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ORIGINAL ARTICLE

Morphometric analysis of palatal rugae in different malocclusions

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Abstract

Objectives Studies of the association between palatal rugae (PR) and malocclusion are scarce. While unstable following treatment such as rapid maxillary expansion, we hypothesized that PR differ among malocclusions because of genetic determination but also different environmental conditions during development.
Our goal was to assess the possible association between PR morphometric measurements and both sagittal and vertical characteristics of malocclusion.

Methods Maxillary pretreatment dental casts of 243 nongrowing individuals (115 males, 128 females, age 25.5 ± 7.5 years) were laser scanned (Perceptron ScanWorks® V5, Hallam VIC, Australia); angular and linear measurements of the first three PR were recorded in transverse and anteroposterior directions. Cephalometric measurements were obtained from corresponding digitized lateral cephalograms. Statistics included analyses of variance to compare PR measurements among sagittal (class I, class II divisions 1 and 2, class III) and vertical (hypodivergent, normodivergent, hyperdivergent) malocclusion groups and the Pearson correlations among PR dimensions and cephalometric measurements.

Results PR measurements were statistically different between malocclusions, especially with respect to vertical patterns. A majority of transverse and anteroposterior rugae measurements were greatest in class II division 2 subjects. PR were more anteriorly directed in hypodivergent than hyperdivergent groups; the transverse separation between opposing rugae points was smaller. Correlations were generally low.

Conclusions The findings suggest the possibility for PR to adapt to environmental effects in developing malocclusions, mostly in the class II division 2 phenotype. This premise reinforces the need to explore in longitudinal studies the long-term environmental influences on rugae superimposed on their genetically determined morphological pattern.

Keywords Laser scanning · Morphometry · Sagittal malocclusion · Vertical malocclusion · Cephalometry

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Morphometrische Analyse der Rugae palatinae bei verschiedenen Malokklusionen

Zusammenfassung

Zielsetzungen Es gibt kaum Studien über den Zusammenhang zwischen den Rugae palatinae (PR) und Malokklusionen. Zwar sind sie nach einer Behandlung, wie z.B. einer raschen Gaumennahterweiterung, instabil, dennoch stellten wir die Hypothese auf, dass sich die PR zwischen den Malokklusionen aufgrund der genetischen Bestimmung, aber auch aufgrund unterschiedlicher Umweltbedingungen während der Entwicklung unterscheiden.

Unser Ziel war es, den möglichen Zusammenhang zwischen morphometrischen PR-Messungen und sowohl sagittalen als auch vertikalen Merkmalen der Malokklusion zu beurteilen.

Methoden Die Oberkiefer-Vorbehandlungsabdrücke von 243 ausgewachsenen Probanden (115 Männer, 128 Frauen, Alter 25,5 ± 7,5 Jahre) wurden mit Laser gescannt (Perceptron ScanWorks® V5, Hallam VIC, Australien),die Winkel- und Linearmessungen der ersten 3 PR in transversaler und anteroposteriorer Richtung aufgezeichnet. Die kephalometrischen Messungen wurden aus entsprechenden digitalisierten lateralen Kephalogrammen gewonnen. Die Statistik umfasste Varianzanalysen zum Vergleich der PR-Messungen zwischen sagittalen (Klasse I, Klasse II/1 und -2, Klasse III) und vertikalen (hypo-, normo- und hyperdivergente) Malokklusionsgruppen sowie die Pearson-Korrelationen zwischen PR-Dimensionen und kephalometrischen Messungen.

Ergebnisse Die PR-Messungen unterschieden sich statistisch signifikant zwischen den Malokklusionen, insbesondere in Bezug auf die vertikalen Muster. Die Mehrheit der Messungen der transversalen und anteroposterioren Rugae war bei Probanden der Klasse II/2 am größten. Die PR waren in hypodivergenten Gruppen stärker nach anterior gerichtet als in hyperdivergenten, die transversale Trennung zwischen gegenüberliegenden Rugae-Punkten war kleiner. Generell waren die Korrelationen niedrig.

Schlussfolgerungen Die Ergebnisse legen die Möglichkeit nahe, dass sich die PR bei sich entwickelnden Malokklusionen, meist im Phänotyp der Klasse II/2, an Umwelteinflüsse anpassen kann. Diese Prämisse verstärkt die Notwendigkeit, in Längsschnittstudien die langfristigen Umwelteinflüsse auf Rugae zu untersuchen, die ihr genetisch bedingtes morphologisches Muster überlagern.

Schlüsselwörter Laser-Scanning · Morphometrie · Sagittale Malokklusion · Vertikale Malokklusion · Kephalometrie

Introduction

Located bilaterally in the anterior third of the palate behind the incisive papilla, the palatal rugae (PR) are uneven, unequal and asymmetrical elevations of the palatal mucosa arranged in a transverse direction [1]. Because of fingerprint-like individuality, relative temporal stability, resistance to external physical and chemical conditions and delayed postmortem decomposition [2], these mucosal folds were evaluated as references for dental cast superimposition to assess orthodontic tooth movement [3–5], as well as in forensic odontology and postmortem identification [6].

The topography of the rugae is variable but generally includes three bilateral rows or bands, the last of which is usually at the level of the premolars. Mimicking the use of the anterior cranial base in the assessment of facial growth [7], orthodontic researchers have used the rugae as oral references to quantify tooth migration, based on the observation that rugae are stable over periods of development [8]. In this context, the following important conclusions have been reported:

- Of the three rugae, the posterior third band has been credited with more stability than the anterior bands [5], even in patients with a cleft palate [9, 10].
- The PR apparently undergo long-term yet slower adaptation during the development of the occlusion. Supporting this premise is the research by Moorrees et al. who studied normal dental development relative to a reference palatal plug made of wax that imprinted the rugae and was carried across the longitudinal annual casts of growing children [3]. The plug was changed after a number of years to carry a new one for another few years, indicating slow but demonstrable growth changes of the rugae themselves, which could reflect changes in arch dimensions, particularly width.
- In addition to this rugal "superimposition" method employing a plug fabricated with wax, acrylic and later elastomeric material [3], direct measurements to 3-dimensionally established rugal landmarks [4] or digital scanning technology [5, 11, 12] have been used in more recent studies.
- Short-term changes of rugae dimensions have been adequately demonstrated in adaptation to orthodontic therapies such as palatal expansion or premolar extraction and space closure [5, 13, 14].

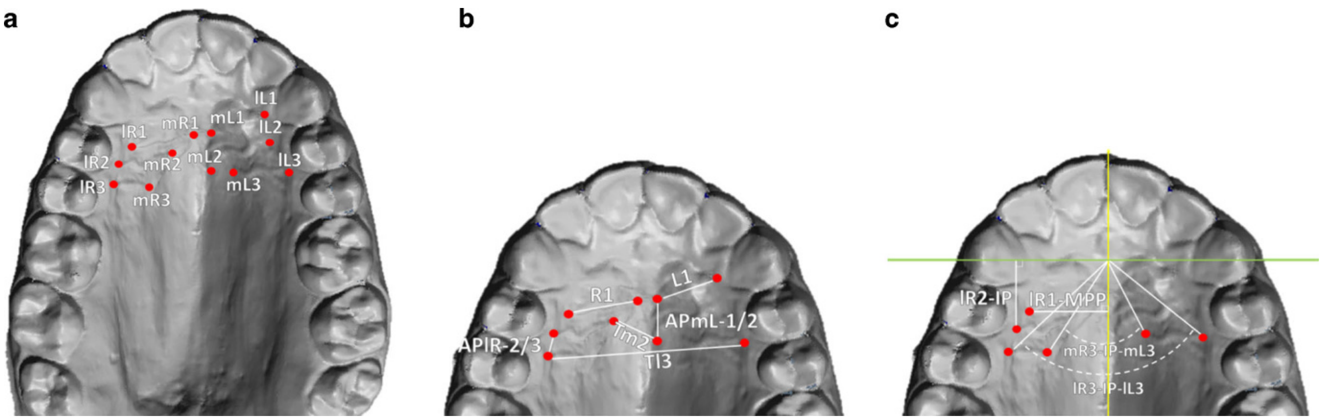

Fig. 1 **a** Anterior, middle, and posterior rugae numbered 1, 2, and 3, respectively. Sides identified as right (R) and left (L). Most medial (m) points: m: mR1/mL1, mR2/mL2, mR3/mL3; most lateral (l) points: l: lR1/lL1, lR2/LL2, lR3/lL3. **b** Rugal measurements: rugae length on right and left sides (R1, R2, R3, L1, L2, L3), from most medial to most lateral points; transverse distances between medial (Tm1, Tm2, Tm3) and lateral (Tl1, Tl2, Tl3) points; anteroposterior (AP) distances between opposing medial and lateral rugae points: APmR-1/2, APmR-2/3, and APmR-1/3 (medial right), APlR-1/2, APlR-2/3, and APlR-1/3 (lateral right), APmL-1/2, APmL-2/3, APmL-1/3 (medial left), APlL-1/2, APlL-2/3, and APlL-1/3 (lateral left). **c** Rugae divergence angles: outer lR3-IP-lL3 (RDA-out); inner mR3-IP-mL3 (RDA-in); rugae angles, formed by the median palatal plane through the raphe (MPP) and line joining medial and lateral points of each rugae: AngR1/MPP AngR2/MPP, AngR3/MPP, AngL1/MPP, AngL2/MPP, AngL3/MPP

Abb. 1 **a** Vordere, mittlere und hintere Rugae wurden mit 1, 2 bzw. 3 nummeriert. Die Seiten sind als rechts (R) und links (L) gekennzeichnet. Die am weitesten medialen (m) gelegenen Punkte: m: mR1/mL1, mR2/mL2, mR3/mL3; die am weitesten lateralen (l) gelegenen Punkte: l: lR1/lL1, lR2/LL2, lR3/lL3. **b** Rugae-Messungen: Länge auf der rechten und linken Seite (R1, R2, R3, L1, L2, L3), von den am weitesten medialen bis zu den am weitesten lateralen Punkten; Querabstände zwischen medialen (Tm1, Tm2, Tm3) und lateralen (Tl1, Tl2, Tl3) Punkten; anteroposteriore (AP) Abstände zwischen gegenüberliegenden medialen und lateralen Rugae-Punkten: APmR-1/2, APmR-2/3 und APmR-1/3 (medial rechts), APlR-1/2, APlR-2/3 und APlR-1/3 (lateral rechts), APmL-1/2, APmL-2/3, APmL-1/3 (medial links), APlL-1/2, APlL-2/3 und APlL-1/3 (lateral links). **c** Rugae-Divergenzwinkel: äußerer lR3-IP-lL3 (RDA-out); innerer mR3-IP-mL3 (RDA-in); Rugae-Winkel, gebildet durch die palatinale Medianebene durch die Raphe (MPP) und die Linie, die die medialen und lateralen Punkte jeder Rugae verbindet: AngR1/MPP AngR2/MPP, AngR3/MPP, AngL1/MPP, AngL2/MPP, AngL3/MPP

Given that malocclusions are influenced by genetic and environmental etiologies [15, 16], rugae morphology may be subjected to similar factors. Despite the assertion of genetic predominance on palatal rugae pattern (shape and size) [17, 18], the individual variability of the rugae has not been fully explored, particularly the extent to which the local growth conditions affect this pattern. More specifically, morphological variations in different malocclusions need exploration.

To date, only a few studies conducted on dental casts have explored such an association [19–23]. The results reflected differences in palatal rugae length [20, 23] and in some morphological patterns [19, 21, 22] between malocclusion categories. However, one was a pilot study [19], another limited to only two malocclusions [20] and the others addressed only the patterns of PRs, having very few measurements [23], mainly the length of rugae. All studies were limited to sagittal classes of malocclusion and included sample sizes that were small for adequate statistical confirmation. These shortcomings were the basis of this study.

Our aims were to (1) assess possible associations between sagittal and vertical cephalometric components of malocclusion and palatal rugae dimensions measured through three-dimensional digital scanning technology, and (2) determine whether PR dimensional differences among malocclusions reflected the phenotypical disparities between these occlusal dysmorphologies.

Materials and methods

The pretreatment orthodontic records of 243 nongrowing individuals (115 males, 128 females, mean age 25.5 ± 7.5 years) were selected from the patient database of the postgraduate orthodontic clinic of the American University of Beirut Medical Center, Beirut, Lebanon. Inclusion conditions were the following: age >16 years for females and >18 years for males, a complete set of fully erupted permanent dentition (excluding third molars), presence of high-quality pretreatment lateral cephalogram and dental cast, and absence of posterior cross-bite as evaluated on dental casts.

The malocclusions were classified into four groups according to strict criteria with a combination of characteristics in each category:

- Class 1 ($n = 48$): bilateral molar normocclusion within one-half cusp, overjet 2–3 mm, ANB = 0–3.5°;

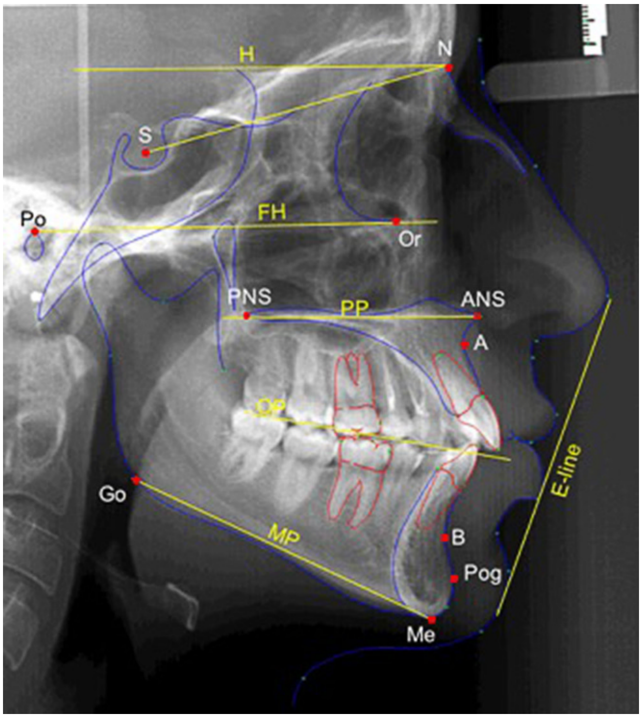

Fig. 2 Cephalometric measurements. Skeletal: SN (mm); SN/H (*H* true horizontal); SN-SAr (saddle angle); SNA; SNB; ANB; ANS-PNS (mm); PP/MP (*PP* palatal plane; *MP* mandibular plane); MP/OP (*OP* occlusal plane); OP/FH (*FH* Frankfort horizontal); MP/H; MP/SN; LFH/TFH (lower/total facial height). Dental: U1-NA (mm), U1/NA (°); U1/SN; U1-Apog, U1/Apog; L1-NB (mm); L1/NB (°); L1/MP; L1-Apog; U1/L1; *OB* percent overlap of mandibular incisors by maxillary incisors; *OJ* horizontal projection of maxillary incisors relative to mandibular incisors. Soft tissue profile: *upper lip E line* distance from upper lip to E-line; *lower lip E line* distance from lower lip to E-line

Abb. 2 Kephalometrische Messungen. Skelettal: SN (mm); SN/H (*H* wahre Horizontale); SN-SAr (Sattelwinkel); SNA; SNB; ANB; ANS-PNS (mm); PP/MP (*PP* Palatinalebene; *MP* Mandibularebene); MP/OP (*OP* okklusale Ebene); OP/FH (*FH* Frankfurter Horizontale); MP/H; MP/SN; LFH/TFH (untere/gesamte Gesichtshöhe). Dental: U1-NA (mm), U1/NA (°); U1/SN; U1-Apog, U1/Apog; L1-NB (mm); L1/NB (°); L1/MP; L1-Apog; U1/L1; *OB* prozentuale Überlappung der Unterkieferschneidezähne mit den Oberkieferschneidezähnen; *OJ* horizontale Projektion der Oberkieferschneidezähne relativ zu den Unterkieferschneidezähnen. Weichgewebeprofil: *upper lip E line* Abstand von der Oberlippe zur E-Linie; *lower lip E line* Abstand von der Unterlippe zur E-Linie

- Class II division 1 (II/1; $n=42$): maxillary molars in distocclusion by more than one-half cusp, overjet ≥4.5 mm, ANB ≥5°;
- Class II division 2 (II/2; $n=40$): molar distoclusion, overbite ≥80%, normal overjet (2–3 mm);
- Class III ($n=48$): molars in mesioclusion by one-half cusp or more, overjet ≤0 mm, ANB < 0°.

Vertical skeletal divergence was classified into three groups based on the angle MP/SN (hypodivergent [Hypo]: <27°; normodivergent [Normo]: 27° ≤ MP/SN ≤ 37°; hyperdivergent [Hyper]: >37°).

Subjects with systemic disease, craniofacial anomalies, history of orthodontic treatment and/or surgical treatment involving the head and neck were excluded. This cross-sectional investigation was approved by the Institutional Review Board of the American University of Beirut (ID#OTO.RH.03).

Digital cast analysis and rugal measurements

One investigator (MS) scanned the maxillary dental models using the laser scanning system Perceptron (ScanWorks® V5 , Hallam VIC, Australia), which generates a three-dimensional model with a point-to-point resolution up to 12 µm. Subsequently, the investigator processed the data using the IMInspect software from PolyWorks (innovMetric Software Inc., Quebec, QC, Canada) to digitize landmarks and compute the palatal rugae measurements.

After digitizing the most medial (m) and lateral (l) rugae points, and the most posterior point of the incisive papilla (IP; Fig. 1a), rugal measurements were computed, including length of rugae, transverse medial and lateral distances among and between bands of rugae, anteroposterior distances (Fig. 1b), and divergence and rugae angles (Fig. 1c). All angles were measured to the median palatal plane drawn through the raphe (MPP).

Radiographic analysis

The digital lateral cephalograms were taken in the same cephalostat (OP100, Instrumentarium, Tuusula, Finland) following a standardized procedure. They were imported into Dolphin Imaging software (Dolphin Imaging and Management Solutions, Version 11.5, La Jolla, CA, USA) and digitized using a customized setting that guided the investigator to locate selected landmarks (Fig. 2). Cephalometric measurements were then automatically generated (Fig. 2).

Statistical analysis

One-way analysis of variance (ANOVA) tests were used to compare palatal rugae measurements among sagittal (class I, II/1, II/2 and III) and vertical (Hypo, Normo and Hyper) malocclusion groups. Tukey's post hoc analysis was applied when ANOVA results were statistically significant. When the assumption of homogeneity of variances was violated for certain variables, robust (Welch's) ANOVA and Games–Howell post hoc tests were used. Pearson product–moment coefficients were employed to assess the correlation of palatal rugae dimensions with cephalometric measurements.

Table 1 Distribution of palatal rugae measures by sagittal malocclusion categorized by ANB angle ($n=243$)
Tab. 1 Verteilung der Maße der palatinalen Rugae, sagittale Malokklusion, kategorisiert nach ANB-Winkel ($n=243$)

	Class I ($n=80$)		Class II div 1 ($n=71$)		Class II div 2 ($n=40$)		Class III ($n=52$)		One-way ANOVA[a]	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Test statistic	p
R1	9.50	1.87	9.66	1.47	9.89	2.10	9.57	1.92	0.44	0.727
R2	9.97	2.54	10.11	2.51	9.97	2.80	10.19	2.49	0.10	0.960
R3	10.61	2.85	10.18	2.87	9.57	2.72	10.82	3.19	1.70	0.167
L1	10.31	1.70	10.21	1.80	10.94	1.99	10.48	1.99	1.46	0.225
L2	10.00	2.60	9.75	2.71	10.33	2.74	10.93	3.02	2.05	0.108
L3	10.80	2.80	10.78	2.72	12.07	2.99	11.70	3.34	2.68	0.047*
Tm1	3.85	1.91	3.38	1.52	3.38	1.72	3.49	1.57	1.22	0.303
Tm2	6.50	2.61	6.34	2.64	7.03	2.99	6.09	2.43	1.02	0.384
Tm3	7.97	3.61	7.79	3.44	9.12	3.72	7.92	2.82	1.46	0.226
Tl1	19.08	2.77	18.97	2.69	20.02	2.33	18.72	3.11	1.88	0.134
Tl2[a]	21.05	3.11	20.94	2.61	21.74	2.21	20.63	3.91	[a]1.42	[a]0.239
Tl3[a]	22.59	3.42	21.79	2.71	23.83	3.11	23.07	4.44	[a]4.31	[a]0.006**
APmR-1/2	4.06	1.67	3.81	1.95	4.98	2.09	4.06	1.75	3.64	0.013*
APmR-2/3	5.07	1.86	5.57	2.31	4.50	1.97	4.96	2.15	2.42	0.067
APmL-1/2	4.66	1.41	4.16	1.69	5.06	1.52	4.94	2.06	3.40	0.018*
APmL-2/3	4.73	1.77	5.26	1.89	5.07	1.59	5.30	2.34	1.30	0.275
APlR-1/2	5.36	2.41	5.93	2.59	7.00	3.17	5.32	2.81	4.00	0.008**
APlR-2/3	5.76	2.79	5.33	2.45	6.05	2.18	5.53	3.06	0.70	0.553
APlL-1/2	4.19	2.10	4.81	2.40	4.76	2.29	3.99	2.00	2.01	0.113
APlL-2/3	5.18	2.27	4.87	2.33	6.15	1.84	5.27	2.63	2.70	0.047*
RDA-out	100.58	16.09	97.52	17.39	99.45	13.67	99.03	17.60	0.44	0.726
RDA-in	38.90	19.59	38.42	19.08	48.09	21.10	38.97	20.72	2.46	0.064
AngR1/MMP	71.19	19.48	69.07	19.02	66.77	17.54	74.07	23.29	1.18	0.320
AngR2/MMP	80.63	19.74	84.76	22.91	89.36	29.07	83.66	23.92	1.29	0.278
AngR3/MMP	90.81	25.97	91.73	25.18	105.82	28.21	92.00	27.95	3.29	0.021*
AngL1/MMP[a]	61.61	17.28	60.06	14.82	60.38	9.97	61.93	18.23	[a]0.21	[a]0.891
AngL2/MMP	61.04	17.21	68.31	18.03	61.32	17.16	62.27	22.11	2.31	0.077
AngL3/MMP[a]	68.02	18.22	71.91	21.25	68.87	11.04	62.44	15.61	[a]3.02	[a]0.032**

* Statistically significant at $p<0.05$; ** statistically significant at $p<0.01$
[a]Welch's robust ANOVA (analysis of variance) reported when assumption of homogeneity of variances violated
SD standard deviation, *div* division

To gauge the interrater reliability, 50 randomly selected casts were digitized by another investigator (RH) and the measurements were computed. To evaluate intrarater reliability, the first author redigitized another 50 randomly selected models at least 14 days after the first assessment. Both reliability judgments were tested with two-way mixed effects intraclass correlations for absolute agreement. The Statistical Package for Social Sciences (SPSS®, version 23.0, IBM, Armonk NY, USA) was used for all analyses. Statistical significance was set at 0.05.

Results

The intraclass correlation coefficients for intraexaminer ($0.897<r<0.997$) and interexaminer ($0.861<r<0.994$) reliability demonstrated high correspondence.

Rugae dimensions in the total sample

- *Length*: The third rugae were, on average, the longest on either side but the first rugae were not necessarily the shortest (R1 shorter than R2 but L1 longer than L2). Lengths of individual rugae showed great variability, the widest range exhibited by L3 (4.33–20.51 mm) and the smallest by R1 (4.44–14.85 mm).
- *Anteroposterior distances:* Anteroposterior distances between opposing rugae points ranged between 4.14 ±

Table 2 Pairwise comparisons for palatal rugae measures with statistically significant differences by sagittal malocclusion categorized by ANB angle ($n=243$)

Tab. 2 Paarweise Vergleiche für Messungen der palatinalen Rugae mit statistisch signifikanten Unterschieden der sagittalen Malokklusionen, kategorisiert nach ANB-Winkel ($n=243$)

	Difference between any two groups	Tukey's post hoc test [a] *p* value					
	One-way ANOVA[a] *p* value	Class I vs. II div 1	Class I vs. II div 2	Class I vs. III	Class II div 1 vs II div 2	Class II div 1 vs class III	Class II div 2 vs class III
L3	0.047*	1.000	0.114	0.306	0.118	0.310	0.934
Tl3[a]	[a]0.006**	0.382	0.200	0.910	0.005**	0.261	0.771
APmR-1/2	0.013*	0.842	0.049	1.000	0.008**	0.881	0.082
APmL-1/2	0.018*	0.258	0.598	0.770	0.034*	0.051	0.987
APlR-1/2	0.008**	0.550	0.010*	1.000	0.188	0.594	0.017*
APlL-2/3	0.047*	0.840	0.135	0.996	0.027*	0.772	0.272
AngR3/MPP	0.021*	0.997	0.020*	0.994	0.039*	1.000	0.067
AngL3/MPP[a]	[a]0.032*	0.628	0.989	0.244	0.755	0.026*	0.103

* Statistically significant at $p<0.05$; ** statistically significant at $p<0.01$

[a]Welch's robust ANOVA (analysis of variance) and Games–Howell post hoc *p* values reported when assumption of homogeneity of variance violated

div division

1.89 mm and 5.8 ± 2.72 mm, the distance generally being 0.5–1 mm larger between the 2nd and 3rd rugal points than between the 1st and 2nd, except for the right lateral rugae.

- *Transverse distances*: Medial separations between opposing rugae were greater posteriorly, mean values increasing from the first (3.56 ± 1.7 mm) to the third (8.09 ± 3.43 mm) rugae.
- *Rugae angulation*: The trend for greater expression from anterior to posterior bands seemingly applies to angulation, although less pronounced on the left. Mean rugae angles relative to MMP ranged between 70.46 ± 19.96° and 93.80 ± 26.93° on the right and between 61.02 ± 15.74° and 68.1 ± 17.92° on the left. The mean outer rugae divergence angle (99.17 ± 16.4°) was 58.25° greater than the inner divergence angle (40.29 ± 20.12°), but individual variations were considerable (96.28° and 104.51° for RDA-out and RDA-in, respectively).

Rugal dimensions in relation to sagittal malocclusion

- *Length*: Among palatal rugae lengths, only L3 showed a borderline significant difference between the malocclusion groups ($p=0.047$; Table 1). Although significance was lost in post hoc testing ($p>0.05$; Table 1), the trend was for greater values in class II/2 compared to class I and class II/1.
- *Anteroposterior distances:* Occlusion-related differences were noted for half of the anteroposterior distances between opposing rugae, especially between the first and second bands (APmR-12, $p=0.013$; APmL-1/2, $p=0.018$; APlR-1/2, $p=0.008$ and APlL-2/3, $p=0.047$, Table 2).
- *Transverse distances:* The separation between the lateral points of the third rugae differed significantly among malocclusions ($p=0.006$), class II/2 subjects having greater values compared to class II/1 ($p=0.005$).

At the medial ends, separation between the 1st and 2nd rugae was significantly larger in class II/2 compared with class II/1 ($p=0.008$ and 0.034 for right and left sides, respectively; Table 2). The same trend was observed for the distance between the left 2nd and 3rd lateral rugae ($p=0.027$). However, the distance between the right 1st and 2nd lateral points was not different between class II/1 and class II/2 ($p=0.188$); the class II/2 values were significantly greater than those of classes I and III ($p=0.010$ and 0.017, respectively).

Rugae angulation: Angular rugae measurements showing differences among the malocclusion groups included AngR3/MPP ($p=0.021$) and AngL3/MPP ($p=0.032$). The right third ruga was more posteriorly directed in class II/2 than in either class I ($p=0.020$) or class II/1 ($p=0.039$), and the left third ruga was more posteriorly inclined in class II/1 compared to class III ($p=0.026$).

Rugal characteristics in relation to vertical malocclusion

- *Length:* Among palatal rugae lengths, only the right first ruga was significantly greater in the hypodivergent (10.38 ± 1.88 mm) than in the normodivergent (9.41 ± 1.73 mm) subjects ($p=0.012$; Tables 3 and 4).

Table 3 Distribution of palatal rugae measures by vertical malocclusion categorized by MP/SN angle ($n = 243$)
Tab. 3 Verteilung der Maße der palatinalen Rugae, vertikale Malokklusion, kategorisiert nach MP/SN-Winkel ($n = 243$)

	Hypodivergent ($n = 42$)		Normodivergent ($n = 124$)		Hyperdivergent ($n = 77$)		One-way ANOVA	
	Mean	SD	Mean	SD	Mean	SD	Test statistic	p
R1	10.38	1.88	9.41	1.73	9.55	1.80	4.75	0.009**
R2	10.61	2.64	9.98	2.57	9.89	2.47	1.22	0.297
R3	10.43	2.72	10.34	2.88	10.34	3.14	0.02	0.985
L1	10.76	1.47	10.27	1.81	10.47	2.07	1.14	0.323
L2	10.71	2.78	10.09	2.57	10.03	3.06	0.96	0.385
L3	11.25	3.28	11.16	2.97	11.23	2.80	0.02	0.977
Tm1	3.17	1.37	3.64	1.77	3.63	1.74	1.35	0.262
Tm2	6.54	2.82	6.41	2.70	6.47	2.49	0.05	0.955
Tm3	10.05	3.83	7.69	3.26	7.68	3.12	8.74	<0.001**
Tl1	20.84	2.62	19.21	2.62	18.05	2.61	15.5	<0.001**
Tl2	22.50	2.83	21.08	3.11	20.19	2.76	8.33	<0.001**
Tl3	24.68	3.41	22.61	3.50	21.66	3.04	11.13	<0.001**
APmR-1/2[a]	4.38	2.32	4.12	1.75	4.03	1.82	[a]0.35	[a]0.705
APmR-2/3	5.69	2.18	5.05	2.14	4.87	1.95	2.19	0.114
APmL-1/2	5.08	1.89	4.63	1.61	4.41	1.68	2.13	0.121
APmL-2/3	5.95	1.62	5.05	2.01	4.59	1.77	7.10	0.001**
APlR-1/2	6.16	2.77	5.87	2.92	5.45	2.38	1.02	0.364
APlR-2/3	5.32	2.48	5.60	2.41	5.86	3.11	0.58	0.561
APlL-1/2[a]	5.44	2.36	3.97	1.88	4.61	2.44	[a]7.39	[a]0.001**
APlL-2/3	6.03	2.03	5.13	2.48	5.07	2.19	2.81	0.062
RDA-out	96.28	16.05	101.18	17.86	97.49	13.68	2.01	0.136
RDA-in[a]	47.58	23.18	39.47	20.42	37.62	16.93	[a]3.00	[a]0.054
AngR1/MMP	76.79	22.59	71.20	19.50	65.81	18.24	4.41	0.013*
AngR2/MMP	96.24	25.62	84.99	22.19	75.48	20.60	12.04	<0.001**
AngR3/MMP	101.43	26.86	94.88	25.15	87.91	28.77	3.71	0.026*
AngL1/MMP	66.40	14.94	62.83	14.80	55.18	16.07	9.15	<0.001**
AngL2/MMP	70.11	19.02	62.89	18.28	60.79	18.71	3.55	0.030*
AngL3/MMP	74.87	18.20	66.14	16.47	67.58	19.33	3.86	0.022*

* Statistically significant at $p < 0.05$; ** statistically significant at $p < 0.01$
[a]Welch's robust ANOVA (analysis of variance) reported when assumption of homogeneity of variances violated
SD standard deviation

- *Anteroposterior distances:* Of the anteroposterior measurements, only APmL-2/3 and APlL-1/2 showed a significant difference among the groups, both significantly longer in hypodivergent than normodivergent subsamples by around 1.5 mm ($p \leq 0.013$). APmL-2/3 was also significantly smaller in hyperdivergent compared to hypodivergent subjects ($p < 0.001$). Measurements in the latter were larger than in either of the two other vertical subgroups.
- *Transverse distances:* The separation between the medial points of the third rugae was greater in hypodivergent than in either normodivergent or hyperdivergent subjects (mean difference of nearly 2.5 mm; $p \leq 0.003$). Normodivergent and hyperdivergent subjects had very similar mean values for the same transverse measurements (Tables 3 and 4).

Nearly all mean distances between opposing lateral rugae points were larger in hypodivergent than in the other groups (Hypo vs. Normo: $p \leq 0.02$; Hypo vs. Hyper: $p < 0.001$). Only the distance between the first rugae lateral points were wider in normodivergent than in hyperdivergent subjects ($p = 0.007$). A similar trend was observed for Tl2 and Tl3, although the differences were not statistically significant (Table 3). All distances between opposing lateral rugae points were significantly associated ($p \leq 0.030$) with vertical divergence (MP/SN; Table 4).

Rugae angulation: The angles formed by all 6 rugae to MPP were also significantly correlated with MP/SN. The angles between right and left palatal rugae with MPP were greater, thus more anteriorly directed, in hypodivergent than in hyperdivergent subjects.

Table 4 Pairwise comparisons for palatal rugae measures with statistically significant differences by vertical malocclusion categorized by sella-nasion to mandibular plane angle ($n = 243$)

Tab. 4 Paarweise Vergleiche für Messungen der palatinalen Rugae mit statistisch signifikanten Unterschieden, sagittale Malokklusion, kategorisiert nach dem Winkel Sella-Nasion zur Unterkieferebene ($n = 243$)

	Difference between any two groups	Tukey's post hoc test *p* value		
	One-way ANOVA *p* value	Hypo vs. Normo	Hypo vs. hyper	Normo vs. Hyper
R1	0.009**	0.012*	0.055	0.857
Tm3	<0.001**	0.002**	0.003**	0.999
Tl1	<0.001**	0.003**	<0.001**	0.007**
Tl2	<0.001**	0.020*	<0.001**	0.092
Tl3	<0.001**	0.003**	<0.001**	0.108
APmL-2/3	0.001**	0.013*	<0.001**	0.208
APlL-1/2[a]	[a]0.001**	0.002**	0.174	0.121
AngR1/MMP	<0.001**	0.330	0.023*	0.120
AngR2/MMP	0.026*	0.036*	<0.001**	0.007**
AngR3/MMP	<0.001**	0.353	0.032*	0.190
AngL1/MMP	0.030*	0.377	0.001**	0.003**
AngL2/MMP	0.022*	0.088	0.032*	0.716
AngL3/MMP	<0.001**	0.021*	0.108	0.850

* Statistically significant at $p < 0.05$; ** statistically significant at $p < 0.01$

[a]Welch's robust ANOVA (analysis of variance) and Games–Howell post hoc *p* values reported when assumption of homogeneity of variance violated

Hypo hypodivergent, *Normo* normodivergent, *Hyper* hyperdivergent

Correlations

Correlations between cephalometric measurements and rugae dimensions were low with $r < 0.15$ and mostly non-significant for linear measurements, and $r < 0.366$ with higher significance ($0.002 < p < 0.000$) for angular measures. Among all correlations with overjet and overbite, the only significant (but low) association was between Tl1 and overbite ($r = 0.282$, $p < 0.001$).

Discussion

This study is the first to use three-dimensional scanning technology to assess morphometric palatal rugae dimensions across the spectrum of sagittal and vertical malocclusions. Two major inferences are drawn from the results:

- *Prevalence of anteroposterior and angular differences among rugae particularly in class II, division 2.* The fact that 8 of 9 statistically significant differences among rugal measurements involved class II/2 (Table 2) suggests an association between this malocclusion and rugae characteristics, possibly because of developmental conditions particular to the class II/2. Indeed, features of this malocclusion are unique, including a broad (U-shaped) maxillary arch, upright maxillary incisors, and deep overbite [24]. Class II/2 was described as a "dentoalveolar malocclusion" because the interaction between overeruption of the incisors and undereruption of the posterior teeth reflects a "self-restricting" dentoalveolar intermaxillary complex, whereby the maxillary anterior teeth particularly contain their mandibular counterparts in all planes of space [24]. This topography circumvents the compensatory movements expected for the dentition during the growth-related displacements of the skeletal maxillary and mandibular bases relative to each other [24]. In this distinctive self-contained dentoalveolar development, unlike in other malocclusions, the palatal rugae might adapt to a sustained environmental impetus.
- *Prevalence of differences in hypodivergent patterns.* Differences in rugae dimensions among the vertical patterns were more consistent than among the sagittal categories, with prevailing differences in hypodivergent subjects. In these patients, all transverse distances between opposing lateral rugae points were greater and the angles between the right and left rugae with MPP were greater, thus more anteriorly directed. The count of 22 statistically significant differences for rugae measures between the hypodivergent and the other groups, and 13 between the hyperdivergent versus the other groups (Table 4) would indicate a developmental influence on palatal morphology of the vertical pattern, more particularly hypodivergence (since only 3 rugal measures were different between the normo- and hyperdivergent groups). Given a comparable finding among class II/2 subjects, and an association be-

tween II/2 and hypodivergence [24], a synergetic or complementary effect of these components is likely. Focused research is warranted in this malocclusion group.

A hereditary etiology is attributed to the shape and pattern of the palatal rugae [17, 18]. Joined with the role of genetics in the development of malocclusions [15, 16], rugae morphology would be expected to differ among malocclusions. Some authors have gone as far as suggesting that an association between these two genetically influenced entities might facilitate the early recognition of a developing malocclusion through the detection of specific palatal rugae features [19]. Such a premise would not be practical given the more solid clinical and radiographic diagnostic tools available to evaluate nascent occlusal dysmorphologies. On the other hand, considering the potential impact of environmental factors in the development of the oral cavity, the perspectives of genetic and environmental influences must be considered. Although several authors have attributed stability and immutability of general rugae features (including form, number and configuration), subtle dimensional changes in the rugae have been noted with age [25–27]. In addition, more obvious alterations of the rugae have been shown upon orthodontic/orthopedic treatment, such as palatal expansion [5, 13, 14]. Accordingly, it is plausible that the palatal rugae might undergo gradual changes in tandem with the development of malocclusion, especially in the class II/2 phenotype, suggesting a role of environmental effects in developing malocclusions grafted on the genetically determined rugal patterns.

Comparison of our findings with available evidence is limited. Two previous studies were restricted to two malocclusions (classes I and II) and to only sagittal characteristics of the four malocclusions considered in this study [20], or to descriptive rather than morphometric measurements [19]. The authors categorized rugae based on length, shape, and direction according to recognized systems [18]. Our findings of similar lengths of the first rugae in the class I and II/2 groups differed from those by Gandikota et al. [20] who reported shorter lengths, and agree more with the work of Kapoor et al. [19] who, despite classifying rugae on length categories without reporting their mean values, found no differences in the prevalence of these groupings among the four malocclusions. In a recent study of Pakistani individuals, the length of the first rugae on the left side and the third rugae on both sides varied significantly among malocclusion groups, but the authors did not report which groups were different [23].

The presence of palatal rugae differences in adults does not necessarily imply their presence in childhood or indicate when such patterns may begin to appear. Statistically significant distances and angles were greater in class II/2 (Table 1) and hypodivergent morphology (Table 3). Longitudinal research in additional samples of the wide spectrum of malocclusions is imperative to confirm our interpretation of the results. Developmental alterations, such as in angulation relative to the midpalatal plane should be explored longitudinally in a large sample of growing children, or in a large cross-sectional study assessing children and adolescents of varying ages.

Conclusions

Palatal rugae dimensions in relation to sagittal components of malocclusion were inconsistent. Class II/2 exhibited the greatest differences in rugae dimensions among sagittal malocclusions. In the vertical dimension, hypodivergent subjects exhibited the largest number of statistically significant differences, and hyperdivergent patients displayed more anteriorly directed rugae and smaller distances between opposing lateral rugae points.

Compliance with ethical guidelines

Conflict of interest M.E. Saadeh, R.V. Haddad and J.G. Ghafari have no actual or potential conflict of interest in relation to the material presented.

Ethical standards This cross-sectional investigation was approved by the Institutional Review Board of the American University of Beirut (ID#OTO.RH.03). Informed consent to publish was obtained from all individual participants included in the study.

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