	0.37	0.709
AngR3/MMP	91.63 (27.13)	95.87 (26.42)	-4.24 (3.38)	-1.26	0.210
AngL1/MMP	61.88 (15.54)	60.46 (15.95)	1.42 (1.99)	0.71	0.476
AngL2/MMP	62.23 (19.7)	64.60 (17.56)	-2.37 (2.36)	-1.00	0.316
AngL3/MMP	66.73 (18.77)	70.00 (18.29)	-3.26 (2.34)	-1.40	0.164

Notes. Linear measures recorded in millimeters; angular measures recorded in degrees; SD: standard deviation; SE: standard error; Ŧ*p* values from Student's t-test at 251 degrees of freedom; *statistically significant at $p < 0.05$; **statistically significant at $p < 0.01$.

Sex differences in anteroposterior distances between opposing rugae have not been previously assessed. Our data suggest that the larger dimensions observed transversely and also anteroposteriorly, are likely reflective of overall larger anthropometric dimensions of the head in males compared to females.

Combined, four linear and one angular rugae measurements correctly classified nearly three-quarters of the sample into their true sex, well over the 50% expected due to chance. Although pseudo-R^2 values for our model were only moderate, as is generally the case in binary logistic regressions, the model was a good fit for our data and was overall statistically significant. Attempts to predict sex from either right-side or left-side variables alone produced inferior predictability and model characteristics, thus highlighting the importance of examining the entire palatal rugae area for maximum benefit. The predictive value for sex obtained in our study compares positively to several previous studies using descriptive palatal rugae measures to predict sex, with predictability reported at 55%,[32] 58 to 60%,[29] and 67%.[33] Bharath et al. and Chopra et al., on the other hand, reported predictive values close to, but slightly higher, than ours: 78% and 71-75%, respectively.[25,34] Exceptionally, Saraf et al. were able to predict sex correctly in 99.2% of their sample using "all rugae shapes", although the exact model used in prediction was not presented.[35]

Table 6. Multivariate analysis showing associations between selected palatal rugae variables and sex (n = 252)

Associated variables	Sex (Base category: male)					
	Coef.	Std. Err.	Wald	*p* value	OR	95% CI for OR
Constant	3.25	0.89	13.28	<0.001**	25.911	
R3	-0.13	0.05	7.05	0.008**	0.880	[0.802; 0.967]
APMR12	-0.24	0.08	10.18	0.001**	0.785	[0.667 ; 0.991]
APMR23	-0.24	0.07	11.34	0.001**	0.790	[0.688 ; 0.906]
APLL23	-0.21	0.07	9.60	0.002**	0.808	[0.706 ; 0.925]
AngleL3/MPP	0.02	0.01	6.21	0.013*	1.022	[1.005 ; 1.040]
X^2 (5)	44.18					
Model *p* value	<0.001**					
R^2 (Tjur's; Nagelkerke's)	0.1690; 0.2150					
Percent correctly predicted	71.40					
Goodness of fit *p* value‡	0.245					

Notes. The multivariate regression models the probability of being female compared to being male. Coef.= regression coefficient; Std. Err.= standard error; OR = odds ratio; X^2 (*y*) refers to the Chi square test statistic and the degrees of freedom. ‡Hosmer and Lemeshow test used to assess the model's goodness of fit. Non-significant *p* value indicates adequate goodness of fit.
*Statistically significant at $p < 0.05$; **Statistically significant at $p < 0.01$.

Right-left rugae asymmetry is another area where our data confirm previous reports from non-numeric classification systems. In addition to the vast literature illustrating right-left rugae asymmetry with respect to shape, number, length and/or direction,[29,36-38] our data suggest that morphometrically the palatal rugae are asymmetrical. It must be emphasized that we deliberately excluded patients who presented with posterior crossbite and included only individuals representing the normal spectrum of maxillary/palatal growth, albeit in varying malocclusions. Although not all assessed variables exhibited asymmetry, our data suggest that palatal rugae symmetry is not the norm in the average individual. Although not directly comparable, a number of previous studies describing palatal rugae morphology have failed to show statistically significant differences between right and left sides with respect to shape, divergence or length categorization (primary, secondary, fragmentary).[34,39]

Our data underscore the variability of the palatal rugae and their potential use for sex determination. While not all subjects were correctly classified using our model, the results support the need to further explore the usefulness of palatal rugae dimensions in sex prediction both separately and as an adjunct to palatal rugae morphological characteristics. Our work is also a first step towards establishing a Lebanese database of palatal rugae characteristics and dimensions with different samples to validate and build on the present findings. The utilization of three-dimensional technology to record measurements from digital maxillary casts is a well-established method with validated accuracy[40-42] and showed a high degree of reproducibility in our sample. The integration of morphometric measurements with the commonly used rugae classification systems should enhance the potential for the use of palatal rugae in sex prediction and accurate population comparisons.

CONCLUSION

1. Palatal rugae dimensions showed wide individual variability, right-left asymmetry, and a moderate potential for sex prediction. The general tendency for larger dimensions in males than females probably reflect parallel findings in dentofacial proportions.
2. Notwithstanding the importance of establishing initial data on palatal rugae in the Lebanese population, similar to findings in other Caucasian groups, the incorporation of morphometric measures as an adjunct to the commonly used rugae classification methods should enhance sex classification using the palatal rugae and facilitate comparability among populations.
3. The addition of palatal rugae to the repertoire of commonly used forensics identifiers is not meant to replace easier better established practices (fingerprints, DNA and dental records). However, at least in specific circumstances, palatal rugae may be the only recourse for identification.

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