Journal of Dental Sciences 18 (2023) 175–183

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.e-jds.com

Original Article

Condylar and ramus volume in asymmetric and symmetric skeletal class III malocclusion: A cone-beam computed tomography study

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Received 30 May 2022; Final revision received 19 June 2022
Available online 5 July 2022

KEYWORDS
Condylar volume;
Mandibular volume;
CBCT;
Skeletal Class III;
Facial asymmetry

Abstract *Background/purpose:* Among the craniofacial structures, the mandible is the only bony structure with movable joints. Each part (including condyle process, coronoid process, and ramus) of mandible would interaction with the muscles and proceed different osteogenesis progress. The objective of this study was to evaluate the mandibles with symmetric and asymmetric skeletal Class III jaw relations by quantifying differences in the condyle process, coronoid process and ramus on CBCT (Cone-beam computer tomography) images. Our hypothesis was that CBCT would reveal no voluminal differences between deviated and non-deviated mandibular segments in asymmetric skeletal Class III.
Materials and methods: CBCT imagines were collected from dental department, KMUH and then divided into symmetric Class III group (Menton deviation $<$ 4mm) and asymmetric Class III group (Menton deviation≧4mm). The mandibular structure would be segmented to ramus, condylar and coronoid process. Each volume was measured. Independent t test was used for comparison between groups, and paired t test was applied for comparison between both segmented parts within each group.
Results: Significant differences between deviation and non-deviation sides in the asymmetric group were found in condylar and ramus segments for volumetric quantitative measurements. There has no significant difference in ramus parts between groups. Significant greater condylar volume was found in non-deviation side of asymmetric group.

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https://doi.org/10.1016/j.jds.2022.06.016

Conclusion: The results demonstrated that in the side with greater mandible growth potential, the condylar and the ramus volume would be greater as well. CBCT is a useful and accurate modality for quantification and evaluation of mandibular asymmetry.

Introduction

The mandible is the only bony structure with movable joints among the craniofacial structures. The mandible is a relatively independent bony unit in the craniofacial structure; its anatomical structure includes the condyle, coronoid process, alveolar process, mandibular body, ramus, and mental region.[1] The mandible is a key structure because (1) the maxilla is attached to the skull with bone sutures; the mandible is the only movable joint in the craniofacial structure. (2) The condylar head of the mandible is chiefly formed through endochondral ossification, and the entire maxilla is formed through intramembranous ossification. (3) The structure connecting the mandible and the skull base is the temporomandibular joint. This joint contains cartilaginous tissue, which enables the joint to bear pressure. The intermaxillary suture is composed of collagen connective tissue, enabling it to bear the tension. (4) The masticatory muscles and the medial pterygoid muscle are attached to the mandible, supporting the chewing action. The maxilla has no role in mouth opening and closing. (5) The mandible is a single bone block, whereas the maxilla comprises a pair of bones connected by a palatal suture. (6) Both the maxilla and mandible develop from the first branchial arch in embryos and are controlled by different branches of the fifth pair of cranial nerves.

The growth and development of the mandible are unique and involve both endochondral ossification and intramembranous ossification. Cartilage covers the condylar surface at the temporomandibular joint. The cartilage undergoes cell proliferation and hypertrophy, eventually replacing endochondral bone. Other parts of the mandible are formed through bone deposition on the bone surface and bone remodeling. The mandibular ramus provides a base upon which the masticatory muscles can attach, and bone remodeling proceeds in the posterior and superior (more upright) directions in parallel with the vertical growth of the middle face. The entire mandibular ramus is involved in the growth of the mandible, including the growth of the mandibular condyle and the mandibular body when the mandibular ramus grows posteriorly and superiorly, away from the mental region. The remodeling of the coronoid process occurs posteriorly, superiorly, and proximally. The growth and development mechanisms of each bone segment of the mandible differ and influence each other.

Research on mandibular size has generally focused on two-dimensional (2D) analyses involving lateral cephalograms (evaluating linear distance and area). However, this method has several limitations, including respect to the head's positioning, magnification, and deformation.[2–6] No method has been established to determine changes in each segment of the mandible; 2D cephalometric analysis cannot provide this information because it can be obtained only through voluminal measurement of a three-dimensional (3D) space. The mandible comprises relatively independent bone units, including the alveolar process, coronoid process, condyle, ramus, mandibular body, and chin. To overcome the limitations of 2D imaging, 3D dental cone-beam computed tomography (CBCT) has been employed increasingly.[7–11] CBCT can be used to evaluate both surface area and volume. Applying CBCT to each part of the mandible may elucidate the causes of mandibular deformity.

Deguchi et al.[12] conducted a CBCT study on patients with skeletal Class I, II, and III to compare the maxillary and mandibular volumes between different skeletal relations. This study showed that the mandible/maxilla volume ratio of skeletal Class III samples was significantly greater than that of Class II samples but did not compare the size of condyle volume or ramus volume.

Kwon et al.[13] reported that the asymmetric position of the mandibular condyle is related to the asymmetry of the cranial base, however the 3D position of the condyle and the cranial base has no significant relationship with the asymmetry of the mandible. Their results showed that cranial measurement variables were not the main factor in determining the degree of facial asymmetry. It appears that mandibular skeletal characteristics per se compensate or exacerbate the effects of cranial asymmetry during the growth phase. The functional or intrinsic growth potential may also induce cranial asymmetry.[13]

Past research on mandibular asymmetry concluded that the non-deviation side has a larger condylar volume[8,14] and linear length in the condylar segment.[15] Although most of these articles did not compare mandibular ramus volume.[14,16,17] The components of the mandible's condyle, ramus, and body might be important factors in explaining the components of facial asymmetry.[12]

Furthermore, the lateral deviation of the menton (Me) significantly influences the judgment of facial asymmetry.[18] Therefore, we would like to know whether there is a difference in the ramus volume in the cases with mandible deviation. And further, analyze the voluminal differences between deviated and non-deviated mandibular segments. We speculate that the mandibular asymmetry might be caused by lateral displacement of the mandible, but the volume of the mandibular segments on both sides was similar.

The objective of this study was to evaluate the mandibles with symmetric and asymmetric skeletal Class III jaw relations by quantifying differences in the mandibular condyle and ramus on CBCT images. Hypothesized that CBCT would reveal no voluminal differences between deviated and non-deviated mandibular segments in individuals with asymmetric skeletal Class III.

Materials and methods

CBCT images (from 64 patients) were collected from the Dental Department of Kaohsiung Medical University Chung-Ho Memorial Hospital (located in southern Taiwan) between August 2017 and December 2018. A NewTom VGi evo (Imola, Italy) CBCT machine was used with the following parameters: radiation time, 3.5 s; voxel size, 0.3 mm; radiation scope, 24×19 cm^2; and radiation dose, 110 kV/4.59 mA. Patients were positioned in a natural cranial position for each scan and were asked to inhale and hold their breath. The occlusion was in the position of maximum intercuspation. ImageJ software (1.48 V) (Rasband, W.S., ImageJ, U.S. National Institutes of Health, Bethesda, MD, USA) was used for cephalometric analyses of the CBCT images. Landmarks were defined as follows: (1) basion (Ba): the midpoint of the anterior part of the foramen magnum, (2) nasion (N): the junction of the frontonasal suture, (3) OrR: the most superior point of the right infraorbital rim, (4) PoR: the most superior point of the external acoustic meatus of the right side, (5) PoL: the most superior point of the external acoustic meatus of the left side, (6) ANS: the most anterior midpoint of the anterior nasal spine of the maxilla, (7) menton (Me): the most inferior midpoint on the symphysis, (8) Jlat: the most lateral and deepest point of the curvature formed at the junction of the mandibular ramus and body, (9) Jmed: the most medial and deepest point of the curvature formed at the junction of the mandibular ramus and body (10) gonion (Go): the midpoint between the most posterior and inferior point on the mandibular angle (11) C point: the lowest point of the sigmoid notch (12) A point (13) B point, and (14) S point (S): the geometric point of the sella turcica. The adult patients aged more than 18 years and with an ANB angle in the CBCT image of $<0°$ were included in the study. Patients with systemic diseases, severe craniofacial deformities, cleft lip and palate, and facial bone trauma were excluded from the study.

Table 1 Intergroup age, ANB (^{0}), SN-MP (^{0}), Me-MSP (mm) distribution comparability.

	Symmetry (M = 15, F = 19)		Asymmetry (M = 13, F = 17)		*P* value
	Mean	SD	Mean	SD	
Age (year)	24.06	4.86	23.46	5.19	0.950
ANB (degree)	−4.61	2.64	−3.6	2.59	0.129
SN-MP (degree)	30.39	5.51	32.44	5.64	0.148
Me-MSP (mm)	1.62	1.03	7.31	2.54	<0.001*

SN: the line between the sella point (S) and nasion (N); MP: the mandibular plane, which means the line between menton (Me) and gonion (Go); SN—MP: the angle between the sella point (S)-nasion (N) line and the mandibular plane (MP); MSP: the midsagittal plane (the basion—nasion line segment perpendicular to the FH plane); Me—MSP: the distance from menton to the midsagittal plane.

*: Significant, $P < 0.05$; M: male; F: female; SD: standard deviation.

The coordinate points (Table 1) were marked in the digital imaging and communications in medicine image files. The Frankfort horizontal plane (FH) was established based on the Or^R, Po^R, and Po^L, and the cranial position was corrected according to the newly established plane (Fig. 1). The Ba—N line segment perpendicular to the FH plane was considered the midsagittal plane (MSP), and the distance of the Me—MSP was considered the grouping standard (Fig. 1).[7,14,19,20] Facial asymmetry was defined as the deviation of the chin in which the menton was more than 4 mm away from the MSP;[14,19,20], 34 and 30 patients were assigned to the symmetric and asymmetric groups, respectively. The mandible was separated from the whole-skull image file. A stereoscopic model was reconstructed using the aforementioned software, and the dental crown above the alveolar ridge was removed (Fig. 2). The condylar and ramual volumes were then measured (Fig. 3). The mandible was divided into the left and right mandible, with MSP serving as the boundary between the two sides, and the lowest point of the bilateral sigmoid notches of the mandible was marked as the C point (L + R). The left and right condyles and coronoid processes were cut out, with the reference plane passing through the lowest point of the sigmoid notches of the mandible and parallel to the FH plane serving as a boundary line; their volumes were subsequently calculated. The obtained condyle volume was divided by the total volumes of the left (non-deviated) and right (deviated) sides.

The most lateral and deepest point of the curvature formed at the junction of the mandibular ramus and body was marked as J_{lat}, and the most medial and deepest point of the curvature formed at the junction of the mandibular ramus and body was marked as J_{med}. The condylar and ramus volumes were determined using the reference plane passing through the lowest point of the mandibular sigmoid notches and parallel to the FH plane. The line passing through J_{lat}, J_{med}, and Go was used as another reference plane to distinguish the mandibular ramus and the mandibular body. The obtained ramus volume was divided by the total volumes of the left (non-deviated) and right (deviated) sides.

Data were analyzed using SPSS 20 (SPSS, Chicago, IL, USA). The Student's t-test and Pearson's correlation test were applied for statistical analyses. This was a retrospective study and was conducted with the approval of the Institutional Review Board of Kaohsiung Medical University Chung-Ho Memorial Hospital (IRB number: KMUHIRB-E(I)-20180,295).

Results

A total of 64 CBCT images of skeletal Class III were collected, including skeletal Class III malocclusion. The images were obtained from 28 men (aged 25.21 $\pm$ 4.63 years) and 36 women (aged 22.33 $\pm$ 5.42 years), as presented in Table 1. Based on mandible deviation, 34 patients (15 men, 19 women; average age, 23.94 $\pm$ 5.03 years) were

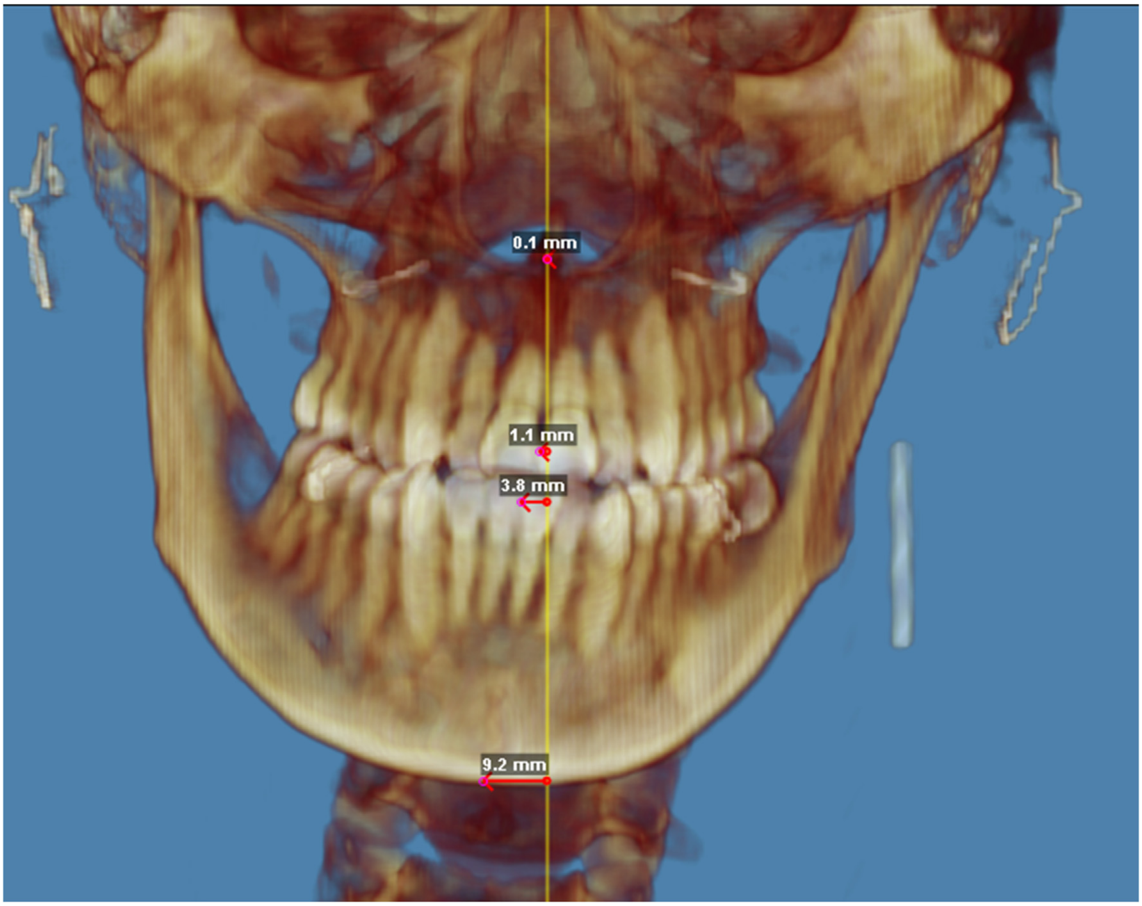

Figure 1 Midline deviation measurement.

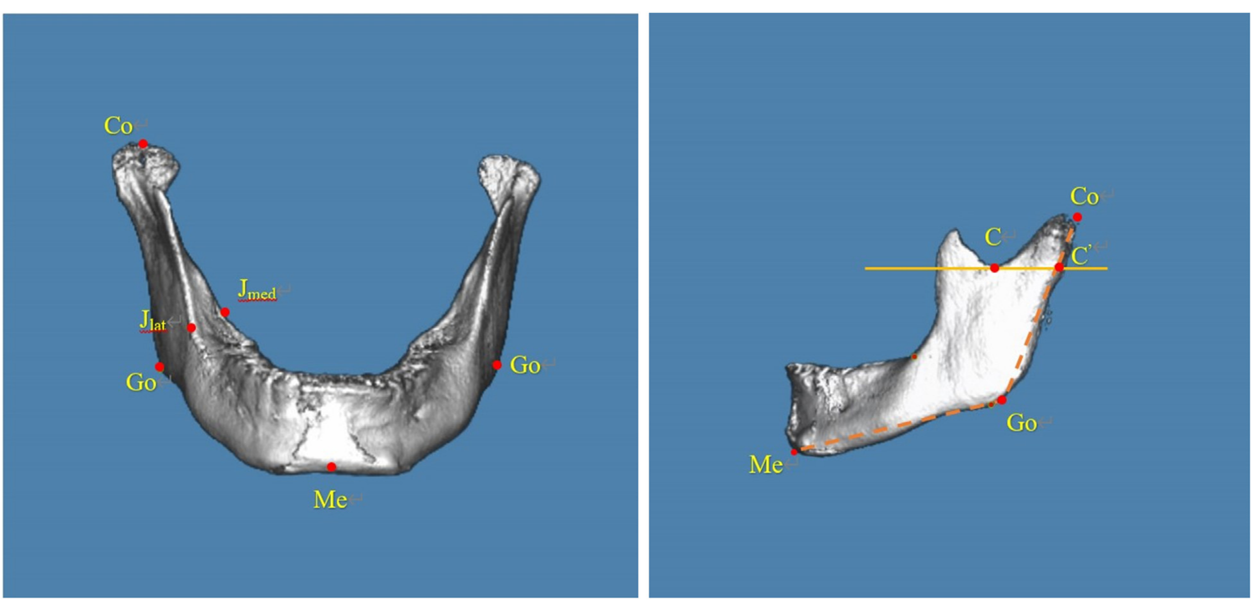

Figure 2 Frontal and lateral views of the definition points for mandible volume marking, imaged using Dolphin software.

assigned to symmetric group, and 30 (13 men, 17 women; average age, 23.20 ± 5.55 years) were assigned to the asymmetric group. No significant difference was identified between the two groups concerning sex or age.

In the cephalometric analysis, the value of the SN–MP angle (the angle between the S point-nasion line and the menton-gonion line) was used to represent vertical facial patterns, and the value of the ANB angle was used to

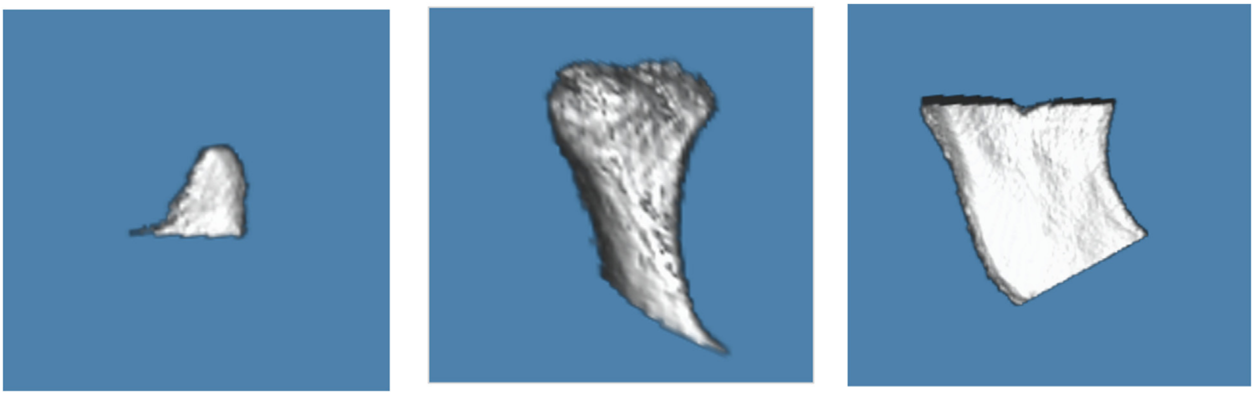

Figure 3 Volume extraction of the mandibular coronoid process, condyle, and ramus, imaged using Dolphin software.

represent anteroposterior horizontal relationships, which were verified using the Student's t-test. The results are listed in Table 2. In the symmetric group, the mean SN—MP and ANB angles were 30.39° ± 5.50° and −4.61° ± 2.63°, respectively. In the asymmetric group, the mean SN—MP and ANB angles were 32.44° ± 5.64° and −3.60° ± 2.59°, respectively. The mean values of the SN—MP and ANB angles did not significantly differ between the two groups (*P* = .148, *P* = .129). The average deviation in the symmetric group was 1.62 ± 1.03 mm, and that in the asymmetric group was 7.31 ± 2.53 mm, with a significant difference between the groups.

The differences in the volume of the mandible's left and right-side segments between the men and women were compared (Table 2), and significant differences were discovered in the condyle volumes on both sides of the mandible (*P* = .001, *P* = .000). The results revealed that the condyle volume on the deviated and non-deviated sides was larger in men than in women (Table 3). In addition, significant differences were identified in the volumes of the

Table 2 The differences in the volume on the left and right segments (deviation and non-deviation side) of the mandible.

	Symmetry group (N = 34)				*P* value	Asymmetry group (N = 30)				*P* value
	Right side		Left side			Deviation side		Non-deviation side		
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Coronoid volume (mm^3)	463.12	115.88	460.96	142.41	0.916	417.13	178.87	446.61	149.64	0.352
Condyle volume (mm^3)	2010.04	468.13	1950.93	681.76	0.410	1709.38	598.81	2036.69	697.58	0.001*
Ramus volume (mm^3)	6709.62	1327.11	6505.86	1417.88	0.192	6551.10	2034.48	7079.07	2194.52	0.013*
Condyle linear (mm)	21.92	4.41	24.08	5.65	0.061	21.54	4.27	23.85	3.81	0.001*
Ramus linear (mm)	40.81	5.37	38.77	5.79	0.062	40.25	5.76	40.13	4.54	0.866

*: Significant, P < 0.05; SD: standard deviation.

Table 3 The comparison of the left and right segments of the mandibular volume in the symmetric group.

Right side	Male		Female		*P* value
	Mean	SD	Mean	SD	
Coronoid volume (mm^3)	489.23	125.97	442.51	106.12	0.249
Condyle volume (mm^3)	2282.78	558.54	1794.71	219.51	0.001*
Ramus volume (mm^3)	6901.67	1404.86	6558	1280.18	0.462
Condyle linear (mm)	24.01	4.34	20.27	3.81	0.012*
Ramus linear (mm)	42.01	5.01	39.86	5.59	0.252
Left side					
Coronoid volume (mm^3)	508.67	130.21	423.29	143.52	0.082
Condyle volume (mm^3)	2393.93	714.71	1601.19	402.7	0.000*
Ramus volume (mm^3)	6777.36	1578.47	6291.51	1279.81	0.329
Condyle linear (mm)	26.24	4.67	22.38	5.88	0.046*
Ramus linear (mm)	40.65	5.83	37.29	5.46	0.093

*: Significant, P < 0.05; SD: standard deviation.

bilateral condyles and mandibular ramus ($P < .005$). Finally, in the asymmetry group, the bilateral condyles and mandibular ramus volumes were more significant in men than in women (Table 4).

In the symmetric group, the volumes of the left and right mandibular segments were compared; no significant differences were identified in the volumes of the condyles and ramus. In the asymmetric group, the volumes of the deviated and non-deviated sides of the mandibular regions were compared; the condyle and mandibular ramus volumes were smaller on the deviated side than on the non-deviated side ($P = .001$, $P = .013$). A significant negative correlation ($r = -0.377$) was observed between the Me–MSP and the condylar volume of the deviated side (Table 5).

Table 5 Pearson correlation test in the Me-MSP and the volume and linear length on the deviation and non-deviation sides.

	R	*P* value
NDev. CondyleVol.	0.155	0.091
NDev. RamusVol.	0.186	0.325
Dev. CondyleVol.	0.046	0.810
Dev. RamusVol.	0.118	0.535
Dev. Condyle (mm)	−0.377	0.040*
Dev. Ramus (mm)	0.118	0.981
NDev. Condyle (mm)	−0.157	0.406
NDev. Ramus (mm)	−0.154	0.415

Deviation: Dev. Non-deviation: NDev.
Volume: Vol.
*: Significant, $P < .05$.

Discussion

In this study, the reference plane proposed by Swennen[21] in 2006 was used to measure and define the condyles, mandibular ramus, mandibular body, and coronoid processes. The mandible was divided into the left and right mandible, with the MSP as the boundary. The lowest point of the bilateral sigmoid notches of the mandible was marked as the C point (L + R), the most lateral and deepest point of the curvature formed at the junction of the mandibular ramus and body was marked as J_{lat}, and the most medial and deepest point of the curvature formed at the junction of the mandibular ramus and body was marked as J_{med}. The condyle volume, coronoid process volume, and ramus volume were determined using a reference plane passing through the lowest point of the mandibular sigmoid notches and parallel to the FH plane. J_{lat}, J_{med}, and Go were used as another reference plane to distinguish the mandibular ramus from the mandibular body.

When assessing a patient's facial asymmetry, the degree of left-right symmetry of the anatomical structure and whether there is lateral deviation require a reference plane as the basis for evaluation. The greater the deviation between the chin position and the midline of the maxilla and mandible, the higher the patient's perception of facial asymmetry. [18] Ahn JS and Hwang HS[18] conducted a 2D study on posterior-anterior cephalograms. They measured the relative positions of mandibular landmarks such as menton, gonion, and antegonial notch to the midsagittal reference line (MSR), which is the connection between crista galli and anterior nasal spine, as the baseline for judging the facial asymmetry. Haraguchi et al. [20] used the 4 mm side-shift of the menton relative to the MSR (midsagittal reference) plane as the classification reference. The side-shift greater than 4 mm was the "asymmetric group". If the menton's side-shift is less than 4 mm and the midline deviation of the upper and lower dentition is less than 2 mm, these cases are into a "symmetric group". Regarding the 3D research on facial asymmetry, past research also used the 4 mm side-shift of Me relative to the MSR plane as the reference. [14,19] Therefore, we took the distance of the Me to a midsagittal plane as the grouping standard in the current study.

Deguchi et al.[12] conducted a CBCT study on 30 Japanese female patients (aged 15–43 years old) to compare the maxillary and mandibular volumes between different skeletal relations. However, their study did not focus on "facial asymmetry," so there is no way to know the difference between the deviated and non-deviated sides of the mandible. In addition, the sample size of this study is

Table 4 The volume and linear length comparison on the deviation and non-deviation sides of the mandible in the asymmetric group.

Deviation side	Male		Female		*P* value
	Mean	SD	Mean	SD	
Coronoid volume (mm^3)	487.29	230.64	363.48	105.06	0.059
Condyle volume (mm^3)	2048.32	550.89	1438.31	499.04	0.004*
Ramus volume (mm^3)	7730.3	2456.33	5649.35	991.58	0.004*
Condyle linear (mm)	22.36	3.41	20.91	4.84	0.369
Ramus linear (mm)	45.23	4.18	36.44	3.39	0.000*
Non-deviation side					
Coronoid volume (mm^3)	474.27	167.86	425.45	135.49	0.385
Condyle volume (mm^3)	2443.51	668.52	1737.45	557.48	0.004*
Ramus volume (mm^3)	8777.03	2087.46	5780.62	1151.91	0.000*
Condyle linear (mm)	24.72	3.79	23.19	3.79	0.280
Ramus linear (mm)	43.29	4.64	37.72	2.63	0.000*

*: Significant, $P < 0.05$; SD: standard deviation.

relatively small, and the sample is only single-sex (female), so it is impossible to know the difference between the sexes.

In 2011, Lee et al.'s[14] research subjects were Koreans, using CBCT data to study adult skeletal Class III patients with facial asymmetry, divided into a facial asymmetry group (15 males and 15 females) and a symmetry group (10 males and ten women). They measured the condyle's position, angle, GMD (greatest mediolateral diameter), height, volume, and volume ratio (non-deviated/deviated). They concluded that the non-deviation side has a larger condylar volume, a longer GMD, and a more significant condylar height than the deviation side. Nevertheless, this article did not mention the comparison of mandibular ramus volume.

In 2010, You et al.[8] used CBCT to study the mandibular morphology of Korean patients with facial asymmetry accompanied by mandibular protrusion. They discovered that the condylar head and mandibular body had significantly higher volumes, and the coronoid process was significantly shorter on the non-deviated side than on the deviated side. In addition, the volume of the mandibular ramus was significantly more prominent on the non-deviated side. However, no significant difference was identified in the mandibular body volumes of the two sides.

In 2016, Nakawaki et al.[22] used Japanese adults' CBCT to analyze differences in mandibular volume among different face types. They concluded that the condylar head volume does not significantly differ with different skeletal patterns. However, the condylar head volume of short faces was significantly more extensive than that of long faces.

In 2018, Mendoza et al.[16] studied Spanish patients' mandibular morphology according to skeletal patterns and facial types and discovered significant differences in condylar head height, mandibular ramus length, overall length, and condylar head volume between the sexes. The condylar head volume of shorter faces was significantly larger. In addition, men with Class III malocclusion and short faces had greater mandibular length and volume. They were most likely to have asymmetry in the linearity and volume of the mandible. However, in terms of volume measurement, this study only measured the condylar volume, not the ramus volume.

Mandibular growth patterns demonstrate that sexual dimorphism develops early in life.[12], [16], [19] Men have larger mandibles at birth than women do. However, mandibular growth becomes more pronounced during puberty. Concerning sex differences, disparities in overall mandible length are the greatest, followed by differences in the length of the mandibular body and the height of the mandibular ramus. The magnitude of the difference is approximately 0—2 mm prior to the onset of puberty. This difference can reach 4—8 mm at the end of puberty.[23] In 2018, Mendoza et al.[16] conducted a study on the morphology of the mandible by using CBCT. The study focused on patients with facial asymmetry in various skeletal structures and facial morphology. The authors discovered that condylar height, length of the ascending mandibular ramus, overall length, and condylar volume significantly differ between the sexes. In the present study, the volumetric differences of each subsection of the left and right sides of the mandible in men and women were compared for both the symmetric and asymmetric groups. The men's and women's left and right mandibular volumes in the symmetric group were compared, and significant differences were identified in the condylar volumes of both sides of the mandible. The results indicate that the mandibular condylar volume was more significant in men than women. A similar result was obtained for the line segment measurements. Analytical comparisons of male and female mandibular deviated and non-deviated side volumes revealed significant differences in the bilateral condyle and mandibular ramus volumes. The results revealed that the mandibular condyle and ramus volumes were more prominent in men than in women in the asymmetric group. Regarding linear measurements, the ramus length differed significantly between the sexes. The length of the ascending ramus was significantly larger in men than in women.

Petrovic et al.[24] developed a mandibular growth regulatory model known as the servosystem theory of craniofacial growth. According to this theory, the independent growth of the maxilla may cause slight malalignment of the upper and lower dentition, which then sends signals to the muscles through proprioceptors that cause the mandible to protrude under the resulting muscle tension. The position of the mandibular condyle then moves forward to stimulate condylar growth. The influence of growth hormones causes the muscle function and elasticity of condylar growth also to become enhanced. This demonstrates how condylar growth can be markedly affected by functional differences and growth hormone levels in the body. You et al.[8] measured the reconstructed volume of computed tomography images of 50 patients with mandibular protrusion. The authors classified these patients into symmetric and asymmetric groups. These researchers' definition of the mandibular volume cutting plane was slightly different from that of our study. However, their results revealed that the volume of the mandibular condyle on the deviated side was significantly smaller than that of the control group, which is consistent with the findings of our study. These findings suggest that in the condylar area, a smaller condyle growth volume is more likely to be observed on the deviated side than a larger growth volume on the non-deviated side. However, mandibular malalignment may also result from the asymmetric growth of other mandibular regions (ie, the ascending ramus and mandibular body).

Nolte et al.[25] compared the volumes and line segments of an asymmetric group of patients with skeletal Class III and discovered significant differences in the condylar volumes of the deviated and non-deviated sides. Mendoza et al.[16] included 159 Spanish samples for a comparison of the volumes of different vertical face types and skeletal relations; the average condyle volume for cases of skeletal Class III jaw relations was 1986.7 ± 146.7 mm^3, which was larger than that of cases of skeletal Class I and Class II jaw relations; however, this difference was nonsignificant.

Saccucil et al.'s[17] study included CBCT data from 94 Caucasians to compare condylar volume and surface differences under different skeletal relations, among which the right condylar volume in cases of skeletal Class III jaw relations was 2592.6 ± 699.6 mm^3 and the left condylar volume was 2570.7 ± 679.4 mm^3. These volumes did not significantly differ from the respective volumes in cases of skeletal Class I and Class II jaw relations. There were no significant differences in right and left condylar volumes across the sample. Saccucil et al.[17] indicated that differences in the volume of the mandibular condyle might vary among subjects of different ethnic groups. In Saccucil et al.'s[17] study, however, they did not compare the difference between facial asymmetry and symmetry cases.

Goto and Langenbach[15] observed that the linear measurement values of all areas on the non-deviated side were larger than those on the deviated side in an asymmetric group of participants. However, the difference was only significant in the condyle segment; the measurement values for the non-deviated side were significantly greater than those in the control group.

For orthodontists, a detailed understanding of the average volume of each segment of the mandible and their correlations can be useful for clinical diagnosis and treatment planning. CBCT assessment should be performed for patients with asymmetry to enable more precise planning of orthodontic treatment and orthognathic surgery.[16] Among the various classifications of skeletal relationships, it is not explicitly indicated whether there are differences in maxillary and mandibular volumes; this is important for understanding or predicting volume changes caused by natural growth and orthopedic treatment.[12] Clinically, our study of the size of the mandible and the difference in the volume between different parts of the mandible is helpful in clinically studying the changes in the jawbone's shape caused by orthopedic treatment.[12]

In our study, no significant difference was identified between the volumes of the bilateral condyles in the symmetry group. In the asymmetric group, a paired t-test was used to compare the differences in the volumes of the ramual regions of the deviated and non-deviated sides. The condyle and mandibular ramus volumes on the deviated side were significantly lower than those on the non-deviated side.

Although there was no significant difference between the left and right condylar volumes, our analyses indicated that the standard deviation values were all as high as 600–700 mm^3. This result suggests that, clinically, condylar volumes have high variability and can differ considerably, even in a single individual. Generally, linear measurements are used in research to reveal the growth of different areas of the mandible. However, 3D imaging can more accurately reflect differences in the growth and development of the mandible with respect to volume. Differences in the total growth volume of the mandible may be attributed to race, and individual differences in condylar volume may be large. The influence of race may be further elucidated with larger sample size.

In conclusion, when comparing the mandible volumes between sex in the asymmetric group, the volumes of men's condyles and mandibular ramus were significantly greater than those among women. In the symmetric group, we found no significant difference in the mandible volumes of the left and right sides. Further comparison of the mandible volumes of the deviated and non-deviated sides revealed that the mandibular condyle and ramus volumes on the deviated side were significantly lower than those on the non-deviated side. The condylar volume of the deviated side was significantly lower in the asymmetric group than in the symmetric group. From the result of the current study, we concluded that in cases of skeletal Class III jaw relations and asymmetric growth of the mandible, condylar volume is significantly lower on the deviated side.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

This study was supported by a grant from the Kaohsiung Medical University Hospital, Kaohsiung, Taiwan (KMUH107-7M33) and was partially funded by Kaohsiung Medical University Hospital, Kaohsiung, Taiwan (KMUH110-0R74).

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