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RESEARCH ARTICLE

Volumetric characteristics of prognathic mandible revealed by skeletal unit analysis☆

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ABSTRACT

The purpose of this study was to evaluate the skeletal units of a normal mandible (class I) and a prognathic mandible (class III), to compare the groups, and to investigate the key functional unit responsible for mandibular prognathism. Hemi-mandibles of 101 cases were evaluated by cone-beam computed tomography. Of these, 50 cases had Class I and 51 had Class III mandibles. The length, volume, and volume/length ratio of each skeletal unit were measured. The ratios of the condyle, body unit, and sum of the hemi-mandible between Class I and Class III showed statistically significant results ($P < 0.05$). However, the ratios of angle, coronoid, and symphysis units did not show any statistical significance on comparison. Dependent on gender, in males the ratio of the condyle of the hemi-mandible showed statistically significant results ($P < 0.05$). Meanwhile in females the ratio of the body and sum of the hemi-mandible showed statistically significant results ($P < 0.05$). Accordingly, the mandibular body and condylar units are thinner in mandibular prognathism. On the basis of the functional matrix theory to determine the aetiology of mandibular prognathism, the key skeletal units are the body and condylar units.

1. Introduction

There have been many theories and studies on how the human mandible is formed. The most known theory states that the mandible is formed by embryonic development from the first pharyngeal arch (Park et al., 2010). This formation is followed by the formation of Meckel's cartilage of mesodermal origin and intramembranous bone of mesenchymal origin of the mandibular body area. The mandible then develops with the formation of secondary cartilages forming functional units such as the condyle, coronoid, and symphyseal areas (Moss, 1968). These units unite to form the mandible. However, each unit retains its own development by the connection of masticatory muscles during the 8th week of gestation (Lee et al., 2001). After the mandible is formed, it grows on the basis of the principle of apposition and resorption (Moss and Simon, 1968).

In 1968, Moss divided the mandible into six functional units: dento-alveolus, condyle, coronoid, angle, body, and symphysis (Moss, 1968). The functional units are independent and each unit is affected by its surrounding functional matrix and the mandible is formed by the sum of the growth of each independent unit. In other words, each of the functional units is affected by their surrounding soft tissue (Moss and Simon, 1968). In the postnatal growth phase, as mentioned above, the mandible develops by apposition and resorption. These theories have previously been studied by many authors through two-dimensional (2D) radiography (Precious and Delaire, 1987).

After birth, mandible growth is done mainly due to condylar displacement and bony apposition and resorption (Lee et al., 2001). Based on the functional matrix theory, the bony growth is regulated by the surrounding functional matrix. Each skeletal unit of the mandible is related with different functional matrix; the coronoid unit is associated with the temporalis muscle, the angular unit is associated with the masseter and medial pterygoid muscle, body unit is associated with the inferior alveolar neurovascular matrix. Thus the growth capacity of each functional unit can be changed by functional activity during postnatal growth period (Shibazaki-Yorozuya et al., 2014).

Normally, many patients present prognathic mandible (class III) in the oral and maxillofacial areas (Hasan et al., 2016; Warmuz et al., 2016). To resolve the problem, there are many orthodontic and surgical interventions (Park et al., 2018). Though the method of treatment for Class III dentofacial dysmorphosis and malocclusion is well known, there is very little known about the aetiology of the problem, and few studies have been performed by authors using

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2D radiography. Based on the functional matrix theory, to understand the aetiology of mandibular prognathism, it is necessary to find out the responsible functional unit that causes mandibular prognathism.

Meanwhile, as timed passed, cone-beam computed tomography (CBCT) has evolved greatly, enabling its use in the oral and maxillofacial region. It is highly useful for evaluating changes in the bony structures. CBCT can provide clinicians more information on the oral and maxillofacial areas as it is a three-dimensional (3D) imaging modality without limitations.

There are studies dividing the mandible into skeletal units in 3D imaging. These studies were done to evaluate the skeletal unit responsible for asymmetry of the mandible and mandibular deformity (You et al., 2010; Park et al., 2010). The reference points and skeletal units were determined and demonstrated in the previous papers. However, there is little understanding of the functional units responsible for mandibular prognathism. To our knowledge there were no volumetric studies of the skeletal units.

The purpose of this study is to find the functional unit responsible for the aetiology between normal mandibles (class I) and prognathic mandibles (class III) using CBCT in order to prevent mandibular prognathism or to find a good treatment strategy for mandibular prognathism. Determining the responsible functional unit may help determine the exact cause or effect of Class III dentofacial dysmorphosis and malocclusion which may guide our treatment to focus on the specific functional unit or soft tissue.

2. Materials and methods

2.1. Subjects

The data of 101 Korean patients who visited the Wonkwang University Daejeon Dental Hospital and underwent CBCT imaging were evaluated (Male subjects: 60, Female subjects: 41). This study was approved by the institutional review board (Wonkwang IRB #: W1810/001-001). We have read the Helsinki Declaration and have followed the guidelines in this investigation.

The inclusion criteria were subjects aged over 18 and below 32 years, who had undergone CBCT imaging of the skull. In Class I patients, CBCT images were taken for various reasons involving trauma and for analysis before orthodontic treatment. For patients with Class III malocclusion, CBCT images were also taken for evaluation of trauma or for analysis before undergoing orthognathic surgery and orthodontic treatment. From all of the patients who had undergone trauma, the non-involved hemi-mandibles were examined. Exclusion criteria were subjects who gave a history of trauma on both sides of the mandible, degenerative joint disease, congenital deformities, moderate to severe asymmetry, tooth loss or fracture, severe alveolar bone atrophy and chronic periodontitis. The patients with asymmetry were excluded by menton deviation more than 2 mm from the mid sagittal plane. In total 101 hemi-mandibles from 101 subjects were analyzed.

2.2. Group classification

The subjects were divided into two groups on the basis of Steiner's analysis, C1-Me-based F1 of Delaire's analysis (Lee et al., 2014) and the sella-nasion-A point angle (SNA), sella-nasion-B point angle (SNB), and A point-nasion-B point angle (ANB) values, calculated from the midsagittal plane from the CBCT image. Subjects with values within the normal by Steiner's analysis and Delarie's analysis were grouped as Class I subjects, and those with high values of SNB with high vales of C1-Me-based F1 were grouped as Class III subjects, excluding patients with low SNA and normal SNB, who are classified as maxillary hypoplasia rather than mandibular prognathism. With this criteria, Class I subjects (30 males and 20 females) and Class III subjects (30 males and 21 females) were examined. The age range of Class I subjects was 18–32 years (mean age 22.94 ± 3.32), and for Class III subjects it was 18–27 years (mean age 20.86 ± 2.44). Also as mentioned above, Class I and Class III subjects were each classified by gender and also compared to each other.

2.3. CT imaging and 3D image reconstruction

3D analysis was performed using 3D CT to evaluate each skeletal unit of the mandible. The CT images were recorded at the Wonkwang University Daejeon Dental Hospital. The imaging conditions were: field of view: 20.8 cm; 100 kV; 76 mAs; scanning time: 1 s; and 0.5 mm thickness. The CT cross-sectional images of all patients were saved in the Digital Imaging Communication in Medicine (DICOM) format, and the 3D images were reconstructed using Mimics 10.0 (Materialise n.v., Leuven, Belgium).

2.4. Reference point selection and analysis

The 3D analysis was carried out using the Simplant Pro 2011 software. The mandible was sectioned into hemi-mandibles at the middle of the symphysis of the mandible. Randomly, right or left hemi-mandibles were chosen and analyzed. In patients who reported a history of trauma, the unaffected hemi-mandible was analyzed.

After the hemi-mandible was selected, reference points were located, and the hemi-mandible was divided into skeletal units. Although all the subjects had no missing teeth and atrophy of the alveolar bone, to minimize the error due to the crown of the third molar, all of the patients' teeth were erased from the alveolar level during the process. Few patients had their third molar removed prior to taking the CBCT. However the healing was done before the time they took CBCT. After the skeletal units were established, their volumes and lengths were also measured.

Definition of the reference points and skeletal units are as follows (Fig. 1.):

- Definition of reference points
- Inferior alveolar foramen (IAF): the most inferior point of the inferior alveolar foramen.
- Anti-inferior alveolar foramen (anti-IAF): point on the buccal aspect of the most inferior point of the inferior alveolar foramen.
- Mental foramen (MF): the most anterior point at the entrance of the mental foramen.
- Anti-mental foramen (anti-MF): point on the lingual aspect of the most anterior point of the entrance of the mental foramen.
- condyle_lateral (CON_l): the most lateral point of the mandibular condyle.
- condyle_medial (CON_m): the most medial point of the mandibular condyle.
- condyle (CON): the middle point of the distance between the condyle_lateral (CON_l) and condyle_medial (CON_m).
- coronoid (COR): the most superior point of the tip of the mandibular coronoid process.
- gonion (Go): the most distal and the most inferior point at the angle of the mandible.
- sigmoid notch (SN): the deepest point of sigmoid notch between the condyle and coronoid.
- posterior ramal notch (PRN): the most anterior point of posterior ramal notch.
- anterior ramal notch (ARN): the most posterior point of anterior ramal notch.

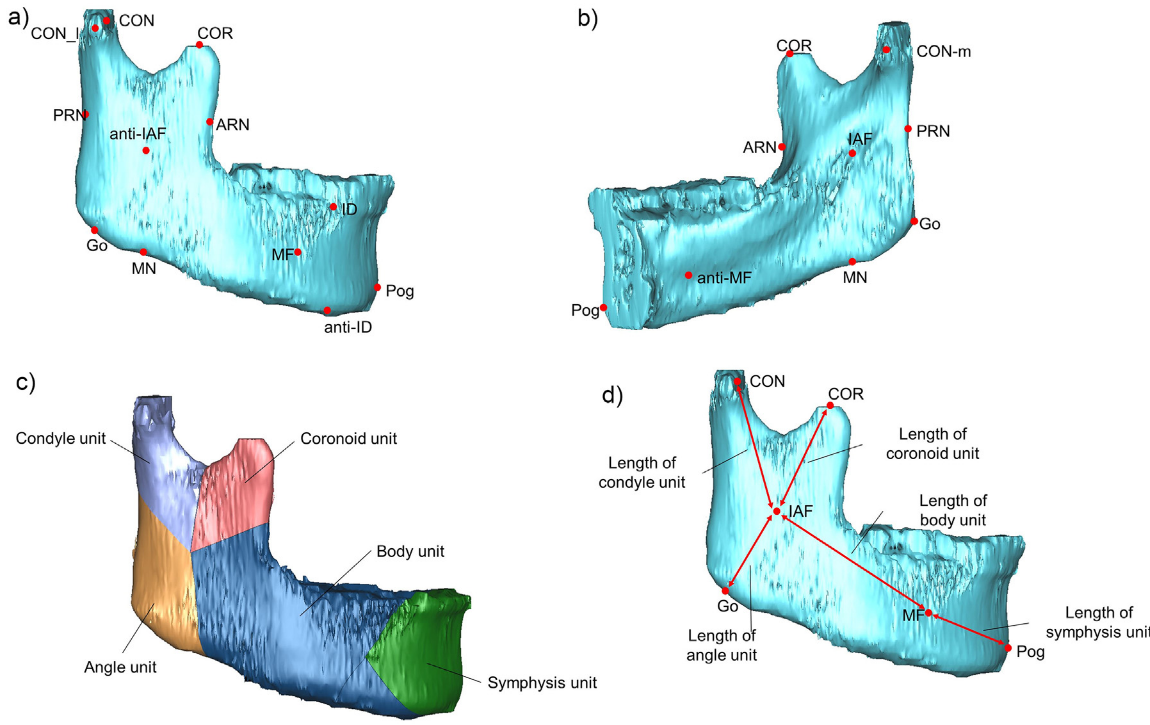

Fig. 1. Hemi-mandible divided into skeletal units. (A) Buccal aspect of the three dimensional model of the hemi-mandible with reference points to divide into skeletal units; (B) Lingual aspect of the three dimensional model of the hemi-mandible with reference points to divide into skeletal units; (C) Division of the hemi-mandible into skeletal units according to the reference points; (D) Length of each skeletal unit of the hemi-mandible measured by connecting the reference points.
Note: Definition of reference points in Fig. 1A, B (1) inferior alveolar foramen (IAF): the most inferior point of the inferior alveolar foramen; (2) anti-inferior alveolar foramen (anti-IAF): buccal aspect of the most inferior point of the inferior alveolar foramen; (3) mental foramen (MF): the most anterior point at the entrance of the mental foramen;(4) anti-mental foramen (anti-MF): lingual aspect of the most anterior point at the entrance of the mental foramen; (5) condyle_lateral (CON_l): the most lateral point of the mandibular condyle; (6) condyle_medial (CON_m): the most medial point of the mandibular condyle; (7) condyle (CON): the middle point of the condyle_lateral (CON_l) and condyle_medial (CON_m); (8) coronoid (COR): the most superior point of the tip of the mandibular coronoid process; (9) gonion (Go): the most distal and inferior point at the angle of the mandible; (10) sigmoid notch (SN): the deepest point of sigmoind notch between the condyle and coronoid; (11) posterior ramal notch (PRN): the most anterior point of the posterior ramal notch; (12) anterior ramal notch (ARN): the most posterior point of the anterior ramal notch; (13) masseteric notch (MN): the most superior point of the gonial (masseteric) notch; (14) $3\hat{4}$ interdental (ID): cervical point between mandibular canine and 1st premolar on the alveolar level; (15)anti-$3\hat{4}$ interdental (anti-ID): vertical point from ID to mandibular border; (16) Pogonion (Pog): most anterior and inferior point and the mandibular symphysis. Note: Definition of skeletal units in Fig. 1C: (1) condylar unit: the area between CON and IAF, purple; (2) coronoid unit: the area between COR and IAF, red; (3) angular unit: the area between Go and IAF, orange; (4) body unit: the area between MF and IAF, blue; (5) symphysis unit: the area between MF and Pog, red. Note: Definition of skeletal units in Fig. 1D: (1) condylar unit line from CON to IAF; (2) coronoid unit line from COR to IAF; (3) angular unit line from Go and IAF; (4) body unit line from MF and IAF; (5) symphysis unit line from MF and Pog.

- masseteric notch (MN): the most superior point of the gonial (masseteric) notch.
- $3\hat{4}$ interdental (ID): cervical point between the mandibular canine and first premolar at the alveolar level.
- anti-$3\hat{4}$ interdental (anti-ID): vertical point from ID to the mandibular border.
- Pogonion (Pog): most anterior and inferior point of the mandibular symphysis.
- Definition of skeletal units
- condylar unit: the area of the hemi-mandible surrounded by SN, IAF, anti-IAF, and PRN.
- coronoid unit: the area of the hemi-mandible surrounded by SN, IAF, anti-IAF, and ARN.
- angular unit: the area of the hemi-mandible surrounded by PRN, IAF, anti-IAF, and MN.
- body unit: the area of the hemi-mandible surrounded by MN, IAF, anti-IAF, ARN, MF, anti-MF, ID, and anti-ID.
- symphysis unit: the area of the hemi-mandible surrounded by MF, anti-MF, ID, and anti-ID.
- sum: integration of all skeletal units.
- Definition of length of the skeletal units
- condylar unit: length between CON and IAF.
- coronoid unit: length between COR and IAF.
- angular unit: length between Go and IAF.
- body unit: length between MF and IAF.
- symphysis unit: length between MF and Pog.
- sum: added lengths of condyle, body, and symphysis.

2.5. Ratio analysis

After the length and volume of each skeletal unit was measured using Simplant Pro 2011 software, to compare Class I and Class III subjects, the ratio of each skeletal unit was calculated. The calculation was performed by dividing the volume of each skeletal unit by the length of each unit. In particular, the ratio of the total hemi-mandible (sum) was measured by dividing the total volume by the length of the hemi-mandible. By dividing the volume by length, we evaluated the thickness of each skeletal unit.

2.6. Reliability of the measurements

Using 2-way mixed-effects intraclass correlations, examiner reliability was evaluated for replicated measurements. All variables mentioned in this study were measured twice on five randomly selected hemi-mandibles, with at least a 14-day interval between the measurements.

2.7. Statistical analysis

The results of the data are expressed as mean ± standard deviation (SD). The length of each skeletal unit was measured from the reference points. To evaluate the relationship between Class I and Class III subjects with respect to each skeletal unit, Student's *T* test was used. Also in comparing subjects according to gender between Class I and Class III subjects with respect to each skeletal unit, Student's *T* test was used.

A *P* value < 0.05 was used to indicate statistical significance. All analyses were performed using IBM SPSS Statistics 23.0 (IBM Corp., Armonk, NY, USA).

3. Results

3.1. Reliability of measurements

To assess the potential error that might occur, examiner reliability was measured with two-way mixed-effects. The intraclass correlation coefficients between repeated measurements were high, ranging from 0.93 to 0.99.

3.2. Discrimination of Class I and Class III subjects

Before dividing the hemi-mandible of each subject into skeletal units, the subjects were classified into two groups: Class I and Class III. They were divided into two groups under the criteria made by Steiner's analysis and Delaire's analysis. The average SNA of Class I subjects was 82.878 ± 3.49°; average SNB, 80.63 ± 3.75°; and average ANB, 2.23 ± 0.89°. The average SNA of Class III subjects was 80.37 ± 3.56°; average SNB, 85.03 ± 4.42°; and average ANB, −4.68 ± 2.88°.

3.3. Evaluation of each skeletal unit

After the 3D-images of the hemi-mandibles were constructed, they were divided into skeletal units as mentioned above. The length, volume, and ratio of each skeletal unit were then measured. When the ratio of each skeletal unit of Class I and Class III groups was compared, significant statistical difference was found with respect to condyle, body unit, and sum (Table 1 and Fig. 2). The ratio of the condyle unit of Class I subjects was 90.1 ± 16.0, and it was 80.1 ± 18.4 for Class III subjects. Additionally, the ratio of the body unit of Class I subjects was 321.4 ± 41.8, and it was 285.6 ± 63.8 for Class III subjects (*P* < 0.05). Finally, the ratio of the sum of Class I subjects was 250.3 ± 30.0, and for the Class III subjects it was 229.7 ± 47.7 (*P* < 0.05). This showed that the hemi-mandible, condyle unit, and body unit of Class III subjects were longer and thinner than those in Class I subjects (Fig. 3).

Furthermore, dependent on gender, when the ratio of each skeletal unit of Class I and Class III groups was compared, significant statistical difference was found with respect to condyle unit in males (Table 2). The ratio of condyle unit of males in Class I subjects was 92.8 ± 15.3 and it was 81.8 ± 20.7 for males in Class III subjects (*P* < 0.05). In females, significant statistical difference was found with respect to body and sum (Table 2). The ratio of body unit of females in Class I subjects was 308.4 ± 51.0 and it was 252.2 ± 48.8 for females in Class III subjects (*P* < 0.05). Additionally the ratio of sum of females in Class I subjects was 237.4 ± 34.1 and it was 205.0 ± 29.6 for females in Class III subjects (*P* < 0.05). There was difference in results according to gender.

Table 1
Statistical evaluation of skeletal Class I and Class III patients by each skeletal unit.

	Class I (*N* = 50)	Class III (*N* = 51)	*P* value
Volume (mm^3)			
Angle	2860.8 ± 809.7	2513.0 ± 852.6	
Condyle	3594.2 ± 740.0	3318.6 ± 854.4	
Body	18429.0 ± 2684.1	17934.4 ± 4405.3	
Coronoid	2525.1 ± 566.3	2299.3 ± 861.0	
Symphysis	4904.9 ± 940.6	5142.0 ± 1273.3	
Sum	32314.1 ± 4757.8	31206.3 ± 7301.4	
Length (mm)			
Angle	23.1 ± 3.4	21.1 ± 4.2	
Condyle	39.8 ± 3.6	41.5 ± 4.5	
Body	57.3 ± 3.9	62.7 ± 3.8	
Coronoid	40.9 ± 3.9	38.1 ± 3.8	
Symphysis	31.7 ± 2.6	31.2 ± 2.8	
Sum	128.8 ± 6.5	135.3 ± 7.3	
Ratio			
Angle	122.5 ± 23.5	118.0 ± 26.2	0.364
Condyle	90.1 ± 16.0	80.1 ± 18.4	0.004*
Body	321.4 ± 41.8	285.6 ± 63.8	0.001*
Coronoid	61.6 ± 11.5	59.6 ± 19.3	0.538
Symphysis	154.3 ± 24.2	164.0 ± 33.0	0.097
Sum	250.3 ± 30.0	229.7 ± 47.7	0.011*

Note: Values are presented as mean ± SD.
Ratio = Volume (mm^3)/Length (mm); Ratio Sum = Volume (Sum)/Length (Condyle + Body + Symphysis).
Abbreviation: SD, standard deviation.
P: *P*-value of unpaired *t*-test.
* *P* < 0.05.

4. Discussion

In our study, to overcome the limitations of 2D evaluation, we have used CBCT. CBCT has less radiation exposure than multi detector computed tomography and is a great method in evaluating changes in bony structures, allowing clinicians to measure the bony volume of the mandible.

There have been many theories and hypotheses on the evaluation of Class III patients (Ribeiro et al., 2006). Although the exact aetiology of mandibular prognathism is still controversial, we have a good amount of knowledge about the development of the mandible (Zielinski et al., 2014). Development of the mandible starts from Meckel's cartilage, from the first pharyngeal arch, forming the origin of the mandibular body. Later, the secondary cartilages appear and the condyle, coronoid, and symphyseal regions, are formed (Lee et al., 2001). These units unite and form the mandibular structure, with its own characteristics, within the functional matrix (Shibazaki-Yorozuya et al., 2014). As mentioned above, each unit retains its own feature (Lee et al., 2001). Each skeletal unit interacts with the soft tissue within its functional matrix (Moss and Simon, 1968).

In our study, we focused on the functional units of the mandibular structures introduced by Moss (Moss, 1968; Moss and Simon, 1968). The functional unit theory divides the mandible into six distinct units. These units are affected by the surrounding functional matrix. This implies that after birth the muscular structures attached to each skeletal unit affect the growth of these skeletal units (Kim et al., 2018).

The main goal of this study is to find out the skeletal unit that is responsible for mandibular prognathism. As our main treatment goal for mandibular prognathism is to give the patient the normal function of the structures and aesthetics. Thus, it is important to find out the problematic unit that is responsible. Also as the functional matrix theory states, if we could find out the responsible skeletal unit associated with mandibular prognathism, we can regulate the soft tissue from a young age and maybe prevent or lessen mandibular prognathism.

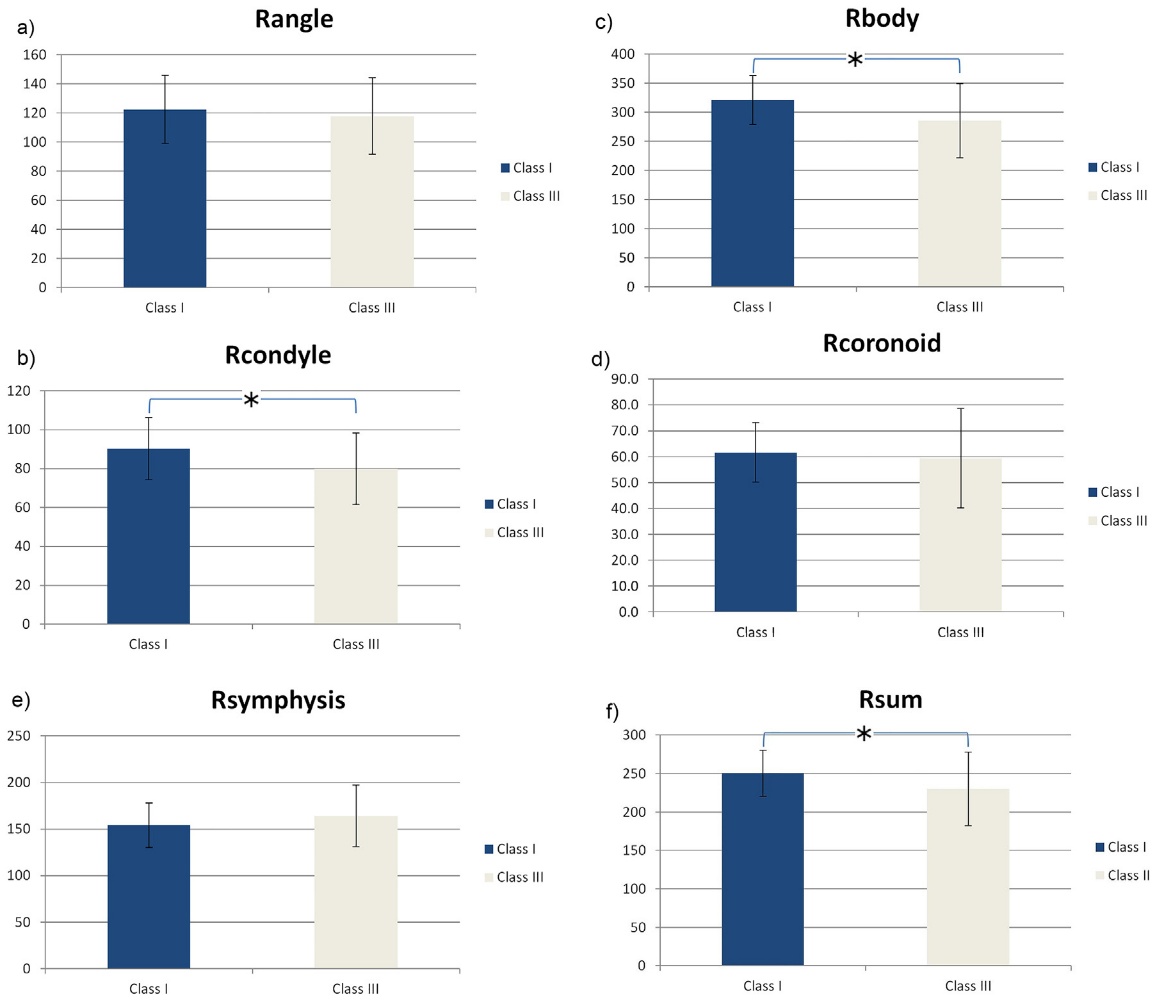

Fig. 2. Statistical evaluation of Class I and Class III patients by each skeletal unit. Ratio is volume/length of each skeletal unit. (A) Ratio comparison of mandibular angle unit; (B) Ratio comparison of condyle unit; (C) Ratio comparison of body unit; (D) Ratio comparison of coronoid unit; (E) Ratio comparison of symphysis unit; (F) Ratio comparison of the sum of all skeletal units.
Ratio = Volume (mm^3)/Length (mm); Ratio Sum = Volume (Sum)/Length (Condyle + Coronoid + Symphysis). *Abbreviations*: Rangle, ratio of angle unit; Rcondyle, ratio of condyle unit; Rbody, ratio of body unit; Rcoronoid, ratio of coronoid unit; Rsymphysis, ratio of symphysis unit; Rsum, ratio of sum of all skeletal units. *P*: *P*-value of unpaired *t*-test. $^*P < 0.05$.

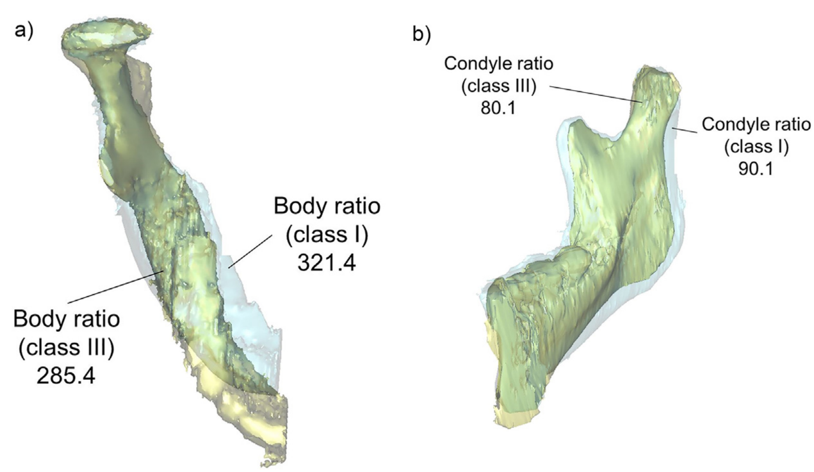

Fig. 3. Comparison of typical form of hemi-mandible of Class I and Class III subjects in occlusal and lingual view. (A) Hemi-mandible of a Class I and Class III subject in occlusal view was merged to visualize the ratio of the body unit; (B) Hemi-mandible of a Class I and Class III subject in lingual view was merged to visualize the ratio of the condyle unit.

Thus, we evaluated patients with Class III malocclusion based on the functional units described as above. The condyle and body units were longer and thinner in Class III subjects. This shows that a longer and thinner mandible was formed because of the body and condyle units of the mandible. This means that the body and condyle unit is the key unit to be treated to resolve mandibular prognathism. Thus, regulating the responsible functional matrix can lessen or prevent mandibular prognathism in young age. If

Table 2
Statistical evaluation of skeletal Class I and Class III patients by each skeletal unit dependent on gender.

	Male			Female		
	Class I (*N* = 30)	ClassIII (*N* = 30)	*P* value	Class I (*N* = 20)	Class III (*N* = 21)	*P* value
Volume (mm^3)						
Angle	3169.7 ± 811.6	2920.5 ± 848.8		2397.4 ± 555.7	1931.0 ± 409.6	
Condyle	3813.7 ± 691.1	3547.5 ± 922.5		3265.1 ± 702.4	2991.7 ± 633.5	
Body	19311.4 ± 2064.9	19713.7 ± 4433.4		17105.5 ± 2999.7	15392.5 ± 2912.7	
Coronoid	2730.4 ± 514.9	2649.5 ± 911.0		2217.1 ± 506.1	1798.9 ± 450.5	
Symphysis	5157.3 ± 847.3	5550.7 ± 1334.0		4526.3 ± 966.7	4555.8 ± 928.3	
Sum	34182.5 ± 3790.5	34381.9 ± 7411.7		29511.4 ± 4761.2	26669.8 ± 4109.4	
Length (mm)						
Angle	24.7 ± 3.1	23.2 ± 4.1		20.8 ± 2.5	18.2 ± 2.1	
Condyle	41.1 ± 3.2	43.4 ± 3.8		37.8 ± 3.3	38.7 ± 4.1	
Body	58.6 ± 3.9	63.7 ± 3.8		55.4 ± 3.1	61.2 ± 3.2	
Coronoid	42.1 ± 3.8	39.9 ± 3.5		39.0 ± 3.4	35.4 ± 2.4	
Symphysis	32.3 ± 2.4	31.9 ± 2.3		30.8 ± 2.6	30.2 ± 3.2	
Sum	132.0 ± 5.4	139.0 ± 5.3		124.0 ± 5.1	130.1 ± 6.5	
Ratio						
Angle	128.0 ± 24.4	125.9 ± 26.5	0.749	114.2 ± 19.7	106.7 ± 21.8	0.254
Condyle	92.8 ± 15.3	81.8 ± 20.7	0.023*	86.2 ± 16.7	77.5 ± 14.6	0.084
Body	330.1 ± 32.6	309.0 ± 63.3	0.111	308.4 ± 51.0	252.2 ± 48.8	0.001*
Coronoid	64.7 ± 9.4	66.1 ± 21.4	0.745	57.1 ± 13.0	50.6 ± 11.1	0.094
Symphysis	149.7 ± 22.6	173.0 ± 34.3	0.081	146.4 ± 24.9	150.9 ± 26.6	0.580
Sum	258.8 ± 23.8	247.1 ± 50.7	0.256	237.4 ± 34.1	205.0 ± 29.6	0.002*

Note: Values are presented as mean ± SD.
Ratio = Volume (mm^3)/Length (mm); Ratio Sum = Volume (Sum)/Length (Condyle + Body + Symphysis).
Abbreviation: SD, standard deviation.
P: *P*-value of unpaired *t*-test.
* $P < 0.05$.

growth is completed, surgical regulation of condyle and body unit may be essential in treating mandibular prognathism.

However when evaluated related to gender, there were some differences. This may be caused by the small sample size or differences in facial pattern that may discriminate males and females. This may be a part of sexual dimorphism of the mandible. This may lead us to a different treatment strategy according to the gender.

There are other similar studies about the mandible (Noleto et al., 2010). Studies about the ramus width of the mandible showed similar results, stating that Class III subjects have longer and thinner mandibles than do Class I subjects (Ribeiro et al., 2006). This may be a different study, but it revealed similar results showing that the prognathic mandible is thinner mediolaterally than the normal mandible.

There are studies that analyzed the mandible by its functional units by evaluating the length of each functional unit. However, there are no studies that assessed the volumetric characteristics of each functional unit. In our study, we evaluated the volume and length of each functional unit. The results of our study may imply that to regulate the growth of the mandible, the key functional units are the condyle and the body part. This is similar to the results of the study by Park that also concluded that the body and condyle units of the mandible showed significant differences when the prognathic, retrognathic, and control groups were compared (Park et al., 2010).

These results imply that in treating mandibular prognathism in patients, to surgically adjust the body and the condyle unit is the key to give the patient the normal function and aesthetics. We could inference that shortening and thickening the condyle and body unit could be a good treatment strategy in mandibular prognathism. This may rationalize the general use of sagittal split ramus osteotomy (SSRO) and intraoral vertical ramus osteotomy (IVRO). Since these techniques surgically adjust the condyle and body unit of the mandible. According to the gender difference, the results may insist that SSRO may be better treatment for females since the technique thickens the body unit and IVRO may be better in males since the technique thickens the condyle unit. Nevertheless, there should be further studies to evaluate the effects of these surgical techniques.

This study was presented to specify the key functional unit that is responsible for mandibular prognathism. According to the theories explained above, the concept that genetic and soft tissue factors might have influenced the growth of the mandible as growth runs along. However, it is still difficult to explain the exact aetiology of mandibular prognathism. This study did not evaluate the muscles and soft tissues that were associated with each skeletal unit as per the functional matrix theory. Evaluation of the soft tissue of each functional unit could be helpful to understand the pathology of skeletal prognathism. Furthermore, there were limitations of this study dependent on gender. Further studies may help to understand the difference between gender differences.

Ethical statement

This study was approved by the institutional review board (Wonkwang IRB #: W1810/001-001). We have read the Helsinki Declaration and have followed the guidelines in this investigation.

Disclosure

None of the authors have any relevant financial relationship(s) with a commercial interest.

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