

Hyoid Bone Position as an Etiological Factor in Mandibular Divergence and Morphology

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Abstract

Objectives: The objective is to determine whether there are differences in the position of the hyoid bone at rest in natural head position in subjects with mandibular hyperdivergence and to evaluate whether there are differences in hyoid position and antegonial notch depth in mandibular hyperdivergent males and females. **Methods and Materials:** This is a retrospective cohort study involving a review of lateral cephalometric radiographs of 45 adult men and women with mandibular hyperdivergency. Hyperdivergency was determined by cephalometric ranges of: SN-GoGn as least +2 SD from normal, Y-axis, PP-GoGN, and gonial angle greater than +1SD from normal. A group of 45 normodivergent adults served as a control, with cephalometric ranges of: SN-GoGn within ± 1 SD of normal, with only one measurement of the other three between +1 and +1.5 standard deviations. A custom digital cephalometric analysis, the Hyoid Analysis, was designed, to measure the vertical and horizontal position and inclination of the hyoid and the antegonial notch depth. **Results:** In hyperdivergent subjects, the posterior aspect of the hyoid is located lower and more posterior, compared to the control group, while there is no difference in position of the anterior surface of the hyoid and the antegonial notch is 0.6 mm deeper. In males, the posterior aspect of hyoid is lower by 8.5 mm, while the anterior surface is located 9.0 mm lower. In males, the hyoid is inclined more steeply than in females by 4.4 degrees and the antegonial notch is deeper than in females by 0.6 mm. **Conclusions:** There are differences in hyoid bone position and mandibular morphology in hyperdivergent subjects compared to normodivergent subjects and in males compared to females.

Keywords

Hyoid Bone, Mandibular Divergence, Orthopedic, Surgery

1. Introduction

Patients with a hyperdivergent mandibular growth pattern often present a challenge for orthodontic treatment, due to a dental open bite tendency that may be complicated by underlying issues such as allergies, lymphatic tissue hypertrophy, muscular hypotonicity, syndromes, and neurologic disorders. Although some open bite cases have an environmental etiology, such as digit-sucking or forward posturing and thrusting of the tongue, other factors may be genetic, such as over-eruption of posterior teeth, a vertical growth pattern of the mandible and airway obstruction [1] [2]. Many cases of mandibular hyperdivergency are established early in growth and do not improve over time [3]. The mandibular morphology in these hyperdivergent patients is distinct: the anterior corpus of the mandible is bent downward and there is strong antegonial notching [4], but exactly how the mandible develops in this manner is unknown.

The etiology of vertical discrepancy is multifactorial and it has been postulated that hyperdivergency may be related to the position of the hyoid bone and the interaction of the suprahyoid muscles with the muscles of mastication [5]. The major muscles of mastication, including the temporalis, masseter, medial and lateral pterygoid have various origins on the cranium but all are inserted at or near the angle of the mandible. When activated, these muscles exert a force elevating the mandible from the posterior region. Conversely, the suprahyoid muscles, including the mylohyoid, geniohyoid and anterior belly of the digastric muscles, have their origins on the anterior corpus of the mandible and insert on the body of the hyoid bone. When activated, these muscles have a depressing effect on the anterior corpus of the mandible. It has been postulated that the interaction between these elevator and depressor muscles on the mandible may create an envelope of function which is directed through the antegonial area, creating a deep notch as the anterior corpus of the mandible is bent downward) [6].

One theory suggests that the growth at the mandibular condyle stops in hyperdivergent patients, while the masseter and medial pterygoid muscle that insert at the gonial angle continue to grow. This muscle growth causes bone deposition at the gonial angle and prevents the resorption that is typical to this area. The cumulative effect is that a notch occurs just anterior to the gonial area [7].

Another theory combines the previous one with elements from the functional matrix hypothesis, which states that the amount of condylar growth indirectly affects the direction of mandibular rotation and the resulting antegonial notch depth. If the growth of the condyle is less than the vertical growth at the midface and alveolus, the mandible rotates downward and backward. The anterior part of the mandible is pushed down into the soft tissue matrix, resulting in resorption below the symphysis while the posterior part of the corpus is lifted up from the soft tissue matrix, stretching the periosteum, and causing apposition to occur below the angle of the mandible. This forms the antegonial notch in hyperdiver-

gent subjects with a short ramus height [8].

Since the hyoid bone has multiple muscular connections to the mandible and the tongue, it has also been postulated that the hyoid may also have a role in the development of mandibular morphology. The hyoid bone, having no bony connection itself, is stabilized mainly by muscles [9]. The suprahyoid muscles consist of the digastric, stylohyoid, geniohyoid, and mylohyoid muscles, while the infrahyoid muscles consist of the sternohyoid, thyrohyoid, sternothyroid and omohyoid muscles which insert on the sternum, the thyroid cartilage and the scapula [5] [10]. Thus, it is possible that the position of the hyoid bone may be related to mandibular morphology through its strong muscular connections.

Determining the position of the hyoid bone is difficult since it is mobile. Slight changes in the position of the hyoid bone may occur with changes in posture, head position, tongue position, and function such as swallowing, mastication and respiration [11] [12] [13] [14] [15]. Additionally, its position changes over time with growth, moving downward and forward [16] [17] and increasing with age [18] [19].

However, the resting position of the hyoid has been found to be stable [20]. Typically, it is vertically positioned anterior to the lower portion of the third cervical vertebra [21] at a fixed distance from that vertebra [22]. This stable position is thought to be due to the necessity of maintaining a patent airway [18]. This has been found to be evident even after a surgical procedure to reposition the mandible posteriorly [22]. Additionally, the hyoid position is stable even in patients who have tongue thrust and mouth breathing habits [20]. In these cases, the resting hyoid position has been found to be highly reproducible on a lateral cephalometric radiograph in natural head position [23].

Some studies have compared the hyoid bone position in hyperdivergent subjects with normodivergent and/or hypodivergent subjects on lateral cephalometric radiographs and came to conflicting conclusions. Bibby [5], Subtelny [24], and Jena [25] all found no difference in hyperdivergent subjects as compared to normodivergent subjects. On the other hand, Haralabikis [26] found significant differences in the horizontal position and inclination of the hyoid but no differences in the vertical position. It was found that the hyoid was more posterior and more steeply inclined in hyperdivergent subjects. Additionally, Joseph [27] found that the hyoid is more inferior in hyperdivergent subjects, while Tumpkin [2] and Opdebeek [28] found that the hyoid is more posterior in hyperdivergent subjects.

There have been conflicting findings on whether there are differences in hyoid position in males compared to females. Some studies have found there are no differences in gender [5] and others have found a difference only when relating the hyoid to the cervical vertebrae [29]. This difference appears after normalizing for head size [15]. Others have found that there are differences but these studies are not in agreement. For instance, Adamidis [14] found that the anterior point of the hyoid is higher in boys aged 10 - 13 years than girls of the same age, while Arslan [29] found that the hyoid is more inferior and anterior in males.

Since there is little definitive data correlating hyoid position and antegonial notch depth with mandibular morphology, a cephalometric analysis was designed to determine the anatomical differences between hyperdivergent and normodivergent subjects and to assess for sexual dimorphisms.

2. Objectives of Study

The objectives of this study are to determine whether there are differences in the position of the hyoid bone at rest in natural head position, vertically, horizontally or in axial inclination. Secondly, what is the effect of hyoid bone position on the antegonial notch depth in subjects with mandibular hyperdivergency as compared to normodivergent subjects? Thirdly, to evaluate whether there are differences in hyoid position and antegonial notch depth between males and females.

3. Null Hypothesis

The null hypothesis states that there are no differences in hyoid bone position or antegonial notch depth in hyperdivergent subjects as compared to normodivergent subjects. Second, there are no morphological differences in hyoid bone position or antegonial notch depth in non-growing males as compared to non-growing females.

4. Materials and Methods

4.1. Subject Selection

This is a retrospective cohort study involving a review of Lateral cephalometric radiographs. All records taken prior to September 11, 2017 at Rutgers University, School of Dental Medicine Department of Orthodontics were searched in Dolphin Imaging. In order to define the hyperdivergent group, cephalometric measurement norms from Cangialosi [30] were used for the angles SN-GoGn, Y-axis, SN-PP, PP-GoGn, and gonial angle and the ratio, UFH/LFH ratio (see **Table 1**).

Inclusion criteria were defined as: male and female patients with all permanent teeth erupted except third molars, a Cervical Vertebral Maturation Index of 5 or 6 (indicating a non-growing individual), and high quality lateral cephalometric radiographs taken in natural head position with the hyoid bone clearly depicted. Exclusion criteria were defined as: patients with clefts or craniofacial syndromes, major facial or mandibular asymmetries, cervical vertebrae anomalies, missing permanent teeth (excluding third molars), a history of treatment with implants, orthodontics or orthognathic surgery, or poor-quality cephalometric radiographs. No other socioeconomic data was included.

The most hyperdivergent subjects had the following characteristics which ultimately became the cephalometric criteria for the experimental group: an SN-GoGN angle of at least + 2 standard deviations from normal, with three other measurements (Y-axis, PP-GoGN, and gonial angle) at least greater than +1

Table 1. Norms and standard deviations of cephalometric measurements from Cangialosi [30].

Norms and Standard Deviation Values for Subject Selection			
Angle	Definition	Normal	SD
Sn-GoGn	Angle between the SN plane and the mandibular plane defined as Go-Gn	29.8°	±5.5
SN-PP	Angle between the SN plane and palatal plane defined as ANS-PNS	8.2°	±3.3
Y-axis	Angle between SN plane and line connecting Sella and Gnathion	66.5°	±3.7
PP-GoGn	Angle between the palatal plane defined as ANS-PNS and mandibular plane defined as Go-Gn	21.9°	±5.6
UFH/LFH	Ratio between upper facial height and lower facial height	0.812	±0.082
Ar-Go-Me	Gonial angle	123.9°	±5.4

standard deviation from normal (**Table 2**). Ultimately, 45 subjects, including 10 males and 35 females, were chosen for the hyperdivergent group from 522 subjects.

A similar process was used to choose the control group. Lateral Cephalometric radiographs in Dolphin Imaging were searched according to the same inclusion and exclusion criteria. The same Cephalometric values for all subjects in the control group were within 1 standard deviation from normal.

The records with the cephalometric values closest to normal were chosen, resulting in the following cephalometric criteria: SN-GoGn within ± 1 standard deviation from normal, with only one out of the other three measurements in the acceptable range of +1 and +1.5 standard deviations (**Table 3**). Ultimately, 45 subjects, including 18 males and 27 females, were chosen for the control group from 2891 subjects.

The hyperdivergent group included 9 males and 36 females, while the normo-divergent group included 18 males and 27 females.

Subjects in both groups were then arranged in order of increasing SN-GoGn value and assigned a coded number, ranging from C1 - C45 for the normo-divergent group and H1-H45 for the hyperdivergent group.

4.2. Hyoid Analysis

A digital cephalometric analysis (Hyoid Analysis) was designed in Dolphin Imaging to measure the hyoid position and depth of the antegonial notch. Two points were chosen to determine hyoid position. H-point is defined as the most superior and anterior point on the anterior curvature of the body of the hyoid. G-point is defined as the most posterior point on the greater cornu of the hyoid (the posterior end of the tubercle). In cases where the hyoid was captured at an

Table 2. Standard deviation and value ranges of cephalometric measurements used to define the hyperdivergent group.

Cephalometric Requirements for Hyperdivergent Group		
Angle	Minimum SD	Minimum Value
Sn-GoGn	>2	>40.8°
Y-axis	>1	>70.2°
PP-GoGn	>1	>27.5°
Ar-Go-Me	>1	>129.3°

Table 3. Standard deviation and value ranges of cephalometric measurements used to define the normodivergent group. Required measurements included: SN-GoGn in the ideal range, with only up to one out of the other three in the acceptable range.

Cephalometric Requirements for Normodivergent Group				
Angle	Ideal Values		Acceptable Values	
	SD Range	Value Range	SD Range	Value Range
SN-GoGn	-1 to +1	24.3° to 35.3°	-	-
Y-axis	-1 to +1	62.8° to 70.2°	+1 to +1.5	70.2° to 72.05°
PP-GoGn	-1 to +1	16.3° to 27.5°	+1 to +1.5	27.5° to 30.3°
Ar-Go-Me	-1 to +1	118.5° to 129.3°	+1 to +1.5	129.3° to 132°

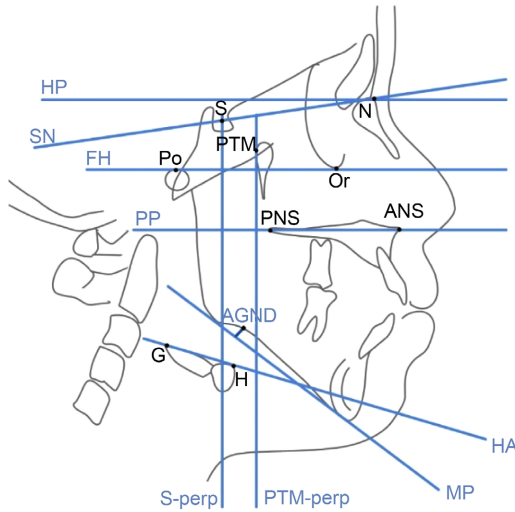
angle on the lateral cephalometric radiograph, resulting in two distinct greater cornu, G-point was placed at the midpoint between the two posterior ends of the tubercles.

To measure the vertical position of the hyoid, a reference plane was drawn: the palatal plane, defined as ANS-PNS. The perpendicular distance from the palatal plane to H-point and G-point were then measured in millimeters. A positive value indicated the points were superior to the reference plane.

To measure the horizontal position of the hyoid, two reference planes were drawn perpendicular to the Frankfort Horizontal plane. One plane was drawn at sella (Sperp), and the other was drawn at the most posterior point on the outline of the pterygomaxillary fissure (PTMperp) according to the method by Jena [25]. The perpendicular distances from G-point to Sperp and from H-point to PTMperp were measured in millimeters. A positive value indicated the points were anterior to the reference plane.

To measure the axial inclination of the hyoid, the angle between the hyoid plane (H-axis, defined as a plane from H-point to G-point) and a horizontal plane seven degrees at Nasion to the SN line, was measured in degrees.

To measure the depth of the antegonial notch, one reference plane was drawn: the mandibular plane, (defined as a line tangent to the lower border of the mandible). Antegonial notch depth was then measured as the perpendicular distance from the deepest portion of the antegonial notch (point AGN) to the mandibular tangent plane, in millimeters. See **Figure 1** for a summary of all



Cephalometric Points	
Po	Porion
Or	Orbitale
S	Sella
N	Nasion
PTM	Most posterior point of pterygomaxillary fissure
ANS	Anterior nasal spine
PNS	Posterior nasal spine
H-point (H)	Most superior and anterior point on the anterior curvature of the body of the hyoid
G-point (G)	Most posterior point on the greater cornu of the hyoid (the posterior end of the tubercle)
AGND	Antegonial notch depth – Deepest portion of the antegonial notch

Reference Plane	Definition
Frankfurt Horizontal (FH)	Po-Or
Horizontal Plane (HP)	7 degrees above SN at nasion
Palatal Plane (PP)	ANS-PNS
S-perp	Vertical line from S, perpendicular to FH
PTMperp	Vertical line from PTM
Hyoid Axis (HA)	H-point – G-point
Tweed Mandibular Plane (MP)	Line tangent to the lower border of mandible

Hyoid Analysis Measurements		
Measurement	Definition	Unit
G-PP	Perpendicular distance from G-point to palatal plane	Millimeters
H-PP	Perpendicular distance from H-point to palatal plane	Millimeters
G-S-perp	Perpendicular distance from G-point to S-perp	Millimeters
H-PTMperp	Perpendicular distance from H-point to PTMperp	Millimeters
Haxis-HP	Angle between hyoid axis and horizontal plane	Degrees
Antegonial notch depth	Perpendicular distance from deepest portion of antegonial notch to the mandibular tangent plane	Millimeters

Figure 1. Tracing of Landmarks, reference planes, and measurements used in the Hyoid analysis. Ante-Gonial Notch Depth (AGND).

cephalometric measurements made.

All cephalometric radiographs in each group were traced by the primary examiner (T.C.) and a second examiner (F.R.).

5. Statistical Analyses

IBM SPSS version 24 was used for all data analysis. Two-way ANOVA was used

to determine whether there is a significant difference between the mandibular divergence groups and genders. The significance level was set to $p < 0.05$. Intraclass Correlation Coefficient (ICC) was used for inter- and intra-examiner reliability, using a Two-Way Mixed and Consistency model.

6. Results

For inter-examiner reliability, both examiners (T.C. and F.R.) were in agreement, as all ICC values were above 0.800 (Table 4). Each examiner waited one month after the initial tracing to retrace the radiographs again. Intra-examiner reliability was good except for G-Sperp which was 0.72 (Table 5).

A summary of all measurements and statistics is shown in Table 6. Two-way interaction between mandibular divergence and gender was checked in all models. No significance was found.

G-PP was significant for both the mandibular divergence and gender groups. In hyperdivergent subjects, the posterior aspect of the hyoid was 47.2 mm below palatal plane, which is 1.3 mm lower than in the normodivergent group (p -value = 0.029). In males, the posterior aspect of the hyoid is 52.4 mm below the palatal plane, which is 8.5 mm lower than in females (p -value < 0.001).

H-PP was significant only for gender. In males, H-point is 65.7 mm below the palatal plane, which is 9.0 mm lower than in females (p -value < 0.001). There was

Table 4. Inter-examiner reliability for both Examiner 1 and Examiner 2 (completed as part of pilot study).

Inter-Examiner Reliability	
Measurement	ICC
G-PP	0.949
H-PP	0.980
G-Sperp	0.983
H-PTMperp	0.993
Haxis-HP	0.925
AGND	0.845

Table 5. Intra-examiner reliability for Examiner 1 (completed as part of pilot study).

Inter-Examiner Reliability	
Measurement	ICC
G-PP	0.978
H-PP	0.997
G-Sperp	0.728
H-PTMperp	0.924
Haxis-HP	0.974
AGND	0.967

Table 6. Descriptive statistics for each cephalometric measurement of the Hyoid Analysis, according to gender and group. An asterisk (*) denotes a significant p-value.

		G-PP			
		N	Mean	SD	p-value
Mandibular	C	45	-45.867	6.6374	0.029*
Divergence	H	45	-47.233	7.6436	
Gender	M	28	-52.414	7.1194	<0.001*
	F	62	-43.902	5.4092	
Interaction					0.909
		H-PP			
		N	Mean	SD	p-value
Mandibular	C	45	-59.313	7.0098	0.242
Divergence	H	45	-59.620	8.2637	
Gender	M	28	-65.675	7.1523	<0.001*
	F	62	-56.663	6.0341	
Interaction					0.731
		G-Sperp			
		N	Mean	SD	p-value
Mandibular	C	45	-15.013	5.7561	0.035*
Divergence	H	45	-18.193	6.1654	
Gender	M	28	-15.404	5.7712	0.436
	F	62	-17.145	6.2726	
Interaction					0.937
		H-PTMperp			
		N	Mean	SD	p-value
Mandibular	C	45	-0.282	6.2142	0.328
Divergence	H	45	1.324	8.5217	
Gender	M	28	-0.646	7.1064	0.476
	F	62	1.048	7.6110	
Interaction					0.598
		Haxis-HP			
		N	Mean	SD	P-value
Mandibular	C	45	25.480	7.5140	0.269
Divergence	H	45	28.844	9.1646	
Gender	M	28	24.071	8.3166	0.036*
	F	62	28.558	8.2767	
Interaction					0.524
		AGND			
		N	Mean	SD	p-value
Mandibular	C	45	1.764	0.8650	<0.001*
Divergence	H	45	2.413	1.0714	
Gender	M	28	2.493	1.0597	<0.001*
	F	62	1.906	0.9578	
Interaction					0.252

no significant difference between hyperdivergent and normodivergent subjects.

G-Sperp was significant only for the mandibular divergence group. In hyperdivergent subjects, G-point is 18.2 mm posterior to Sperp, which is 3.2 mm more posterior than in normodivergent subjects (p -value = 0.035). There was no significant difference between genders.

H-PTMperp was not significant for either mandibular divergence or gender.

H-axis-HP was significant only for gender. In males, the hyoid is inclined at a mean of 24.1° , which is 4.4° higher than in females (p -value = 0.036). There was no significant difference between hyperdivergent and normodivergent subjects.

AGND was significant for both mandibular divergence and gender. In hyperdivergent subjects, the antegonial notch is a mean of 2.4 mm deep, which is 0.6 mm deeper than in normodivergent subjects (p -value < 0.001). In males, the antegonial notch is a mean of 2.5 mm deep, which is 0.6 mm deeper than in females (p -value < 0.001).

7. Discussion

7.1. Hyoid Position

Cranial base landmarks have been traditionally chosen as reference points from which to measure the vertical and horizontal position of the hyoid bone, since multiple studies have found that the hyoid is consistent in location when compared to local landmarks, including the cervical vertebrae, pharynx, and cervical spine [18] [26] [31]. The reason for this is thought to be due to the necessity of maintaining a consistently patent airway [18] [22] [28]. Therefore, landmarks further away may reveal more differences in hyoid position.

Although the mandible is further away than the cervical vertebrae and multiple studies have used it as a reference plane from which to measure hyoid bone position [5] [10] [14] [26], the mandible was not used in this study for multiple reasons. First, it has been found that the hyoid bone may move in close conjunction with the mandible due to the connecting muscles and ligaments, resulting in minimal differences when using the mandibular plane as a reference for hyoid position [26]. Second, the differences in mandibular plane steepness are being tested in this study. Therefore, utilizing the mandible as a reference frame may affect the results and prevent accurate assessment of the hyoid position.

The data from this study shows that the posterior aspect of the hyoid (G-point) is indeed in a different position in hyperdivergent subjects as compared to normodivergent subjects. In hyperdivergent subjects, G-point is located 1.3 mm lower and 3.2 mm more posterior than in normodivergent subjects. There was not a significant difference in the vertical or horizontal position of H-point or the inclination of the hyoid.

These results are similar to the findings by Jena [25] in which the horizontal position, vertical position and inclination of the hyoid in hyperdivergent and normodivergent subjects are comparable as measured at H-point. However, the studies differ in that no measurements were completed at G-point, so that data from this study including G-point cannot be compared.

Haralibikis [26] also studied the hyoid position in hyperdivergent and normodivergent subjects and separated subjects based on gender. Overall, significant differences in the horizontal position and inclination of the hyoid were found, while there were no differences in the vertical position. H-point was found to be significantly more posterior in open bite subjects than in normal subjects when measured from $PTR \perp FH$ (the equivalent of PTM-perp) and $Po \perp FH$. This is in direct contrast to the results of this study, which found no difference between hyperdivergent and normodivergent subjects. It was also found that hyperdivergent subjects had a more steeply inclined hyoid when measured from the palatal plane and basion-nasion plane. This is in contrast to this study, which found that there is no difference in hyoid inclination. However, the data cannot be directly compared, since the reference planes used are different. Lastly, there were no vertical differences found between hyperdivergent and normodivergent subjects as measured from H-point, which is again similar to our findings.

The findings of this study do not agree with studies which found that the hyoid at H-point is more inferior or more posterior in hyperdivergent subjects. For instance, Joseph [27] measured the perpendicular distance from H-point to the mandibular plane and found that the hyoid is more inferior in hyperdivergent subjects than normodivergent subjects, which is in conflict with multiple studies that have found that the hyoid moves in conjunction with the mandible.

Our data shows that there is a significant difference in hyoid position with regard to gender. In males, the entire hyoid is located at a lower position while the hyoid is more steeply inclined. This contradicts studies that have found no sexual dimorphism in hyoid bone position, including Bibby [5], Subtelny [24], and Andersen [31]. However, these studies all recruited young, growing children as subjects. Growth may affect the conclusions of these studies, since the hyoid has been found to move forward and downward with growth [16] [17] and increasing age [18] [19].

It has been found that hyperdivergent patients have shorter cranial bases [32] [33]. The vertical discrepancy could be that the palatal plane of hyperdivergent patients is somehow higher in the posterior region, causing the distance from G-point to the palatal plane to be increased but no difference in the distance to H-point. However, this would contradict Nahoum's findings that patients with open bites tend to be hyperdivergent and may have a tipped up palatal plane [34] [35] which would actually increase the distance to H-point instead of G-point.

However, Haralibikis [26] also measured the distance from H-point to the palatal plane and found that this value was increased in males. It was determined that this occurred because the palatal plane was tipped upward. Measurements were not made from G-point, so this data cannot be compared. It is likely that these differences are due to head size differences between males and females.

7.2. Antegonial Notch Depth

In this study, the antegonial notch was found to be 0.6 mm deeper in hyperdi-

vergent subjects, which is statistically significant, and several studies [4] [36] [37] [38] support the finding that hyperdivergent subjects have a deeper antegonial notch.

Singer [4] conducted a study in which cephalometric measurements of subjects with deep antegonial notches (greater than 3 mm in depth) were compared with subjects with shallow antegonial notches (less than 1 mm). They found that those with deeper notches are more hyperdivergent (SN-MP is increased by 9.62 degrees), have a larger gonial angle (Ar-Go-Gn is increased by 6.14 degrees), are more retrusive (SNB is decreased by 3.96 degrees) and have shorter mandibles (Go-Gn length is decreased by 8.13 mm, while Ar-Gn is decreased by 3.04 mm), and (ANS-Me is increased by 5.15 mm). Lambrechts [36] also found that those subjects with deeper notches had steeper mandibular planes, more retrusive chins, longer anterior facial heights, and larger gonial angles.

Davidovitch [37] found that antegonial notch depth is smallest in hypodivergent subjects, increases in normodivergent subjects, and is largest in hyperdivergent subjects. This supports the findings that hyperdivergent subjects have deeper antegonial notches than normodivergent subjects. He also found that males have a deeper antegonial notch than females in hypodivergent, normodivergent, and hyperdivergent groups. Mangla [38], who measured the antegonial notch depth using the same method as this study found no sexual dimorphism in antegonial notch depth.

Stronger muscular activity may account for increased antegonial notch depth in males. Notch depth has been found to be correlated with increased masseter muscle activity which may increase bone deposition at the gonial angle, thereby deepening antegonial notch depth [39]. Therefore, it appears that mandibular morphology is largely dependent on the action and interaction of the muscles which surround it.

7.3. Limitations

The sample size of this study was relatively small due to limitation of the sample to meet relatively strict cephalometric criteria for hyperdivergency. Additionally, the number of female and male subjects was not equal. However, this study did find significant sexual dimorphism between hyoid bone position and antegonial notch depth. Therefore, it would be beneficial in future studies to attain the same number of male and female subjects and to split the pooled subjects into four groups: male hyperdivergent subjects, male normodivergent subjects, female hyperdivergent subjects, and female normodivergent subjects, as Haralabikis [26] did in his study. This would allow the comparison of hyperdivergent subjects to normodivergent subjects in each gender and would help correct for any gender issues that may have affected the data in this study, such as head size differences between males and females.

7.4. Clinical Significance and Future Directions

Further research into the etiology of mandibular hyperdivergency will ultimately

help clinicians' better understanding of the anatomical limitations of orthodontic treatment. This study indicates that there are indeed anatomical differences outside the mandible, which are related to its morphology. If the precise etiology can be more clearly determined, it may be possible to better determine which patients will respond successfully to conventional orthodontic therapy and which patients may require combined orthodontic therapy and orthognathic surgery. In addition, since hyoid bone position is important to the maintenance of airway patency, hyoid position may be related to airway problems, such as Obstructive Sleep Apnea (OSA) and could be an early diagnostic feature of this syndrome. Future studies, possibly using software such as video fluoroscopy, depicting movement of the hyoid during swallowing may also lead to evaluation of swallowing as an etiological factor in malocclusion.

8. Conclusions

1) In hyperdivergent subjects, the posterior aspect of the hyoid is located 1.3 mm more inferior and 3.2 mm more posterior than in normodivergent subjects, while there is no difference in vertical position of the anterior surface of the hyoid.

2) The antegonial notch is 0.6 mm deeper in hyperdivergent patients than in normodivergent patients.

3) In males, the posterior aspect of the hyoid is positioned more inferiorly by 8.5 mm, while the anterior surface is located 9.0 mm lower than in female subjects.

4) In males, the hyoid axis is more steeply inclined than in females by 4.4 degrees.

5) The antegonial notch is 0.6 mm deeper in males than in females.

6) There are statistical differences in hyoid bone position in hyperdivergent subjects compared to normodivergent subjects and in males compared to females. Therefore, the Null hypothesis is rejected.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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