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Correlation of Tongue Posture with Dental Arch Characteristics in Different Skeletal Patterns Using Cone-Beam Computed Tomography

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Abstract

Objectives This study assessed the correlation of tongue posture with dental arch characteristics in sagittal and vertical skeletal patterns using cone-beam computed tomography (CBCT).

Methods This cross-sectional study evaluated 225 CBCT scans of sagittal Class I, II, and III patients. Class I and II groups were subdivided into high-angle, normal-angle, and low-angle vertical subgroups. Palatal length, width, and height, maxillary width (Wmax), mandibular width (Wman), tongue posture according to Graber's analysis, tongue length (TGL), and tongue height (TGH) were three-dimensionally (3D) measured. Statistical analyses were conducted using one-way and two-way analysis of variance (ANOVA), and Pearson and Spearman tests (alpha=0.05).

Results All dental arch parameters were significantly greater in Class III than in Class I and II ($P<0.05$), except for Wman, palatal length, and palatal height. Palatal height was significantly greater in Class II and III than in Class I ($P<0.05$). Wmax was lower in the high-angle than in the low-angle subgroup, and palatal length was lower in the high-angle subgroup than in low-angle and normal-angle subgroups ($P<0.05$). In Class I normal-angle patients, Wmax had a positive correlation with TGL. In Class I low-angle patients, Wmax had a moderate positive correlation with TGH.

Conclusion: Significant differences were found in Wmax and palatal length among the vertical groups. In different skeletal patterns of Wmax, Wman had a low to moderate positive correlations with D4, D5, D5′, TGL, and TGH. Wmax in Class I was significantly lower than in Class III; this variable was significantly lower in Class II than in Class III. Palatal width was significantly lower in Class I and Class II than in Class III. Palatal height was significantly lower in Class I than in Class II and Class III.

Keywords Malocclusion; Tongue; Cone-beam computed tomography

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Introduction

Evidence shows that tongue posture at rest plays a crucial role in the etiology of malocclusions, treatment planning, and post-orthodontic treatment relapse.[1] A review of orthodontic literature shows that our conception of soft tissue forces and oral muscular balance has remained relatively unchanged. According to Proffit's Equilibrium Theory, the alignment of teeth is in balance with environmental factors, such as tongue posture. Thus, changing the environmental factors that affect dentition, particularly tongue posture, plays a fundamental role in establishing a stable occlusion that is in harmony with environmental forces.[2]

During the past years, numerous two-dimensional (2D) studies have addressed the correlation between tongue posture at rest and different skeletal patterns or dental arch characteristics, yielding conflicting results. While some studies have found no significant correlation between tongue posture at rest and different skeletal classes or dental arch parameters [3]; others have shown significantly larger tongue volume in Class III individuals, leading to the aggravation of Class III malocclusion due to tongue size. Also, some other studies have indicated an inferior position of the tongue in Class II individuals and a significant correlation between the anterior tongue position and mandibular protrusion.[4]

Significant differences have been reported in dental arch characteristics, particularly in the tongue-palate distance among different occlusion classes. The tongue-palate distance was found to be greater in Class III individuals compared to Class I and Class II individuals. Moreover, individuals in Class III exhibited a more inferior tongue position than those in Class I, with a significant correlation between tongue posture and dentoalveolar properties of the jaws. Class III individuals were observed to have a larger mandibular inter-molar distance at the gingival level, a smaller maxillary inter-canine distance, and a larger volume of the floor of the mouth.[5] Another study indicated a higher tongue posture in vertical growers.[6] In contrast, other studies reported a lower tongue position at rest in individuals with a vertical growth pattern of the face.[7]

Considering the controversy in the results of studies that used 2D imaging modalities for assessing the correlation of tongue posture with skeletal patterns and dental arch characteristics, and the scarcity of studies that have addressed these topics simultaneously using three-dimensional (3D) imaging modalities, particularly in the Iranian adult population, the purpose of this study was to assess the correlation of tongue posture with dental arch parameters in different sagittal and vertical skeletal patterns using cone-beam computed tomography (CBCT).

Methods

This retrospective cross-sectional study was conducted on 225 CBCT scans taken between 2016 and 2021 retrieved from two oral and maxillofacial radiology clinics. The study protocol was approved by the Ethics Committee of the university (IR.SBMU.DRC.REC.1400.042).

Sample Size

The sample size was calculated to be 30 in each group, assuming an alpha of 0.05, beta of 0.2, study power of 80%, and effect size of 0.5. However, due to the low prevalence of Class III malocclusion cases in the study population, only 25 cases were evaluated in this group (a total of 225). The following formula was used to determine the required number of samples based on the primary purpose of the study:

$$N = \frac{\left(Z_{1-\alpha/2} + Z_{1-\beta}\right)^2}{\frac{1}{4}\left[ln\left(\frac{1+r}{1-r}\right)\right]^2} + 3$$

Eligibility Criteria

The inclusion criteria included individuals over 18 years old, with fully erupted permanent teeth (to second molars), having at least one first molar and one second molar in each dental arch, maintaining the tongue at rest during CBCT without full contact with the palate, and exhibiting no or mild (0-4 mm) crowding in each dental arch.

The exclusion criteria included a history of orthodontic or orthopedic treatments, the presence of dental or craniofacial anomalies, syndromic patients, individuals with a history of trauma, missing teeth (except for one first or second molar in each dental arch) or having supernumerary teeth, and noticeable teeth rotation.

Data Collection

The CBCT scans were taken with a maximum voltage of 80 kV, a maximum amperage of 2 mA, an exposure time of 17 seconds, and a voxel size of 0.39 mm. All measurements were conducted by a trained dental student blinded to the patients' demographic information. Anatomical reference points and landmarks from 20 cases were randomly identified, and the related measurements were repeated by an orthodontist to assess the inter-examiner agreement. Also, to assess the intra-examiner agreement, 20 CBCT scans were randomly selected and re-measured by the same dental student after a two-week interval. A t-test was then applied to calculate the intra-examiner agreement.

All images were reconstructed using OnDemand 3D software (CyberMed File version: 1.0.10.6388, Date created: 2017) and evaluated in coronal, axial, sagittal, and 3D sections. A total of 229 axial slices with 0.78 mm slice thickness were evaluated for each patient. The age and gender of patients were retrieved from their records, and their skeletal class of occlusion, skeletal measurements, tongue height (TGH), tongue length (TGL), tongue posture, maxillary width (Wmax), mandibular width (Wman), palatal height, length, and width were measured.

Skeletal Analysis

Jarabak ratio: First, the posterior facial height and then the anterior facial height were calculated in the mid-sagittal plane on the 3D view. The posterior facial height/anterior facial height ratio was multiplied by 100 (S-Go/N-Me x 100). Values between 52% and 65% indicated a normal face, > 65% indicated a short face, and < 62% indicated a long face.[8]

Steiner's analysis: Se-MeGo: First, the SN and MeGo lines were drawn in the midsagittal plane on the 3D view. Next, a line was drawn parallel to the MeGo line at point S, and the angle formed between these two lines was calculated. Values between 28 and 40 degrees indicated a normal face, > 40 degrees indicated a long face, and < 28 degrees indicated a short face.[9]

ANB angle: The angle formed between A, N, and B in the mid-sagittal section on the 3D view was calculated. Values between 0 and 4 degrees indicated Class I, > 4 degrees indicated Class II, and < 0 degrees indicated Class III.[10]

Wits analysis: Vertical lines were drawn at points A and B on the functional occlusal plane. Values between -1 mm and 1 mm indicated Class I, > 1 mm indicated Class II, and < -1 mm indicated Class III.[10]

Inclination angle: The angle formed at the intersection of the palatal plane with the PN line (a line perpendicular to Se-N at point N') was measured. [8] Values < 81.1 degrees indicated retro-inclination, 81.1 to 88.9 degrees indicated normal inclination, and > 88.9 degrees indicated ante-inclination.

According to the above-mentioned analyses, the patients were assigned to seven groups as follows:

(I) Class I with a normal growth pattern, (II) Class I low-angle, (III) Class I high-angle, (IV) Class II with a normal growth pattern, (V) Class II low-angle, (VI) Class II high-angle, and (VII) Class III.

Tongue Analysis

The following measurements were made for tongue analysis:

Tongue length (TGL): The distance between the epiglottis (EB) and the tongue tip (TT) in the mid-sagittal section on the sagittal view in X-ray mode [12] (Figure 1a).

Tongue height (TGH): The length of the vertical bisect from the dorsum surface of the tongue to the line connecting the EB and TT on the sagittal view [11] (Figure 1b).

Tongue posture (Graber's analysis): A horizontal line was drawn from the incisal edge of the mandibular central incisor

to the cervical third of the distal surface of the second molar in the mid-sagittal section on the 3D view. The point in the cervical third of the distal surface of the second molar was considered the center point from which 30, 60, 90, 120, and 150-degree angles were drawn. The distances between the distal surface of the second molar and the tongue contour (D1 to D5 lines) and from the tongue contour to the palate at these points (D1' to D5') were measured [12] (Figure 1c).

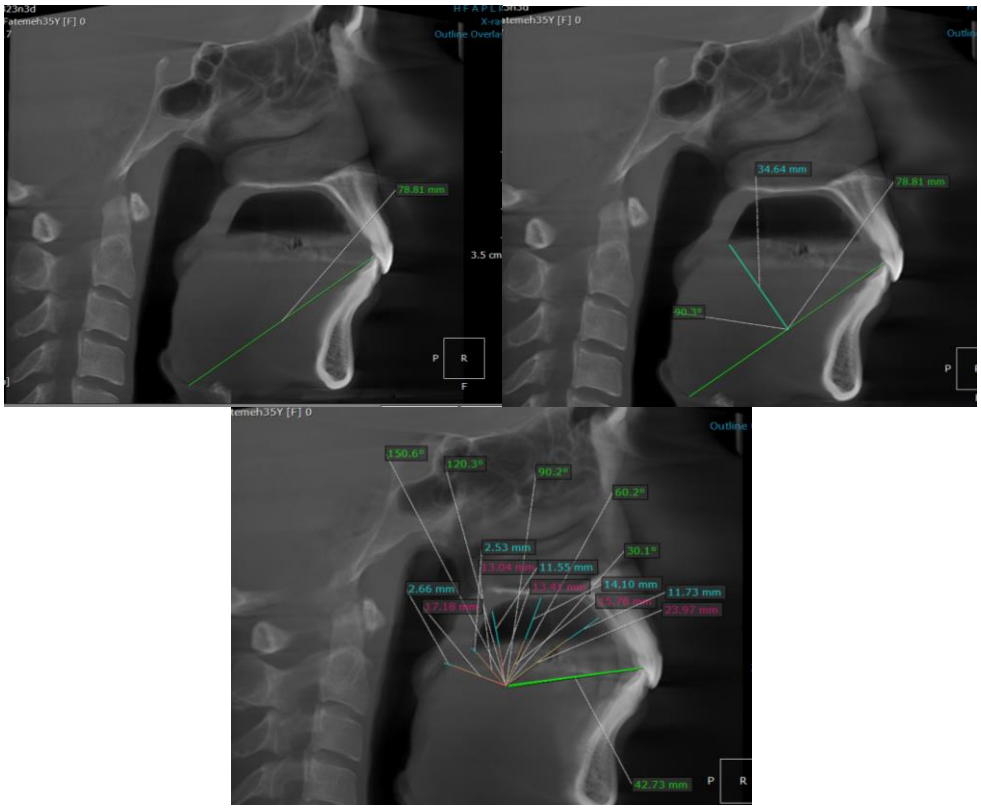

Figure 1: Tongue analyses; (a) TGL; (b) TGH; (c) Tongue posture on 3D view in X-ray and R modes

Other measurements included the following:

Maxillary width: The distance between the most concave point of the zygomatic process and the most occlusal point of bone at the site of the maxillary first or second molars bilaterally on the 3D view (Figure 2).

Mandibular width: The distance between the right and left gonion (Figure 2).

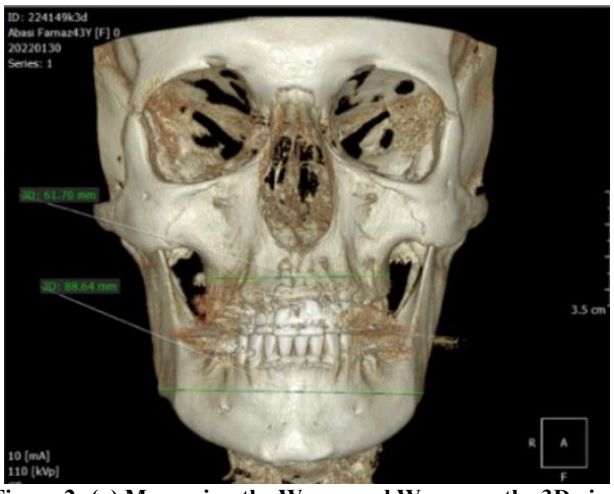

Figure 2: (a) Measuring the Wmax and Wman on the 3D view

Palatal width (Figure 3a): The distance between the alveolar bone at the middle and palatal parts of the maxillary second molars on the coronal view.

Palatal height (Figure 3b): The distance between the deepest part of the bony palate and the plane passing through the most anterior and posterior points of the maxilla and alveolar bone crest at the site of the right and left maxillary first or second molars adjusted in different sections and measured on the sagittal plane.

Palatal length (Figure 3c): The distance between the most anterior and posterior points of the maxilla and the bisection between the maxillary second molars on the axial section.

After identifying these landmarks, they were compared among different skeletal classes and vertical patterns. All images were viewed in PowerPoint 2016, and the measurements were made in Excel 2016.

Statistical Analyses

Data were analyzed using SPSS version 20 (SPSS Inc., IL, USA). The intraclass correlation coefficient (ICC) and paired t-test were used to calculate the inter- and intra-examiner agreements. The Kolmogorov-Smirnov test was

used to assess the normality of data distribution. The Levene's test, Tukey's honestly significant difference (HSD) test, and Welch test were applied to analyze the homogeneity of variances. Dental arch parameters were compared among the three sagittal skeletal classes using one-way analysis of variance (ANOVA), and among six sagittal and vertical patterns using two-way ANOVA. The Pearson and Spearman's rank tests were used to analyze the correlation of tongue parameters with dental arch parameters. The level of statistical significance was set at 0.05.

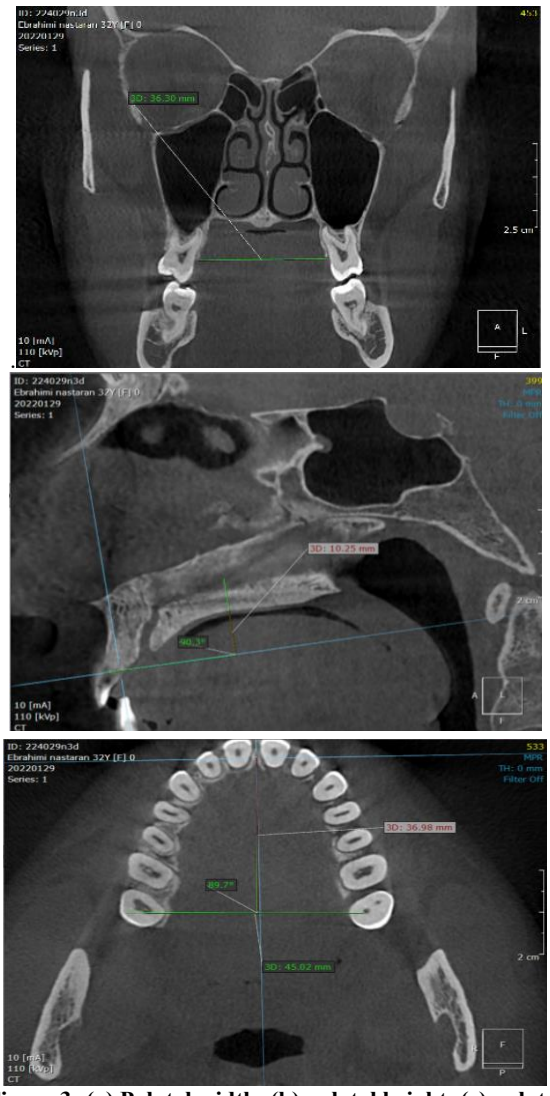

Figure 3: (a) Palatal width; (b) palatal height; (c) palatal length

Results

A total of 225 CBCT scans were evaluated, including 149 females (66.12%) and 76 males (33.8%). The mean age of participants was 33.06±10.77 years (age range = 18-77 years).

Intra- and Inter-examiner Agreements

The ICC value was found to be 1 for intra-examiner agreement and 0.998 for inter-examiner agreement. A paired t-test revealed no significant difference in the measurements made by the same examiner for assessing intra-examiner agreement (P=0.592). Similarly, there was no significant difference in the measurements conducted by the two examiners for assessing inter-examiner agreement (P=0.740).

The Kolmogorov-Smirnov test showed normal data distribution (P>0.05). The assumption of homogeneity of variances was met for some variables by the Levene's test (P>0.05), while it was not met for others. Consequently, the data were subjected to one-way ANOVA and Tukey's HSD post-hoc test for the variables with homogeneity of variances, and to Welch and Games-Howell post-hoc tests for the variables without homogeneity of variances.

There was 100 Class I, 100 Class II, and 25 Class III patients.

Dental Arch Parameters Based on Sagittal Classes

Table 1 presents the mean dental arch parameters in the three sagittal classes. As shown, significant differences were found between the three classes in Wmax (P=0.024), palatal width (P=0.002), and palatal height (P=0.003).

Table 1- Mean dental arch parameters in the three sagittal classes

Variable	Sagittal skeletal class	Mean	Std. deviation	P value (one-way ANOVA)
Wmax	Class I	58.9913	3.47644	0.024*
	Class II	58.9764	3.53358	
	Class III	61.0172	3.22856	
	Total	59.2098	3.51950	
Wman	Class I	92.9062	6.69299	0.060
	Class II	91.8021	5.91020	
	Class III	95.1752	7.60015	
	Total	92.6676	6.51819	
Palatal width	Class II	46.8668	3.96733	0.002*
	Class III	49.0784	3.60945	
	Total	47.0436	3.79923	
	Class I	37.7304	3.46807	
	Class II	37.4223	2.99891	
	Class III	39.9548	2.68870	
	Total	37.8406	3.26305	
Palatal height	Class I	13.1953	2.29657	0.003*
	Class II	14.0329	2.06626	
	Class III	14.6352	2.36528	
	Total	13.7276	2.25331	
Palatal length	Class I	37.2965	2.35813	0.437
	Class II	37.7026	2.39217	
	Class III	37.2952	2.13192	
	Total	37.4768	2.34834	

*Pearson's correlation test

Pairwise comparisons by the Tukey's HSD test yielded the following results:

Wmax was significantly lower in Class I than in Class III (P=0.026); this variable was also significantly lower in Class II than in Class III (P=0.025).

Palatal width was significantly lower in Class I (P=0.006) and Class II (P=0.001) than in Class III.

Palatal height was significantly lower in Class I than in Class II (P=0.021) and Class III (P=0.011). No other significant differences were found (P>0.05).

Dental Arch Parameters Based on Sagittal and Vertical Classes

Of the 100 Class I patients, 37 were low-angle, 33 were normal, and 30 were high-angle. Among the 100 Class II patients, 36 were low-angle, 33 were normal, and 31 were high-angle. Table 2 presents the mean dental arch parameters categorized by sagittal and vertical classes.

Two-way ANOVA showed a significant effect of vertical skeletal pattern only on Wmax (P=0.016) and palatal length (P=0.001). There was a significant effect of sagittal skeletal pattern only on palatal height (P=0.011), and a significant interaction effect of sagittal and vertical skeletal patterns only on palatal length (P=0.006). In other words, Wmax differed significantly among high-angle, normal, and low-angle cases (P=0.016), being significantly smaller in high-angle than in low-angle cases (P=0.019). Palatal height also differed significantly among different sagittal classes (P=0.011), with Class II individuals having significantly greater palatal height than Class I cases (P=0.021). Palatal length was also significantly different among different vertical classes (P=0.001), being lower in high-angle cases than in low-angle (P=0.001) and normal (P=0.008) cases. Furthermore, sagittal and vertical patterns had a significant interaction effect on palatal length (P=0.006). Specifically, palatal length was higher in Class I low-angle cases than in Class I normal angle cases (mean difference=-1.45, P=0.020). However, the value was lower in Class II high-angle cases than in normal Class II patients (mean difference=-1.88, P=0.004), as shown by the Tukey's test.

No other significant effect was found on any parameter (P>0.05).

Correlation of Tongue Variables with Dental Arch Characteristics in Different Sagittal Skeletal Classes

Class I:

Table 3 presents the correlation of tongue variables with dental arch characteristics in Class I individuals. The following correlations were found (negative r values indicate the presence of an inverse correlation):

Significant correlations were found between Wmax and TGL, Wman and TGL, TGH and D2, between palatal width and TGH, TGL, D1, D2, D1', D4', and D5', between palatal height and TGH, D2, and D3', and between palatal length and TGL.

Table 2- Mean dental arch parameters based on sagittal and vertical classes

Variable	Sagittal skeletal class	Vertical skeletal class	Mean	Std. deviation
Wmax	Class I	High angle	57.27	2.82
		normal	59.54	3.90
		Low angle	59.89	3.11
	Class II	High angle	58.56	2.99
		normal	59.09	4.00
		Low angle	59.22	3.57
Wman	Class I	High angle	93.88	6.23
		normal	92.58	7.24
		Low angle	92.39	6.63
	Class II	High angle	91.95	5.21
		normal	91.54	5.11
		Low angle	91.90	7.17
		normal	47.30	5.18
		Low angle	46.84	3.26
Palatal width	Class I	High angle	37.42	3.03
		normal	37.36	2.98
		Low angle	38.30	4.14
	Class II	High angle	36.60	2.71
		normal	38.07	3.44
		Low angle	37.52	2.69
Palatal height	Class I	High angle	13.98	2.50
		normal	13.22	1.94
		Low angle	12.52	2.26
	Class II	High angle	13.99	1.98
		normal	14.06	2.24
		Low angle	14.03	2.02
Palatal length	Class I	High angle	36.37	2.53
		normal	36.91	1.70
		Low angle	38.37	2.33
	Class II	High angle	36.77	2.28
		normal	38.65	2.28
		Low angle	37.63	2.30
		Low angle	33.57	4.87
		normal	25.46	4.90
		Low angle	25.63	4.62
		Low angle	22.07	10.23
	Class II	High angle	19.05	4.34
		normal	20.81	4.21
		Low angle	21.62	4.17
		normal	1.73	2.01
		Low angle	1.84	2.11
		Low angle	19.61	4.66

Class II:

Table 4 presents the correlation of tongue variables with dental arch characteristics in Class II individuals. The following correlations were found:

Significant positive correlations were found between Wmax and TGL and D3, between Wman and TGH, TGL, D4, and D5, between W-U3-occlusal and TGH, TGL, D2, and D3, between palatal width and TGH, D3, D4, and D5, between

palatal height and TGH, D2, and D3, and between palatal length and TGH, D1, and D2.

Table 3- Correlation of tongue variables with dental arch characteristics in Class I individuals

Cl 1		TGL	TGH	D1	D1'	D2	D2'	D3	D3'	D4'	D5'
Wmax	Correlation Coefficient	0.333*	0.193	0.193	0.090-	0.127	0.00	0.030	0.003	-0.079	0.087
	P value	0.001*	0.055	0.054	0.373	0.207	0.998	0.767	0.977	0.434	0.392
Wman	Correlation Coefficient	0.372*	0.378*	0.142	0.081-	0.208✝	0.013	0.070	0.089	-0.126	-0.051
	P value	0.00*	0.00*	0.160	0.421	0.038✝	0.897	0.489	0.378	0.213	0.617
Palatal Width	Correlation Coefficient	0.335*	0.231*	0.213*	0.243*-	0.240✝	-0.160	0.157	-0.096	-0.262*	-0.198*
	P value	0.00*	0.021*	0.034*	0.015*	0.016✝	0.111	0.119	0.340	0.008*	0.048*
Palatal Height	Correlation Coefficient	0.077	0.199*	0.126	0.082	0.240✝	0.183	0.056	0.235*	0.024	-0.081
	P value	0.443	0.048*	0.210	0.419	0.016✝	0.068	0.583	0.018*	0.810	0.425
Palatal Length	Correlation Coefficient	0.294*	0.189	0.168	0.076	0.103	0.051	0.130	0.062	0.059	0.137
	P value	0.003*	0.060	0.094	0.450	0.308	0.614	0.198	0.541	0.563	0.174

*Pearson's correlation test
✝Spearman correlation test

Table 4- Correlation of tongue variables with dental arch characteristics in Class II individuals.

Cl 2		TGL	TGH	D1	D2	D3	D4	D5
Wmax	Correlation Coefficient	0.216*	0.159	0.119	0.118	0.209*	0.175	0.168
	P value	0.031*	0.115	0.240	0.062	0.037*	0.082	0.095
Wman	Correlation Coefficient	0.335*	0.292*	0.103	0.120	0.140	0.227*	0.237*
	P value	0.001*	0.003*	0.310	0.234	0.166	0.023*	0.018*
	P value	0.046*	0.195	0.334	0.136	0.293	0.137	0.045*
Palatal Width	Correlation Coefficient	0.085	0.209*	0.061	0.170	0.234*	0.245*	0.243*
	P value	0.403	0.037	0.547	0.091	0.019	0.014	0.015
Palatal Height	Correlation Coefficient	0.000	0.286**	0.172	0.238*	0.213*	0.130	0.109
	P value	1.000	0.004	0.086	0.017	0.034	0.196	0.280
Palatal Length	Correlation Coefficient	0.162	0.201*	0.273**	0.225*	0.181	0.092	0.048
	P value	0.107	0.045	0.006	0.025	0.071	0.362	0.633

*Pearson's correlation test

Class III:

Table 5 presents the correlation of tongue variables with dental arch characteristics in Class III individuals. The following correlations were found (negative r values indicate the presence of an inverse correlation):

Significant correlations were found between Wmax and TGL, between W-U6-alveolar and D1, between W-L6-occlusal and TGL, D3, D4, and D1', between W-U6-occlusal and D5, and between palatal height and TGH.

Table 5- Correlation of tongue variables with dental arch characteristics in Class III individuals

Cl 3		TGL	TGH	D1'	D3	D4	D5
Wmax	Correlation Coefficient	0.457*	0.158	0.193	0.065-	0.090	0.196
	P value	0.022*	0.451	0.356	0.757	0.667	0.349
	P value	0.100	0.100	0.200	0.330	0.181	0.032

Palatal Height	Correlation Coefficient	0.276	0.470*	-0.114	0.297	0.213	0.122
	P value	0.181	0.018	0.587	0.149	0.308	0.562

*Pearson's correlation test

Correlation of Tongue Variables with Dental Arch Characteristics in Different Sagittal and Vertical Skeletal Patterns

Class I high-angle:

As shown in Table 6, the following correlations were found (negative r values indicate the presence of an inverse correlation):

Significant correlations were found between palatal width and D4' and D5', and between palatal height and D2.

Class I normal-angle:

As shown in Table 6, the following correlations were found (negative r values indicate the presence of an inverse correlation):

Significant correlations were found between Wmax and TGL, between Wman and TGL, D3, D4, and D5, and between palatal width and TGL.

Class I low-angle:

As shown in Table 6, the following correlations were found (negative r values indicate the presence of an inverse correlation):

Significant correlations were found between Wman and TGH and TGL, between palatal width and TGL, and D4', and between palatal height and D5'.

Class II high-angle:

As shown in Table 7, the following correlations were found (negative r values indicate the presence of an inverse correlation):

Significant correlations were found between palatal width and D4 and D5, and between palatal height and TGH and D5'.

Class II normal-angle:

As shown in Table 7, the following correlations were found (negative r values indicate the presence of an inverse correlation):

Significant correlations were found between Wmax and TGL, between Wman and TGH and TGL, between palatal width and TGL, and between palatal height and D2 and D3.

Class II low-angle:

As shown in Table 7, the following correlations were found (negative r values indicate the presence of an inverse correlation):

Significant correlations were found between Wman and TGL, D4, and D5, between palatal width and D2', between palatal height and D1, D2, and D3, and between palatal length and D1, D2, D3, and D4.

Table 6- Correlation of tongue variables with dental arch characteristics in class 1 normal-angle, low-angle and high angle patients

Cl 1 High angle		TGL	D2	D4'	D5'
Palatal Width	P value	0.023	0.614	0.697	0.708
	Correlation Coefficient	0.062	0.118	-0.388✝	-0.363✝
	P value	0.747	0.201	0.034✝	0.049✝
Palatal Height	Correlation Coefficient	0.155	0.027	-0.069	0.388✝
	P value	0.413	0.889	0.717	0.034✝

✝Spearman correlation test

Table 7- Correlation of tongue variables with dental arch characteristics in class 2 normal-angle, low-angle patients and high angle patients

Cl 2 Normal Angle		TGH	TGL	D1	D2	D3
Wmax	Correlation Coefficient	0.253	0.392*	0.095	0.315	0.273
	P value	0.156	0.024*	0.598	0.074	0.124
Wman	Correlation Coefficient	0.474*	0.369*	0.219	0.331	0.338
	P value	0.005	0.035*	0.221	0.060	0.054
Palatal width	Correlation Coefficient	0.305	0.370*	0.129	0.337	0.332
	P value	0.085	0.034*	0.475	0.055	0.059
Palatal height	Correlation Coefficient	0.310	0.037	0.294	0.398*	0.355*
	P value	0.079	0.839	0.097	0.022*	0.043*

*Pearson's correlation test

Discussion

This study assessed the correlation of tongue posture with dental arch parameters in different sagittal and vertical skeletal patterns using CBCT.

In the present study, Wmax was found to be significantly higher in Class III individuals than in Class I and II individuals; however, the difference between Class I and II was not significant. This finding was consistent with the results of Braun et al.[13] but contrary to the findings of Iwasaki et al. [4]. They reported smaller Wmax in Class III individuals than in Class II individuals. This difference between the results may be due to differences in age range since the present study was conducted on Iranian adults over 18 years of age, while Iwasaki et al. [4] evaluated Japanese children in the age range of 7-12 years. This difference in the results may indicate the change in growth pattern of Wmax with age, and also the effects of development and race on this variable. The Wmax was smaller in high-angle patients than in low-angle patients in the present study, which was consistent with the results of Ning et al. [14]

Palatal width was greater in Class III patients than in Class I and II patients, which was different from the results of Huang et al. [15], probably because they measured different landmarks and sagittal classes (only Class I and II), and their method of measurement for determination of morphology of the palate was different as well (they used Dolphin 3D imaging software).

In the present study, the palatal height was greater in Class II individuals than in Class I cases, which was consistent with the results of Alarashi et al. [16] and contradictory to the findings of Huang et al. [15], regarding the sagittal classes. Huang et al. [15] reported a higher palatal height in high-angle and normal Class II patients than in low-angle Class II patients and placed a greater emphasis on the palatal morphology in vertical dimensions. However, no significant difference was found in this regard between different vertical groups in the present study. This difference may be attributed to their focus on the posterior part of the palate, utilization of Dolphin 3D imaging software for measurements, and assessment of patients aged 18-35 years. In the present study, the palatal height was higher in Class III patients than in Class I patients, which was in line with the results of Primozic et al. [5].

In the present study, the palatal length was not significantly different among the sagittal classes; however, a significant difference was found in this regard among the vertical groups, such that palatal length was lower in high-angle patients than in low-angle and normal groups. Also, palatal length was higher in Class I low-angle patients than in Class I normal and high-angle individuals. This value was greater in Class II normal patients than in Class II high-angle patients. These findings were contrary to our expectations, and future studies are required on palatal length in individuals with different vertical growth patterns.

In the present study, Wmax showed a small to moderate correlation with TGL in Class I and II normal-angle and Class III individuals and had a very low correlation with D3 in Class II individuals. Thus, it can be concluded that TGL, irrespective of its position at rest, has a greater effect on transverse maxillary growth pattern, as this correlation is noted in most skeletal patterns. Thus, it may be concluded that higher TGL increases the tongue force, and subsequently the Wmax.

Wman in Class I normal and Class II normal and high-angle cases had a low positive correlation with TGL and TGH, and very low to low positive correlation with tongue posture (D2-D5). It may be explained by the fact that a higher position of the dorsum of the tongue in the mandible, along with higher TGH and TGL, leads to increased mandibular growth due to higher tongue force. Unlike the maxilla, the tongue position and height, in addition to TGL, significantly influence the transverse mandibular growth (Wman).

In Class I and II individuals, a very low to low correlation existed between palatal width and TGH, and palatal width had a low inverse correlation with D4' and D5'. This finding indicates that a higher tongue position at D4' and D5' increases the palatal width. This correlation was not observed in Class III individuals, because as stated by Primozic et al. [5], the tongue position is lower in Class III individuals, and it does not affect the palatal width.

In Class I, II, and III individuals, a very low to low correlation existed between palatal height and D1 and D2, which may indicate that a higher tongue position, irrespective of the growth pattern, increases the palatal height.

This study had some limitations. The sample size in Class III did not reach the statistically required number, and therefore, vertical groups could not be assessed in this class. If possible, measurement of tongue volume is more reliable for assessing its effect on dental arch characteristics than the tongue posture, because the results regarding tongue posture may not be reproducible, as patients may not be able to reproduce the exact same tongue position.

Future studies are required to find a reliable method for CBCT assessment of tongue posture and tongue volume. Also, sagittal classes can be further subdivided to find the responsible jaw for the discrepancy. Thus, the relationship of sagittal subgroups with dental arch characteristics may be assessed. Also, the inter-canine width at the alveolar level should be evaluated in future studies.

Conclusion

All dental arch parameters (except for palatal height and length, W-L3, and Wmax) showed significant differences

across different sagittal groups. Notably, significant differences were observed in Wmax and palatal length among the vertical groups. Wmax was significantly lower in Class I than in Class III, and this variable was also significantly lower in Class II than in Class III.
Palatal width was significantly lower in Class I and Class II than in Class III.
Finally, palatal height was significantly lower in Class I than in Class II and Class III

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