

Evaluation of mandibular volume classified by vertical skeletal dimensions with cone-beam computed tomography

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ABSTRACT

Objective: To investigate the relationship between anteroposterior and vertical differences in maxillofacial morphology and mandibular volume.

Materials and Methods: Subjects comprised 213 Japanese adults (84 males and 129 females) who were divided into three groups based on mandibular basal arch (ANB) and Wits, measured in a cephalometric analysis: Class I ($-1^\circ \leq \text{ANB} < 4^\circ$, $-1 \text{ mm} \leq \text{Wits} < 0 \text{ mm}$), Class II ($\text{ANB} \geq 4^\circ$, $\text{Wits} \geq 0$), and Class III ($\text{ANB} < -1^\circ$, $\text{Wits} < -1 \text{ mm}$). Subjects were also divided into three groups based on the mandibular plane angle (Mp), as follows: hypodivergent ($\text{Mp} < 23^\circ$), normodivergent ($\text{Mp} = 23\text{--}30^\circ$), and hyperdivergent ($\text{Mp} > 30^\circ$) groups. Mandibular volume was measured from cone-beam computed tomographic images that were analyzed using AnalyzeTM image processing software and compared among the three groups in each classification.

Results: No significant differences were noted in mandibular volume among Classes I, II, and III. An inverse relationship was found between mandibular volume and Mp, and a significant difference was noted in mandibular volume between the hypodivergent and hyperdivergent groups.

Conclusions: In addition to two-dimensional analysis, such as lateral cephalometry, three-dimensional information such as volume, provided by cone-beam computed tomography, contributes to a more detailed assessment of maxillofacial morphology. (*Angle Orthod.* 2016;86:949–954.)

KEY WORDS: Cone-beam computed tomography; Mandibular volume; Maxillofacial morphology; Skeletal pattern

INTRODUCTION

In clinical orthodontics, it is important to predict the growth of craniomaxillofacial morphology.¹ Previous studies have identified environmental factors, such as persistent habits² and functional malocclusion,³ as

factors influencing craniomaxillofacial size and morphology. However, similarities in craniomaxillofacial morphological growth patterns within a family¹ and the racial characteristics of maxillofacial morphology⁴ demonstrate that genetic factors also play a role. Craniomaxillofacial morphology is therefore influenced by various factors, including environmental and genetic factors.⁵

In previous craniomaxillofacial morphometric studies, skeletal abnormalities were evaluated by measuring angles and distances using lateral cephalograms.⁶ However, since the two-dimensional (2D) information provided by cephalograms is limited,⁷ a three-dimensional (3D) analysis using 3D computed tomography (CT) is now performed.⁸ However, the application range of previous CT is also limited by low vertical resolution and high radiation doses. Cone-beam CT (CBCT) is now used not only for craniomaxillofacial analysis but also in the evaluation and simulation of 3D orthodontic-orthopedic treatment⁹ and implant treatment¹⁰ because of its high resolution in a longitudinal direction¹¹ and low radiation dose.¹²

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Although a large number of studies using CBCT have been performed, few have conducted a 3D analysis of maxillofacial morphology based on skeletal classifications.^{8,13,14} Nair et al.⁸ previously examined 30 patients with skeletal Class II malocclusion who were classified into hyperdivergent and hypodivergent groups; the volume of the maxilla and mandible were investigated, but no significant differences were noted. However, the upper/lower jaw bone ratio was significantly smaller in the hyperdivergent group.⁸ It was concluded that a small mandibular volume is more closely related than a small maxillary volume to the hyperdivergent group,⁸ suggesting a relationship between vertical maxillofacial morphology and mandibular volume.¹⁵

The objective of the present study was to investigate the relationship between the characteristics of craniomaxillofacial morphology from cephalometry and quantitative characteristics of the mandible calculated from CBCT images.

MATERIALS AND METHODS

Subjects comprised 213 Japanese adults (84 males; mean age, 26.9 ± 7.7 years, 129 females; mean age 27.3 ± 10.2 years) who visited the Department of Orthodontics, Showa University Dental Hospital, and gave consent to participate in this study. Subjects with congenital and systemic diseases were excluded. Cephalometry and CBCT were used to measure craniomaxillofacial morphology. Subjects from a previous study (58 males and 60 females, 115 in total)¹⁴ were included. This study was performed after approval was obtained from the Ethics Committee of Showa University Dental Hospital and related committees.

To measure craniomaxillofacial morphology, lateral cephalograms were traced and Power Cephalo software was used for measurements (ReazaNet, Tokyo, Japan). Lateral cephalograms were used to perform the craniofacial measurements (SNA [°], SNB [°], ANB [°], FH-MP [°], Wits [mm], Co-Gn [mm], Co-Go [mm], and Go-Mn [mm]) (Figure 1).

Maxillofacial morphology was classified, based on ANB and Wits, into skeletal Class I ($-1^\circ \leq \text{ANB} < 4^\circ$; 32 males, 50 females, $-1 \text{ mm} \leq \text{Wits} < 0 \text{ mm}$; 0 males, 0 females), Class II ($\text{ANB} \geq 4^\circ$; 25 males, 45 females, $\text{Wits} \geq 0$; 39 males, 71 females), and Class III ($\text{ANB} < -1^\circ$; 27 males, 34 females, $\text{Wits} < -1 \text{ mm}$; 45 males, 58 females).¹⁶ Maxillofacial morphology was also classified based on mandibular plane angle (Mp) into a hypodivergent group ($\text{Mp} < 23^\circ$; 16 males, 16 females), a normodivergent group ($\text{Mp} = 23\text{--}30^\circ$; 39 males, 48 females), and a hyperdivergent group ($\text{Mp} > 30^\circ$; 29 males, 65 females).¹⁷

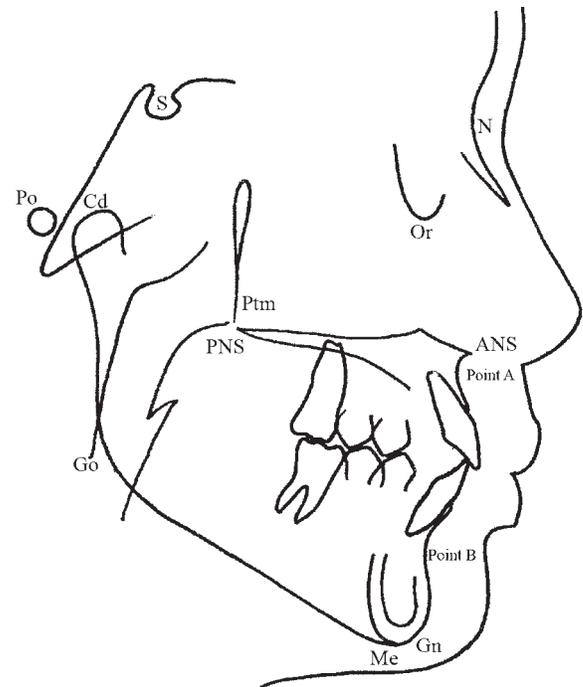


Figure 1. Craniofacial measurements performed on lateral cephalograms (SNA [°], SNB [°], ANB [°], FH-MP [°], Wits [mm], Co-Gn [mm], Co-Go [mm], and Go-Mn [mm]).

Images were acquired using a dental cone-beam X-ray CT scanner (CB MercuRay, Hitachi Medico Technology, Tokyo, Japan) and KaVo 3DeXam (KaVo, Biberach, Germany) installed in the Department of Radiology of the university hospital. Volume was measured following the method reported by Katayama et al.¹⁴ The mandible was extracted from the image data obtained and analyzed using Analyze™ 3D reconstruction software (Biomedical Imaging Resource, Mayo Clinic and Foundation, Rochester, Minn). Mandibular volume was measured by autotracing the outer circumference of the cortical bone in all slides using Analyze™. These autotraces were superimposed to prepare an object map for volume measurements (Figure 2). Dental crown data were extracted separately from those of the mandible because they are affected by artifacts, such as prostheses.



Figure 2. Automated volume evaluation performed using Analyze image processing software. L indicates autotracing of the outer circumference of the cortical bone; R, the object map created for the measurement of mandibular volume.

Table 1. Means and Standard Deviations (SDs) of the Measurements from Cone-Beam Computed Tomography (CBCT) and Lateral Cephalogram Analysis

	Males (n = 84)		Females (n = 129)	
	Mean ± SD	Range	Mean ± SD	Range
Mandibular volume, mm ³	67,243.6 ± 17,484.4	40,048.2 to 96,340.3	56,639.4 ± 9366.1	33,517.7 to 85,793.7
Class I (ANB), mm ³	65,333.2 ± 12,567.3	45,935.7 to 96,340.3	56,488.2 ± 9309.6	33,517.7 to 82,991.5
Class II (ANB), mm ³	66,922.7 ± 8928.4	50,996.2 to 79,565.7	57,492.1 ± 10,019.9	39,907.5 to 85,793.7
Class III (ANB), mm ³	60,681.3 ± 9198.8	40,048.2 to 92,396.7	55,733.1 ± 8708.2	41,186.0 to 78,220.6
Class II (Wits), mm ³	64,475.7 ± 9198.9	45,935.7 to 96,340.3	56,853.8 ± 9617.5	33,517.7 to 85,793.7
Class III (Wits), mm ³	62,782.9 ± 11,193.9	40,048.2 to 92,396.7	56,194.1 ± 9266.4	41,186.3 to 81,436.1
Hypodivergent, mm ³	71,540.9 ± 14,099.6	51,524.6 to 96,340.3	59,625.6 ± 9303.8	44,335.6 to 81,436.0
Normodivergent, mm ³	63,301.7 ± 10,230.0	40,048.2 to 79,565.7	58,364.0 ± 10,558.4	33,517.7 to 85,793.6
Hyperdivergent, mm ³	64,117.4 ± 10,246.8	46,133.7 to 80,568.2	54,630.8 ± 8045.7	39,799.2 to 72,183.3
SNB, °	81.0 ± 5.5	69.1 to 96.2	79.0 ± 4.7	67.0 to 90.3
ANB, °	1.1 ± 4.4	-10.3 to 9.8	1.9 ± 4.1	-12.4 to 9.9
Wits, mm	-1.7 ± 9.0	-27.6 to 11.1	1.3 ± 7.8	-22.1 to 13.8
Mandibular plane angle, °	27.8 ± 5.9	10.2 to 41.2	30.2 ± 6.6	13.9 to 48.2

Mandibular volume was evaluated based on the difference between ANB and SNB in each group using the Kruskal-Wallis test. Mandibular volumes were then compared among the three groups using a one-way analysis. Because a significant difference was noted, between-group comparisons were performed using the Student's *t*-test. The relationship between mandibular measurement items and volume was investigated using a simple regression analysis and Pearson's correlation coefficient test. All statistical analysis was performed using Statcel2 statistical analysis software (OMS Publishing, Saitama, Japan), with the significance level set at 5%. Errors were tested using Dahlberg's formula.

The statistical power and the effect size were calculated using the G*Power Version 3.1.9.2 program (<http://www.softpedia.com/get/Science-CAD/G-Power.shtml>).

RESULTS

Because two CT systems were used, differences in measurements were investigated. An aluminum bar (30 × 30 × 100.5 mm) was imaged three times using CB MercuRay and KaVo 3DeXam. Errors in the volume measured by CB MercuRay and KaVo 3DeXam from the actual volume of the bar were -0.37% and -0.36%, respectively, but were not significant based on the significance level of 5%. Accordingly, it was not necessary to calibrate the volume measured using the CB MercuRay and KaVo 3DeXam. The means, standard deviations, and maximum and minimum values of the cephalometric and CBCT measurement parameters are shown in Table 1.

Table 2 shows the means, standard deviations, and maximum and minimum angles of ANB, SNB, and SNA in each group. No significant differences were noted in any parameter among the groups in either males or females ($P > .05$).

Figure 3 shows comparisons of mandibular volume among the ANB-based group and among the Wits-based group. No significant differences were noted in either sex ($P > .05$).

Figure 4 shows comparisons of mandibular volume among the Mp-based groups. A significant difference was noted in mandibular volume between the hyperdivergent and hypodivergent groups in males ($P = .048$) and females ($P = .034$). Mandibular volume was large in the hypodivergent group and small in the hyperdivergent group.

Table 3 shows the relationship between maxillofacial morphology and mandibular volume. An inverse relationship was found between mandibular volume and Mp in both sexes, and this difference was significant in females ($r = 0.25$, $P = .003$).

The statistical power was calculated as 0.47 in males and 0.52 in females.

DISCUSSION

The objective of the present study was to classify maxillofacial morphology based on information provided by conventional lateral cephalograms and to compare these with the mandibular volume from CBCT among the classified groups. Katayama et al.¹⁴ previously classified maxillofacial morphology horizontally (ie, based on ANB) into Classes I, II, and III and investigated mandibular volume; however, no significant differences were noted among the groups. In the present study, we increased the sample number by an approximately twofold measure, performed a similar investigation, and the results obtained were reproduced. In contrast, an inverse relationship was noted between Mp and mandibular volume. Maxillofacial morphology was vertically classified based on Mp into hypodivergent, normodivergent, and hyperdivergent groups, and mandibular volume was compared among

Table 2. Means and Standard Deviations (SDs) of the Lateral Cephalogram Analysis between Vertically and Horizontally Classified

ANB	Males (n = 84)		Females (n = 129)	
	Mean ± SD	Range	Mean ± SD	Range
Hypodivergent, °	-0.2 ± 5.0	-10.3 to 7.5	0.7 ± 3.9	-5.3 to 6.6
Normodivergent, °	0.3 ± 3.9	-5.5 to 8.6	0.8 ± 3.2	-8.6 to 6.1
Hyperdivergent, °	2.7 ± 4.1	-7.3 to 9.8	2.9 ± 4.5	-12.4 to 9.9
Class I, °	1.4 ± 1.3	-0.9 to 3.9	1.5 ± 1.5	-1.0 to 4.0
Class II, °	6.3 ± 1.7	4.1 to 9.9	6.2 ± 1.5	4.1 to 9.9
Class III, °	-3.9 ± 2.4	-10.3 to -1.0	-3.4 ± 2.6	-12.4 to -1.1
SNA				
Hypodivergent, °	82.9 ± 3.8	74.1 to 88.6	82.2 ± 3.5	74.9 to 87.8
Normodivergent, °	82.4 ± 3.6	74.6 to 90.2	81.7 ± 3.6	72.9 to 89.7
Hyperdivergent, °	81.5 ± 3.6	74.5 to 87.4	79.8 ± 4.1	71.9 to 90.8
Class I, °	80.7 ± 3.9	74.6 to 90.2	80.9 ± 4.3	72.0 to 89.8
Class II, °	82.5 ± 3.4	74.5 to 87.4	82.2 ± 3.5	73.9 to 90.9
Class III, °	82.0 ± 4.1	74.1 to 88.3	79.1 ± 3.4	72.2 to 86.1
SNB				
Hypodivergent, °	83.1 ± 5.5	75.9 to 96.2	81.5 ± 3.4	76.8 to 88.6
Normodivergent, °	81.9 ± 5.4	72.1 to 91.9	81.1 ± 4.2	72.5 to 90.3
Hyperdivergent, °	78.7 ± 5.0	69.2 to 87.8	76.9 ± 4.4	67.0 to 88.5
Class I, °	80.7 ± 3.9	72.2 to 91.1	79.5 ± 4.9	90.3 to 68.2
Class II, °	76.2 ± 3.6	69.2 to 82.2	76.2 ± 3.4	67.0 to 83.6
Class III, °	86.1 ± 4.2	78.2 to 96.2	82.5 ± 3.5	74.1 to 89.4
Wits				
Hypodivergent, mm	5.8 ± 5.3	0.6 to 17.6	5.3 ± 4.9	0.4 to 15.6
Normodivergent, mm	7.8 ± 5.0	0.2 to 18.5	6.1 ± 4.3	0.5 to 18.0
Hyperdivergent, mm	7.8 ± 6.2	0.2 to 27.6	6.1 ± 5.4	0.1 to 22.1
Class I, mm	5.5 ± 3.6	0.5 to 15.1	4.9 ± 3.5	0.2 to 13.7
Class I, mm	4.2 ± 3.2	0.2 to 11.1	3.0 ± 2.9	0.1 to 13.8
Class III, mm	12.9 ± 5.2	3.7 to 27.6	11.5 ± 4.6	2.3 to 22.1

these groups. This volume was small in the hyperdivergent group and large in the hypodivergent group.

Mandibular volume was measured by tracing the outer circumference of the mandibular cortical bone in CBCT images. The mean mandibular volume was 67.2 cm³ in males and 56.6 cm³ in females. Hashiba¹⁸ and Veli et al.¹⁹ reported that this volume was 51.6–60.0 cm³, whereas it was 35.6–48.0 cm³ in females in measurements performed by Nair et al.⁸ and Deguchi et al.,¹³ showing variations among researchers. A threshold was set in previous studies,^{8,13} and mandibular volume was measured based on these specific

thresholds. The voxel values of CBCT cannot be used as absolute values to determine bone density, unlike CT values, and, thus, these values are used here as relative values.²⁰ Difficulties are associated with extracting a specific bone with low bone density from a region containing several bones, such as the head of the mandible;²¹ therefore, the threshold needs to be changed for extraction.²² We set a threshold in all slides to clarify the boundary between soft tissue and cortical bone and traced the outer circumference of the cortical bone.²² Thus, mandibular volume was measured accurately.

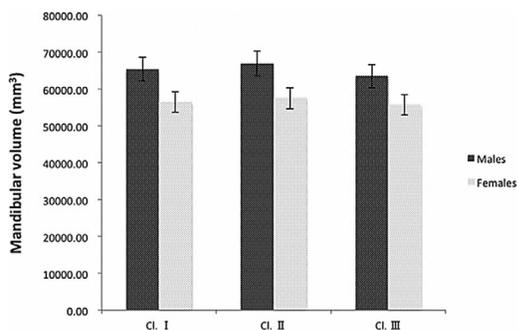


Figure 3. Mandibular volume in three groups (Classes I, II, and III) presented by gender. Volume is presented in mm³. Error bars represent standard deviations.

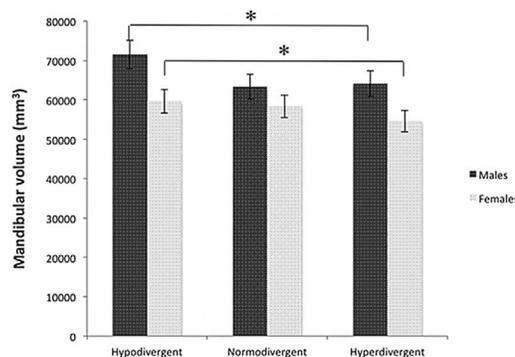


Figure 4. Mandibular volume in three groups (hypodivergent, normodivergent, and hyperdivergent groups) presented by gender. Volume is presented in mm³. Error bars represent standard deviations. **P* < .05.

Table 3. Regression Analyses Between Craniomaxillofacial Morphology and Volume

	Males		Females	
	<i>r</i>	<i>P</i> -Value	<i>r</i>	<i>P</i> -Value
SNA	0.03	.76	0.20	.07
SNB	0.06	.53	0.14	.09
ANB	0.17	.10	0.03	.71
WITS	0.13	.27	0.01	.94
Mp	0.16	.13	0.25	.003**
Co-Gn	0.02	.83	0.30	.0005**
Go-Me	0.21	.06	0.09	.26
Co-Go	0.06	.60	0.29	.0008**

***P* < .01

In a previous study²³ examining the mandibular volume in patients affected by unilateral and bilateral cleft lip and palate, the mandibular volume was found to be positively correlated with Co-Gn and Co-Go and negatively correlated with SNB and Sn-Mp. In another previous study,⁸ patients with skeletal Class II malocclusion were classified into hypodivergent and hyperdivergent groups and the upper and lower jaw bone volume was investigated. No significant differences were observed in these volumes between the groups; however, a significant difference was noted in the upper/lower jaw bone ratio. Subjects in the present study were not limited to patients with skeletal Class II malocclusion; they were classified into the hypodivergent, normodivergent, and hyperdivergent groups. Mandibular volume was compared among the groups, and no significant differences were noted in ANB, SNA, and SNB. Although the workload was large, accurate measurements were performed by tracing the outer circumference of the cortical bone and its 3D reconstruction. Maxillary volume was not included in the evaluation because the maxilla is a part of the craniofacial complex and has an intricate shape.²⁴

Masseter volume,²⁵ occlusal force,²⁶ and fiber type²⁵ differ between hyperdivergent and hypodivergent groups. The hyperdivergent skeletal pattern presents poor muscle activity,⁸ and this induces excess molar eruption and weaker inhibition of periosteal bone apposition in the angular region, which is associated with the vertical growth of maxillofacial morphology.²⁷ Because an inverse relationship has been reported between vertical facial morphology and masseter length,²⁸ the masticatory muscles have a strong influence on vertical maxillofacial morphology,²⁹ resulting in a thicker alveolar ridge and cortical bone³⁰ in the hyperdivergent group than in the hypodivergent group. The differences observed in mandibular volume between the hypodivergent and hyperdivergent groups may be due to the alveolar ridge and cortical bone thickness.

Sex differences have been identified in most human skeletal bones;³¹ these differences are marked in the

skull and largest in the mandible.^{32,33} In the present study, mandibular volume was $67,243.6 \pm 17,484.4 \text{ mm}^3$ in males and $56,639.4 \pm 9366.1 \text{ mm}^3$ in females, reflecting a significant difference ($P = .000$). Mandibular remodeling and morphology vary depending on the occlusal force level, and this may be one cause of this sex difference.³³ Previous studies reported that differences in masticatory muscle volume reflect skeletal differences³⁴ and that changes in occlusal force alter mandibular morphology and size.³⁵ The examination of the association between the mandibular volume and functional components, such as airway obstruction and masticatory muscles, might prove meaningful in future studies.

Lateral cephalograms have been used to predict the growth of craniomaxillofacial morphology and to evaluate treatment outcomes;³⁶ however, an accurate evaluation of maxillofacial morphology using a 2D analysis of lateral cephalograms is difficult because of differences in magnification and flexion rates.³⁷ Morphology that cannot be evaluated by a 2D analysis may be assessed by a 3D analysis using CBCT and lateral cephalograms.⁸ Previous studies^{8,13} that measured mandibular volume only examined 20–30 patients. To the best of our knowledge, the present study measured mandibular volume in the largest number of subjects. The addition of an evaluation of the maxilla may lead to a more detailed elucidation of maxillofacial morphology, thereby contributing to clinical knowledge.

CONCLUSIONS

- No significant differences were observed in mandibular volume among skeletal Classes I ($-1^\circ \leq \text{ANB} < 4^\circ$), II ($\text{ANB} \geq 4^\circ$), and III ($\text{ANB} < -1^\circ$), supporting the findings of a previous study.
- A significant difference was noted in mandibular volume among the hypodivergent ($\text{Mp} < 23^\circ$), normodivergent ($\text{Mp} = 23\text{--}30^\circ$), and hyperdivergent ($\text{Mp} > 30^\circ$) groups.
- An inverse relationship was noted between mandibular volume and Mp.

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