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Tongue and Hyoid Bone Positions and Its Relations to the Mandibular Anterior Teeth: A Cone-Beam Computed Tomography Study

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ABSTRACT

Objectives: This study aimed to investigate the position of the tongue and hyoid bone at rest according to incisal relationships using cone beam computed tomography and to examine whether dentoskeletal measurements are correlated with these positions.

Materials and Methods: Participants were categorised into normal, open bite, cross-bite and combined open-crossbite groups according to overjet and overbite. Linear and volumetric measurements of tongue dimensions and positions of the tongue and hyoid bone were compared among the four groups using one-way analysis of variance and the Bonferroni post hoc test. Pearson correlation coefficients were calculated to evaluate the relationships of tongue and hyoid bone positions with dentoskeletal parameters.

Results: Downward and forward positions of the tongue and hyoid bone were observed in the cross-bite and open-crossbite groups. Overjet and mandibular incisor-to-mandibular plane angles were negatively correlated with all parameters of the vertical and horizontal tongue and hyoid bone positions. Horizontal skeletal parameters negatively correlated with tongue-to-palate distance, tongue tip ratio, oral cavity airway volume and horizontal hyoid bone position. Vertical skeletal parameters correlated with the horizontal position of the tongue and hyoid bone.

Conclusion: The downward and forward positions of the tongue and hyoid bone at rest were related to anterior cross-bite but not to anterior open bite, indicating that the tongue position was related to the most anteriorly positioned teeth. The inferior and anterior positions of the tongue correspond to a constricted maxilla, skeletal Class III relationship, retroclined mandibular incisors and negative overjet.

1 | Introduction

The position, function and size of the tongue have been reported to significantly affect facial bone growth, development and tooth alignment [1]. Patients with malocclusion exhibit a variety of peculiar tongue positions, indicating that skeletal and dental malocclusion may correlate with varying tongue positions depending on severity. Compared to normal occlusion, patients with Class II malocclusion exhibit a superiorly positioned tongue [2]. Therefore, patients with Class III malocclusions may display a significantly more inferiorly-positioned tongue [3].

Patients with anterior open-bite have more forward-positioned tongue tips than individuals with normal occlusion [4]. This altered tongue posture has been hypothesised to be associated with backward mandibular rotation, although causality has not been definitively established [5, 6]. Given these potential interrelationships, a thorough assessment of tongue posture is essential to elucidate the aetiology of open-bite malocclusion and the stability of orthodontic treatment.

The hyoid bone, owing to its muscular connections with the tongue, serves as an indirect indicator of the tongue position [2, 4, 7]. In skeletal Class III patients with mandibular prognathism, the hyoid bone is located more anteriorly than in patients with Class I or II malocclusion [8]. Similarly, patients with short-face syndrome exhibited a more anteriorly positioned hyoid bone than those with long-face syndrome [9].

However, most existing studies have relied on two-dimensional cephalograms, which are limited to linear and angular assessments and are compromised by anatomical overlap [2, 10, 11]. These studies did not comprehensively investigate sagittal, vertical and transverse discrepancies in relation to the resting tongue position, making it difficult to identify the primary etiologic factors of anterior open-bite, anterior cross-bite, or a combination of both. Furthermore, previous studies have rarely explored how tongue position differs depending on the incisal relationship. It would be valuable to evaluate tongue posture based solely on intraoral conditions without the need for lateral cephalograms to assess skeletal relationships.

Cone-beam computed tomography (CBCT) enables three-dimensional (3D) analysis of tongue posture across the axial, sagittal and coronal planes [12]. Therefore, this study aimed to investigate the resting horizontal and vertical positions of the tongue and hyoid bone according to the incisal relationships—overjet (OJ) and overbite (OB)—using CBCT images, and to evaluate their correlations with dental and skeletal cephalometric parameters.

2 | Materials and Methods

2.1 | Participants

This retrospective study was approved by the institutional review board of Yonsei University Dental Hospital (IRB No. 2-2017-0059). Seven hundred and ten patients who had CBCT images and lateral cephalograms taken before treatment at the Department of Orthodontics, Yonsei University Dental Hospital between January 2014 and June 2017 were initially screened. The inclusion criteria were as follows: (1) age $\geq$18 years; (2) availability of lateral cephalograms and CBCT images acquired in centric occlusion with relaxed tongue and lip posture; and (3) CBCT images from the nasal floor to the epiglottis. The exclusion criteria were as follows: (1) craniofacial anomalies; (2) nasal obstruction, adenoid, or tonsil hypertrophy; (3) tongue-tie (ankyloglossia); (4) orofacial myofunctional disorders; (5) CBCT images with severe motion artefacts; and (6) two or more missing teeth, except the third molars. Assessment of tongue-tie was performed by using Kotlow's free-tongue length system, with tongue-tie defined as $<$16 mm [13]. Orofacial myofunctional evaluation with scores (OMES) protocol was used to assess the presence of orofacial myofunctional disorders [14].

Participants were then categorised into four groups according to OJ and OB: normal-bite as a control group (1 mm $\leq$ OJ $<$ 4 mm and 1 mm $\leq$ OB $<$ 4 mm), open-bite group (OJ $>$ 0 mm and OB $<$ 0 mm), cross-bite group (OJ $<$ 0 mm and OB $>$ 0 mm) and open-crossbite group (OJ $<$ 0 mm and OB $<$ 0 mm) (Figure 1). Individuals having 0 mm $\leq$ OJ and OB $<$ 1 mm were excluded to enhance group distinctiveness. Based on a previous study [7], the minimum required sample size was calculated as 69 participants (17 participants per group) with $\alpha = 0.05$, 80% power, and effect size of 0.60 using the G*Power program (G* Power 3.1.9.4, Dusseldorf, Germany).

As shown in the study flowchart, 119 participants met the following inclusion criteria: (1) normal-bite ($n = 37$), (2) open-bite ($n = 29$), (3) cross-bite ($n = 32$) and (4) a combination of open-crossbite ($n = 21$; Figure 1).

2.2 | Measurements

CBCT scans were obtained using Alphard VEGA (ASAHI Roentgen IND, Kyoto, Japan) at 8.0 mA and 80 kV for 17 s, with a voxel size of 0.3 mm, in an upright position. Images were saved in the DICOM format and reconstructed in 3D using OnDemand 3D software (Cybermed Co., Seoul, Korea). Reorientation was standardised by aligning the palatal plane—defined by anterior and posterior nasal spines (ANS-PNS, respectively)—parallel to the ground in both the sagittal and coronal planes. In the mid-sagittal section, the palatal plane and its perpendicular plane at the PNS were used as the horizontal and vertical reference planes (HRP and VRP, respectively) (Table 1; Figure 2A), as reported previously [15].

Linear and volumetric measurements were performed to identify tongue dimensions and tongue and hyoid bone position (Table 1; Figure 2A). To assess tongue dimension, tongue height and length were measured, while tongue-to-palate distance, tongue tip position to the VRP (TT-VRP), and maxillary incisal (U1) position to the VRP (U1-VRP) were measured to determine tongue position (Figure 2A). The tongue tip ratio (TT-VRP/U1-VRP) was calculated to identify the sagittal position of the tongue relative to U1, with a value $<$ 1 indicating that the tongue tip is posterior to U1 and a value $>$ 1 indicating that the tongue tip is anterior to U1 [16]. The tongue tip was identified as the most anterior point visible across the series of sagittal sections. The position of the hyoid bone was assessed by measuring the distance from its most anterosuperior point to the HRP and VRP. Intermolar width discrepancy (ΔIMW) was defined as the discrepancy between the maxillary and mandibular intermolar widths and measured as the linear distance between the central fossa of the left and right first molars (Table 1; Figure 2A).

For volumetric analysis, the intraoral airway—defined as the space between the dorsum of the tongue and the palate—was segmented to calculate the intraoral airway volume (IAv), serving as an indicator of the tongue's vertical position (Table 1; Figure 2B). Following an established protocol [17], the intraoral airway boundaries were standardised as follows: superiorly by the palatal surface, inferiorly by the tongue

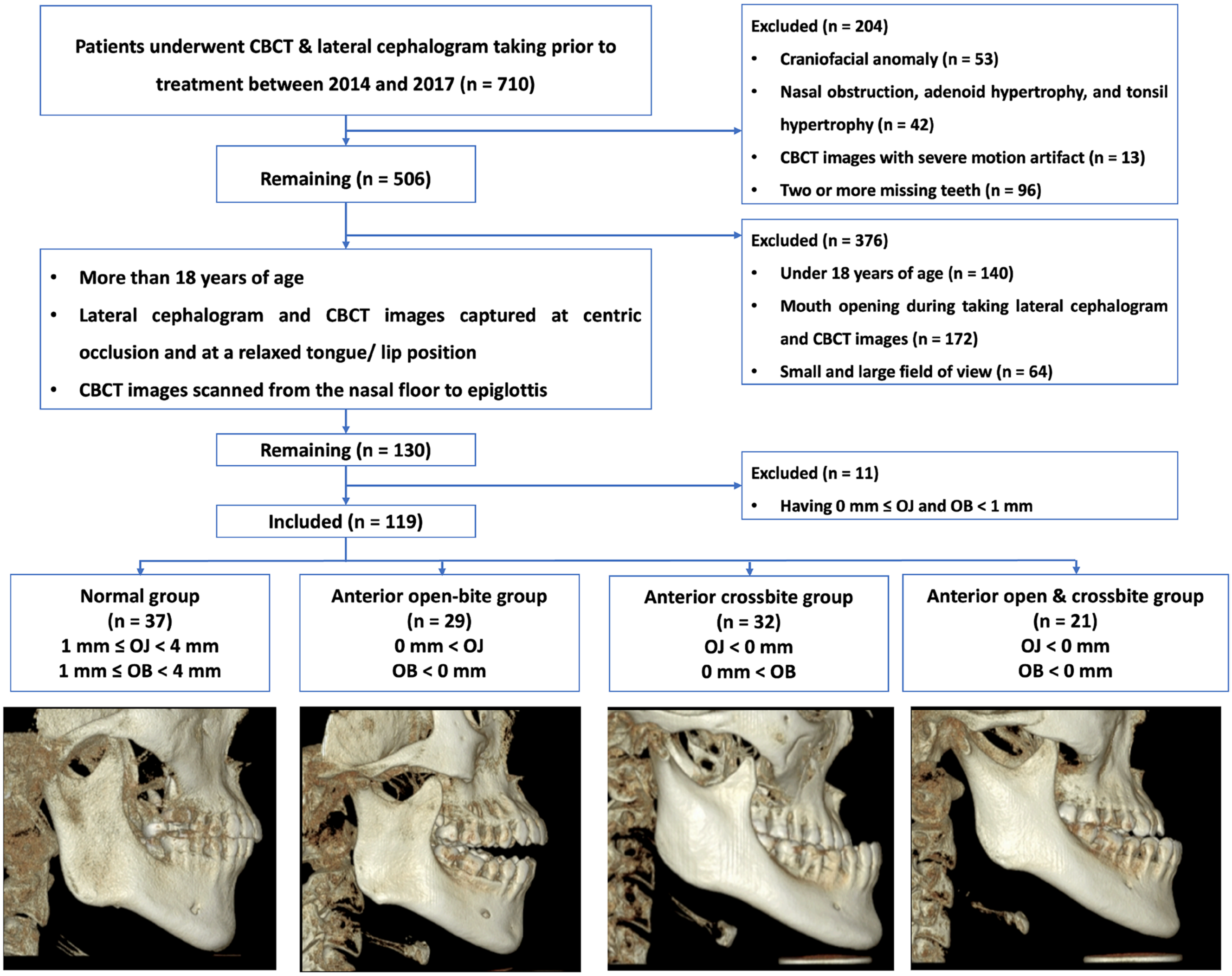

FIGURE 1 | Study flow chart and the four investigated groups.

dorsum, anteriorly and laterally by the dentition, and posteriorly by a vertical plane through the anterosuperior point of the hyoid bone, perpendicular to the ANS–PNS plane. A two-stage semi-automatic segmentation was performed using ITK-SNAP software (version 4.2.0; www.itksnap.org; Penn Image Computing and Science Laboratory, Philadelphia, PA, USA) [18]. In the intensity-based pre-segmentation stage, a global thresholding algorithm converts grayscale images into a binary map, distinguishing the intraoral airway from the surrounding structures [18]. Contrast calibration was based on image intensity, with lower and upper thresholds set at −1000 and 73 Gy, respectively [19, 20]. In the active contour stage, seed points were manually placed, and a region-growing algorithm iteratively identified connected voxels with similar intensities, refining the segmentation until completion [18]. This method, which is faster and more reliable than manual segmentation, enabled 3D visualisation of the intraoral airway and subsequent IAv computation [21].

On lateral cephalograms, the facial height ratio (FHR, the ratio of posterior to anterior facial height), mandibular plane angle, palatal plane angle, ANB angle, Wits appraisal, angle between the sella-nasion (SN) plane and the axis of the maxillary central incisor (U1 to SN angle), and the mandibular incisor to mandibular plane angle (IMPA) were measured using V-Ceph software (Osstem Inc., Seoul, Korea; Table 1; Figure 2C).

2.3 | Statistical Analysis

A single examiner performed all measurements. Intra-examiner reliability was assessed by repeating the measurements for five randomly selected participants per group at a 2-week interval, yielding high consistency (intraclass correlation coefficient > 0.92).

The normality of the data was confirmed using the Shapiro–Wilk test. Analysis of covariance (ANCOVA) was performed to compare tongue dimensions, as well as the positions of the tongue and hyoid bone across groups (Table 2). Age and sex were included as covariates in this analysis. Pearson correlation coefficients were calculated to evaluate the relationships between the positions of the tongue and hyoid bone and various skeletal and dental parameters (Table 3). Statistical tests were conducted using SPSS version 20 (SPSS Inc., Chicago, IL, USA), with significance set at $p < 0.05$.

TABLE 1 | Definitions of landmarks and measurements used in this study.

	Definition
Landmarks	
Tongue tip (TT)	The most anterior point of the tongue
Epiglottis	The deepest point of the epiglottis
Maxillary incisor (U1)	Incisal edge of the maxillary central incisor
Anterior nasal spine (ANS)	The most anterior-inferior midline bony projection of the maxilla at the anterior edge of the nasal floor
Posterior nasal spine (PNS)	The most posterior-inferior midline point at the junction of the palatine bones marking the posterior edge of the hard palate
Nasion (N)	The most anterior point of the frontonasal suture
Sella (S)	The center of the sella turcica
Menton (Me)	The most inferior point on the symphyseal outline
Gonion (Go)	The intersection point of the ramus and mandibular plane
Hyoid bone	The most antero-superior point on the body of the hyoid bone
Tongue length	The length of the tongue between epiglottis and tongue tip
Tongue height	The length of the vertical bisector from the dorsal tongue surface to a line connecting between epiglottis and tongue tip
Tongue-to-palate distance	The perpendicular distance from the highest point of the dorsal tongue surface to the bony palate. The highest point of the dorsal tongue surface was identified by scrolling through coronal sections
TT-VRP/U1-VRP (tongue tip ratio)	The ratio of the distance from TT and U1 to VRP. The tongue tip was identified as the most anterior point by scrolling through multiple sagittal sections
Intraoral airway volume	The airway volume of oral cavity proper, which includes the space between the dorsum of the tongue and the palate
Horizontal distance of hyoid bone	The horizontal distance between the most antero-superior point of the hyoid bone and the PNSper line
Measurements	
Vertical distance of hyoid bone	The vertical distance between the most antero-superior point of the hyoid bone and the palatal plane (ANS to PNS)
Intermolar width discrepancy (ΔIMW)	Difference between the maxillary intermolars width and the mandibular intermolars width. Intermolar width was defined as the linear distance between the central fossa of the left first molar to the central fossa of the right first molar
Anterior facial height (AFH)	The distance from Nasion to Menton
Posterior facial height (PFH)	The distance from Sella turcica to Gonion
The facial height ratio	The ratio of PFH to the AFH
FMA angle	The angle between the Frankfort horizontal plane (Orbitale to Porion) and the mandibular plane (Menton to Gonion)
Mandibular plane angle	The angle of the mandibular plane (Menton to Gonion) to the SN plane (Sella turcica to Nasion)
Palatal plane angle	The angle of the mandibular plane (Menton to Gonion) to the palatal plane (ANS to PNS)
ANB angle	The angle formed by A point, Nasion, and B point
Wits appraisal	The distance between the points of contact of the perpendicular lines from A point and B point on the occlusal plane

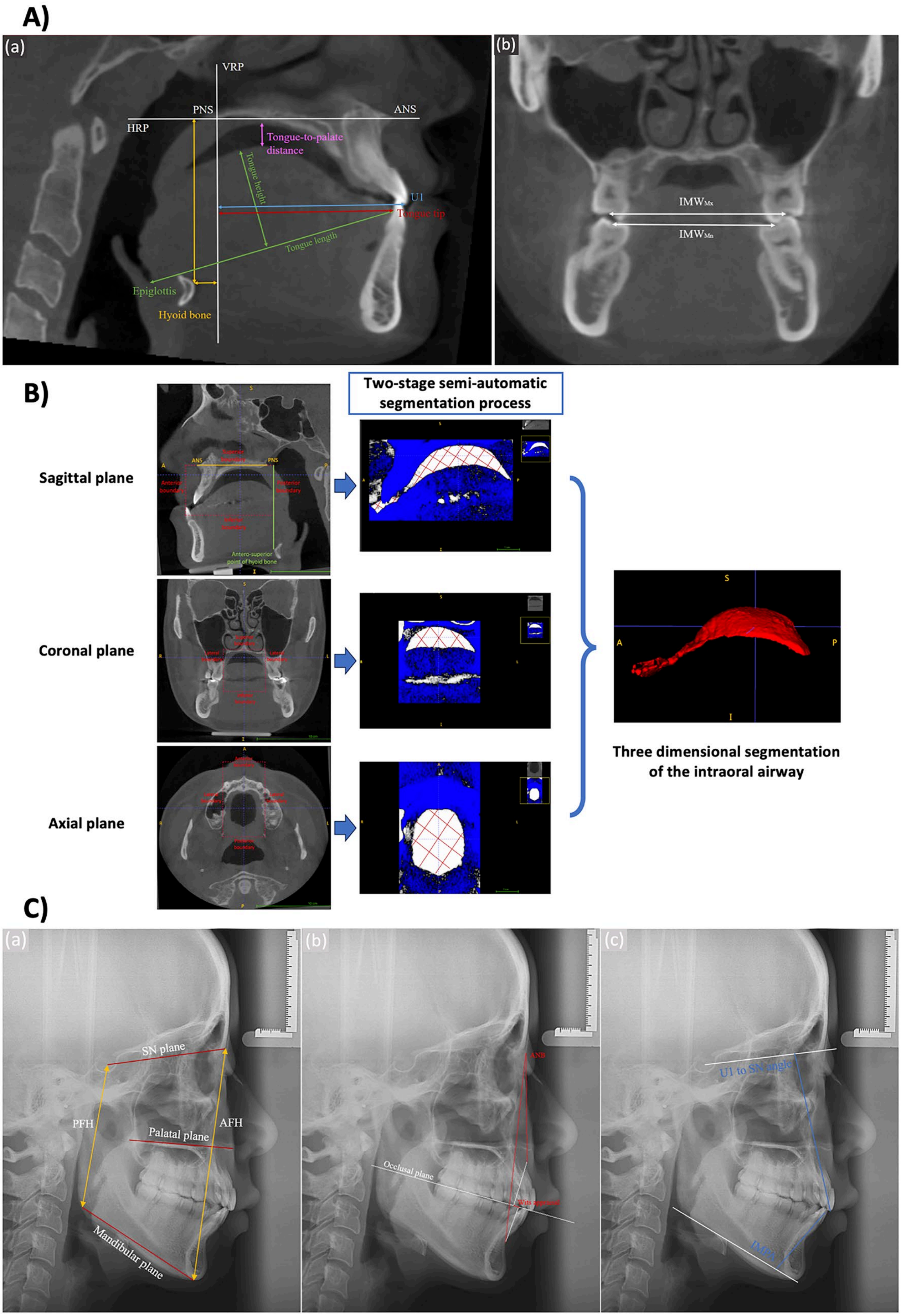

FIGURE 2 | Investigations on cone-beam computed tomography (CBCT) images and cephalogram. (A) Parameters after reorientation. (a) Linear measurements: tongue height, tongue length, tongue-to-palate distance, tongue tip position and maxillary incisal position; (b) Intermolar width difference; (B) Two-stage segmentation to investigate intraoral airway volume; (C) Cephalometric measurements. (a) Vertical skeletal measurements, (b) Horizontal skeletal measurements, (c) Dental measurements.

3 | Results

Descriptive statistics for tongue and hyoid bone measurements across groups are presented in Table 2; Figure 3A. Tongue dimensions showed no significant differences between the groups ($p > 0.05$), whereas tongue position varied significantly ($p < 0.001$). The tongue-to-palate distance, tongue tip ratio, and IAv were significantly greater in the two cross-bite groups than in the open-bite and normal-bite groups ($p < 0.01$), suggesting downward and forward positioning of the tongue in the cross-bite groups (Figure 3A,B). No significant differences were found between the normal- and open-bite groups ($p > 0.05$). The hyoid bone position differed significantly among the four groups ($p < 0.001$). The horizontal distances between the hyoid bone and the VRP were smaller in the two cross-bite groups than in the other groups ($p < 0.001$), whereas the vertical distances from the hyoid bone to the HRP were greater in the cross-bite group than in the normal- and open-bite groups ($p < 0.001$). Similarly, the open-crossbite group had a greater vertical parameter of the hyoid bone position than the open-bite group ($p < 0.05$), indicating a more forward and downward hyoid position in cross-bite cases (Table 2; Figure 3A).

As shown in Table 2, cephalometric analysis showed smaller IMPA and greater U1 to SN angles in the two cross-bite groups than in the normal- and open-bite groups ($p < 0.001$). ΔIMW was significantly smaller in the open-crossbite group than in the normal-bite group ($p < 0.01$). The horizontal skeletal parameters—ANB angle and Wits appraisal—were significantly smaller in the two cross-bite groups than in the normal- and open-bite groups ($p < 0.001$). The cross-bite group exhibited the highest FHR but significantly lower mandibular and palatal plane angles than the other groups ($p < 0.001$).

In the correlation analysis (Table 3), both OJ and IMPA were negatively correlated with all parameters of the vertical and horizontal tongue and hyoid bone positions ($p < 0.05$), suggesting that negative OJ and retroclined mandibular incisors were associated with inferiorly and anteriorly positioned tongue and hyoid bone at rest. The IAv and horizontal hyoid bone position showed positive correlations with the U1 to SN angle ($p < 0.05$), indicating that lower tongue posture and anteriorly positioned hyoid bone are related to proclined maxillary incisors. Additionally, horizontal skeletal parameters showed significant negative correlations with tongue-to-palate distance, tongue tip ratio, IAv, and horizontal hyoid bone position ($p < 0.01$), indicating that a skeletal Class III relationship is associated with downward and forward tongue positions and an anteriorly positioned hyoid bone. Regarding vertical skeletal parameters, the FHR was positively correlated with the tongue tip ratio and horizontal hyoid bone position, whereas the mandibular and palatal plane angles were negatively correlated with these variables ($p < 0.01$), indicating that a hypodivergent skeletal pattern is associated with an anteriorly positioned tongue and hyoid bone.

4 | Discussion

This study evaluated the resting position of the tongue and hyoid bone in relation to different incisal relationships and examined their correlations with dental and skeletal cephalometric measurements. The findings indicated that downward and forward postures of the tongue and hyoid bone were associated with anterior cross-bite but not with anterior open-bite, suggesting that the most anteriorly positioned teeth influenced tongue posture at rest. Additionally, inferior and anterior tongue positioning was correlated with maxillary constriction, skeletal Class III relationships, retroclined mandibular incisors and negative OJ. The anteriorly positioned tongue and hyoid bone correspond to a hypodivergent skeletal pattern.

This study suggests that both tongue and hyoid bone positions are related to the most anteriorly positioned teeth rather than the open-bite. Horizontally, the tongue and hyoid bone were positioned more anteriorly in the two cross-bite groups than in the open-bite and normal-bite groups. Contrary to the conventional proposal implicating altered tongue posture at rest as a key etiological factor in anterior open-bite [22, 23], this study found no significant differences in tongue and hyoid bone positions between the open-bite and normal-bite groups, reinforcing the multifactorial nature of open-bite aetiology [24]. Furthermore, tongue thrust does not necessarily coincide with open-bite malocclusion [25]. Vertically, the tongue was positioned lower in the cross-bite group than in the open-bite and normal-bite groups, indicating a stronger relationship between low tongue posture and anterior cross-bite than with anterior open-bite. Patients with Class III malocclusion have been shown to exhibit a tongue positioned more inferiorly and anteriorly than those with skeletal Class I malocclusion, although these observations were based on images captured during swallowing [26].

The association between downward-forward tongue/hyoid positioning and anterior cross-bite may also relate to relatively large tongue volume and the potential nasal septum deviation leading to nasal obstruction. Enlarged tongue volume has been observed in individuals with skeletal Class III malocclusion, consistent with previous findings [10, 16, 27], suggesting that a large tongue and low tongue posture may contribute to the forward mandibular positioning characteristic of Class III malocclusion and anterior cross-bite. Additionally, Class III malocclusion has been associated with nasal septum deviation, which may result in nasal obstruction and subsequently a lowered hyoid bone position. The lower hyoid position observed in the two cross-bite groups further supports the relationship between anterior cross-bite and low tongue posture. Tongue posture has been suggested to play a more significant role than tongue function in malocclusion [11]. Although a causal relationship cannot be established, the findings of the present study demonstrate that low tongue posture is significantly associated with mandibular prognathism, which may be related to anterior cross-bite [25]. However, tongue dimensions showed no significant correlation with incisal relationships, consistent with previous reports [4].

Notably, dental parameters such as OJ and IMPA exhibited stronger correlations with tongue and hyoid bone postures than the OB and U1 to SN angles, suggesting that a downward and forward tongue posture at rest is more closely linked to anterior cross-bite and mandibular incisor inclination than to anterior open-bite and maxillary incisor angulation (Figure 3B). Two prevailing theories may explain this finding. According to the functional matrix hypothesis, bone growth occurs in response

TABLE 2 | Comparisons of demographic features, tongue & hyoid bone measurements and cephalometric measurements among the four investigated groups.

	Normal-bite ($n = 37$)	Open-bite ($n = 29$)	Cross-bite ($n = 32$)	Open-crossbite ($n = 21$)	
	$1 \leq OB < 4$, $1 \leq OJ < 4$	$OB < 0$, $OJ > 0$	$OB > 0$, $OJ < 0$	$OB < 0$, $OJ < 0$	p
Sex					
Male	16 (43.2%)	8 (27.6%)	26 (81.3%)	13 (61.9%)	
Female	21 (56.8%)	21 (72.4%)	6 (18.7%)	8 (38.1%)	
Demographic features					
Age (year)	24.6 ± 5.6	24.2 ± 4.9	22.7 ± 3.8	21.5 ± 3.0	0.074
Overbite (mm)	2.3 ± 0.8	−2.9 ± 1.7	2.4 ± 1.5	−2.5 ± 2.1	< 0.001***
Overjet (mm)	2.5 ± 0.6	4.2 ± 1.9	−3.4 ± 2.4	−3.2 ± 3.1	< 0.001***
Tongue & hyoid bone measurements					
Tongue dimension					
Tongue length (mm)	78.3 ± 6.7	77.5 ± 8.5	78.4 ± 6.7	75.5 ± 7.8	0.120
Tongue height (mm)	35.8 ± 3.7	35.2 ± 3.2	37.5 ± 4.2	34.7 ± 6.0	0.282
Tongue position					
Tongue-to-palate distance (mm)	1.9 ± 2.3^{A}	4.1 ± 4.7^{AB}	6.4 ± 5.3^{BC}	8.8 ± 6.2^{C}	< 0.001***
Tongue tip ratio	0.9 ± 0.0^{A}	0.9 ± 0.1^{A}	1.0 ± 0.1^{B}	1.0 ± 0.1^{B}	< 0.001***
Intraoral airway volume (mm^3)	1014.8 ± 1747.4^{A}	3409.8 ± 4921.3^{AB}	5276.8 ± 5062.9^{BC}	8401.6 ± 7688.2^{C}	< 0.001***
Hyoid bone position					
Horizontal (mm)	−8.8 ± 7.2^{A}	−11.5 ± 7.6^{A}	−1.5 ± 6.6^{B}	−1.3 ± 7.0^{B}	< 0.001***
Vertical (mm)	60.6 ± 8.2^{AB}	59.7 ± 7.9^{A}	68.6 ± 9.3^{C}	65.9 ± 5.0^{BC}	0.037*
Dental parameters					
IMPA (°)	92.5 ± 8.7^{B}	94.5 ± 6.3^{B}	83.3 ± 7.4^{A}	78.8 ± 10.4^{A}	< 0.001***
U1 to SN angle (°)	104.4 ± 9.6^{A}	106.9 ± 6.6^{A}	112.6 ± 8.6^{B}	113.3 ± 5.8^{B}	< 0.001***
Transverse discrepancy					
ΔIMW (mm)	5.1 ± 1.7^{B}	4.0 ± 2.9^{AB}	4.0 ± 3.4^{AB}	2.1 ± 4.2^{A}	< 0.001***
Horizontal skeletal parameters					
ANB angle (°)	2.4 ± 2.9^{B}	3.9 ± 3.5^{B}	−3.8 ± 3.2^{A}	−3.4 ± 2.9^{A}	< 0.001***
Wits appraisal (mm)	−3.9 ± 4.2^{B}	−2.0 ± 5.5^{B}	−11.9 ± 5.1^{A}	−14.3 ± 6.3^{A}	< 0.001***
Vertical skeletal parameters					
Facial height ratio (%)	64.7 ± 4.9^{BC}	60.8 ± 4.9^{A}	67.6 ± 5.9^{C}	62.2 ± 3.1^{AB}	< 0.001***
Mandibular plane angle (°)	37.0 ± 5.7^{B}	42.3 ± 7.0^{C}	32.7 ± 7.1^{A}	39.8 ± 3.8^{BC}	< 0.001***
Palatal plane angle (°)	26.7 ± 5.2^{AB}	31.5 ± 7.2^{C}	22.9 ± 6.3^{A}	30.6 ± 3.4^{BC}	< 0.001***

Note: Data are presented as mean ± standard deviation. Tongue tip ratio is calculated by dividing the distance of tongue tip to the vertical reference plane by the distance of the maxillary incisal tip to the vertical reference plane. ΔIMW, intermolar width difference. ANCOVA was performed for comparison, controlling for sex and age. Different superscript letters indicate there were statistically significant differences.
Abbreviations: OB, overbite; OJ, overjet.
*$p < 0.05$.
***$p < 0.001$.

TABLE 3 | Pearson correlation coefficients of tongue and hyoid bone position with cephalometric measurements.

	Tongue position			Hyoid bone position	
	Horizontal	Vertical			
	Tongue tip ratio	Tongue-to-palate distance	Intraoral airway volume	Horizontal	Vertical
Dental parameters					
OJ	−0.499***	−0.328***	−0.390***	−0.638***	−0.294**
OB	0.143	−0.113	- 0.231*	0.135	0.159
U1 to SN angle	0.177	0.160	0.190*	0.372***	0.108
IMPA	−0.315***	−0.349***	−0.350***	−0.489***	−0.203*
ΔIMW	0.041	−0.232*	−0.236*	−0.075	−0.294**
Horizontal skeletal parameters					
ANB angle	−0.465***	−0.224*	−0.299***	−0.637***	−0.155
Wits appraisal	−0.476***	−0.309***	−0.394***	−0.596***	−0.092
Vertical skeletal parameters					
Facial height ratio	0.269**	−0.131	−0.130	0.328***	0.170
Mandibular plane angle	−0.295**	0.090	0.051	−0.450***	−0.116
Palatal plane angle	−0.262**	0.074	0.029	−0.449***	−0.029

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

to function; thus, tongue posture is considered to affect dentofacial form [16]. Conversely, another perspective focuses on the adaptation of the tongue to the surrounding structures and concludes that tongue posture is affected by dentofacial structures, with adaptive changes occurring in the tip, dorsum and root of the tongue [26]. Additionally, negative correlations between the ΔIMW and vertical position of the tongue and hyoid bone suggested that the constricted maxilla corresponded to a lower position of the tongue and hyoid bone. Based on the functional matrix theory [28], a palatal vault might provide insufficient space to accommodate a proper tongue position, leading to a lowered tongue posture in patients with a constricted maxilla [29]. A previous report using lateral cephalograms did not identify a relationship between the intermolar width ratio and tongue posture, possibly because of mild maxillary constriction in the sample population [10]. In this study, a 3D approach was used, which allowed for a more precise assessment of tongue posture at rest in the oral cavity [7].

Interestingly, dental parameters, such as OJ and IMPA, show stronger correlations with tongue posture than skeletal parameters, such as ANB and Wits. This is likely because the tongue exerts its influence most directly on the dentition and alveolar processes, rather than on the basal skeletal structures [30]. The continuous light forces from the tongue at rest, together with its functional posture, primarily affect the anterior teeth and supporting alveolar bone, gradually altering tooth inclination and dental relationships over time [10]. In contrast, skeletal parameters like ANB and Wits reflect the underlying maxillomandibular relationship, which is largely determined by growth and genetic factors and is therefore less immediately responsive to soft tissue pressures [31]. Consequently, tongue posture tends to be more closely associated with dental parameters than with skeletal parameters.

The skeletal Class III relationship is associated with downward and forward tongue position and forward hyoid bone position, as evidenced by negative correlations between horizontal skeletal parameters and the positions of both structures. While previous studies have reported an inferior tongue position in skeletal Class III malocclusion compared with other skeletal patterns [10, 31, 32], the findings in the present study also revealed significant anterior positioning of the tongue at rest in this skeletal pattern. Similarly, the hyoid bone was positioned more anteriorly, which is consistent with previous observation [26]. Additionally, a hypodivergent cephalometric pattern was correlated with the anterior positioning of both the tongue and the hyoid bone, supported by negative correlations with the mandibular and palatal plane angles.

Clinically, while the causality between resting tongue posture and dentoskeletal structures remains unclear, these findings highlight the importance of assessing downward and forward tongue postures at rest, particularly in anterior cross-bite with Class III malocclusion, hypodivergent skeletal pattern and constricted maxilla. Additionally, a deeper understanding of the relationship between tongue posture at rest and dentoskeletal structures will be helpful for orthodontic treatment planning and long-term stability. While establishing new positions for the mandible and mandibular incisors in patients with Class III

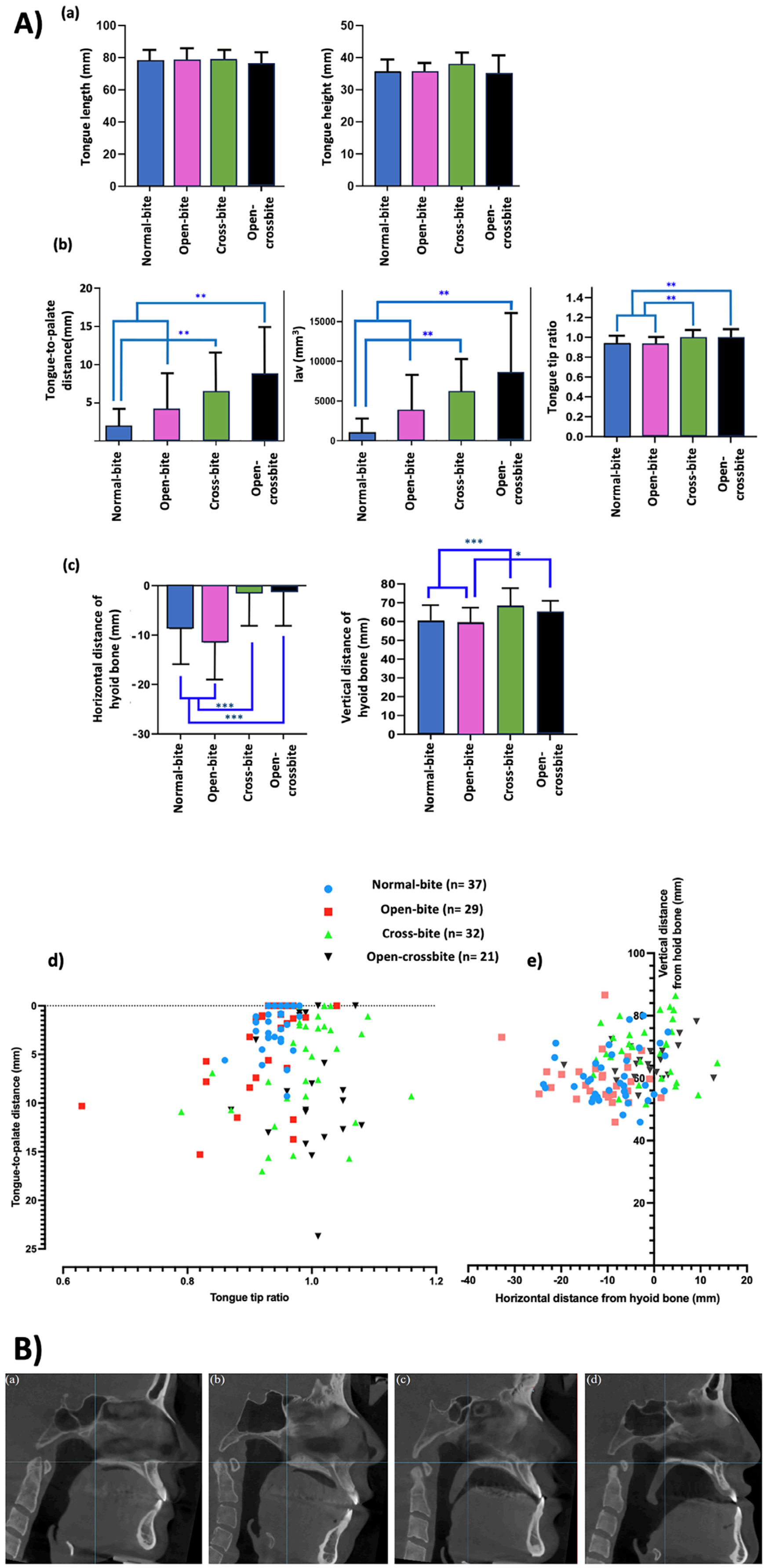

FIGURE 3 | Legend on next page.

FIGURE 3 | Comparison of tongue and hyoid bone dimensions and positions across four group. (A) Bar graphs and distribution plots presenting the results across the four groups: Normal-bite ($n=37$), open-bite ($n=29$), cross-bite ($n=32$) and open-crossbite ($n=21$). (a) Tongue dimension measurements; (b) Tongue position measurements; (c) Hyoid bone position measurements; (d) Relation between tongue tip ratio and tongue-to-palate distance; (e) Relation between vertical and horizontal position of the hyoid bone (*$p<0.05$; **$p<0.01$; ***$p<0.001$); (B) Representative lateral views of reconstructed from CBCT images for four groups: (a) normal-bite; (b) open-bite; (c) cross-bite; (d) open-crossbite.

anterior cross-bite, clinicians should guide them to adapt to the new tongue positioning to maintain treatment outcomes and prevent relapse.

To ensure reliable assessment of tongue position, this study included participants aged 18 or older who had completed physical growth, including the tongue, as children typically exhibit higher dorsal tongue height than adults [33]. However, resting tongue posture may not be entirely stable during CBCT due to respiration. The respiratory phase at the time of CBCT acquisition may influence the observed tongue posture, as the scan captures a static image at a single time point without controlling for breathing. Another limitation of this study is its cross-sectional design, which precludes establishing causality. Dynamic changes in the tongue position were not evaluated, and body mass index (BMI) data were unavailable, despite reported associations with tongue pressure [34]. These factors represent limitations that should be considered when interpreting the results. Future longitudinal cohort studies assessing tongue and hyoid bone positions both at rest and during swallowing, while accounting for BMI, are warranted to more comprehensively elucidate their influence on dentofacial structures.

Resting tongue posture is recognised as an important factor in malocclusion development, as continuous low-level pressures from the tongue can, over time, shape dentofacial structures and arch form more than the intermittent forces generated during oral functions [16, 35–37]. Despite the study's limitations, the present findings provide valuable clinical insights for the management of anterior crossbite in Class III malocclusion. Clinicians can identify abnormal tongue patterns and implement timely myofunctional interventions, particularly in growing patients. Moreover, incorporating tongue position assessment into retention protocols may help support long-term treatment stability.

5 | Conclusions

1. The downward and forward positions of the tongue and hyoid bone at rest were related to anterior cross-bite but not to anterior open-bite, indicating that the tongue position is related to the most anteriorly positioned teeth.
2. The inferior and anterior positions of the tongue corresponded to a constricted maxilla, skeletal Class III relationship, retroclined mandibular incisors and a negative OJ. In addition, the anteriorly positioned tongue and the hyoid bone correspond to a hypodivergent skeletal pattern.
3. The inclination of the mandibular incisors and OJ showed a greater correlation with the tongue and hyoid bone positions than those of the maxillary incisors and OB.

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Ethics Statement

This retrospective study was approved by the institutional review board of Yonsei University Dental Hospital (IRB No. 2-2017-0059).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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