Original Article

Use of a novel body mandibular plane (mental foramen–protuberance menti) in analyzing mandibular asymmetry compared with conventional border mandibular plane

Ho-Jin Kim[a]; Hyung-Kyu Noh[a]; Hyo-Sang Park[b]

ABSTRACT

Objectives: To compare a novel body mandibular horizontal plane (mental foramen–protuberance menti; Body-MHP) with the conventional border mandibular horizontal plane (gonion–menton [Me]; Border-MHP) to assess mandibular body inclination and dental compensation of skeletal Class III patients with and without facial asymmetry.

Materials and Methods: Retrospective data obtained from diagnostic cone-beam computed tomography of 90 skeletal Class III patients (mean age, 21.67 $\pm$ 2.93 years; range, 15.0–30.6 years) were divided into symmetry ($n = 30$) and asymmetry groups ($n = 60$). The asymmetry group was subdivided into roll ($n = 30$) and non-roll types ($n = 30$). The differences in body inclination and dental measurements (distance and angle) according to two mandibular planes (Body-MHP and Border-MHP) were assessed in the groups and subgroups.

Results: Mandibular body inclinations relative to the Body-MHP were not different in the roll-type asymmetric mandible between the sides, while those relative to the Border-MHP were different ($P < .001$). For the mandibular first molar positions relative to the Border-MHP, the differences in vertical distance between the sides were undermeasured and the inclination differences were overmeasured when compared relative to the Body-MHP.

Conclusions: The Body-MHP demonstrated better bilateral similarity in body inclination compared with the Border-MHP in patients with roll-type facial asymmetry. The novel body mandibular plane ensures an accurate diagnosis for tooth movement and jaw surgery, particularly in the roll-type asymmetric mandible. (*Angle Orthod.* 2023;93:195–204.)

KEY WORDS: Mandibular horizontal plane; Facial asymmetry; Roll type; CBCT

INTRODUCTION

Recently, cone-beam computed tomography (CBCT) has been broadly used for orthodontic diagnosis to yield valuable three-dimensional (3D) data, especially for patients who require orthognathic surgery.[1–3] During CBCT analysis, well-established reference planes using appropriate landmarks of stable structures are necessary to improve the reliability and reproducibility of the diagnosis.[4,5]

Proper positioning of the mandible is of utmost importance for successful orthognathic corrections in patients with facial asymmetry.[6] In most instances, the mandible in facial asymmetry patients tends to have distortion,[7,8] which causes difficulty in positioning the mandible into a symmetric position. The mandibular horizontal plane commonly used in previous research studies[9,10] was constructed by the gonion (Go) and menton (Me) points because of the simplicity and ease of construction. However, those landmarks are affected by secondary compensating bone changes during mandibular growth and modeling.[11,12] When performed with this reference plane, mandibular surgery for facial asymmetry may retain some asymmetry in the position and buccolingual inclination of the teeth or mandibular body.

As the bone adjacent to the mandibular canal is less variable during bone modeling,[11,12] the mental foramen

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(MF) is considered a stable landmark with high precision, presenting good reproducibility in identification in earlier studies.[13–15] Thus, this landmark was suggested as an alternative for the reliable mandibular horizontal plane.[4] Using this stable structure the mandibular plane may have less variability and influence from bone modeling and compensation during asymmetric growth. For this reason, this CBCT study aimed to compare a novel mandibular horizontal plane (using the MF and protuberance menti [PM] points) with the conventional border mandibular horizontal plane (using the Go and Me points) to assess mandibular body inclination and tooth linear/angular measurements in the symmetric and asymmetric mandibles of skeletal Class III patients. The null hypothesis was that there would be no significant differences in body inclination and dental compensation between the two mandibular planes.

MATERIALS AND METHODS

Study Samples

This retrospective study received approval from the institutional review board of Kyungpook National University Dental Hospital (institutional review board No. KNUDH-2021-07-02-00).

The sample size was calculated from the dental linear variables of a previous CBCT study[4] investigating skeletal and dental measurements in patients with facial asymmetry using G*power (version 3.1.9.7; Heinrich Heine University of Düsseldorf, Düsseldorf, Germany). The necessary sample size was at least 29 patients in each group, with a test power of 0.80 (two-sided significance level of .05) and an effect size of 0.75. Therefore, to increase the power, a sample of 30 patients was included for each group or subgroup in this study.

The asymmetry group comprised 60 patients (45 males, 15 females; mean age, 22.31 $\pm$ 3.71 years; range, 15–29.2 years) with moderate to severe facial asymmetry (menton deviation $>$ 4 mm, relative to the midsagittal plane) who were diagnosed in the Department of Orthodontics at Kyungpook National University Dental Hospital in Daegu, Korea, between January 2010 and December 2020. To compare the two mandibular planes according to the asymmetry type of the mandible, the asymmetry group was divided into two subgroups based on the difference in ramus height between the nondeviated (NDv) and deviated (Dv) sides (ΔNDv–Dv; subtracting the value of Dv from that of NDv): roll type (side-to-side difference in ramus height of $>$3 mm) and non-roll type (side-to-side difference in ramus height of $<$1.5 mm). The sample size of each subgroup was determined to be 30 participants. Thirty patients (17 males, 13 females; mean age, 21.34 $\pm$ 2.42 years; range, 16.6–30.6 years) with $<$2-mm menton deviation (relative to the midsagittal plane) were included in the symmetry group.

The inclusion criteria in all samples were the following: skeletal Class III relationship (ANB $<$ 0°), no prosthetic crowns and/or implants, no congenitally missing teeth, no spacing, and tooth size–arch length discrepancy $<$ 3 mm. The exclusion criteria included a history of previous orthodontic treatment or orthognathic surgery or craniofacial disorder/trauma.

Data Acquisition and Measurements

Diagnostic CBCT data were acquired using a dental computed tomography scanner, CB MercuRay (Hitachi, Osaka, Japan; 120 kVp, 15 mA, 19-cm field of view, 0.377-mm voxel size, 9.6-second scan time). The CBCT data were exported and reconstructed to 3D images using Invivo 5 Anatomy imaging software (Anatomage Inc, San Jose, Calif).

Table 1 and Figure 1 describe all landmarks and reference planes used in this study. The midsagittal and Frankfort horizontal (FH) planes were used as reference planes of the cranium.[4] For the mandible, two horizontal planes were constructed: the conventional border mandibular horizontal plane (Border-MHP), using Go and Me, and the novel body mandibular horizontal plane (Body-MHP), using MF and PM.

Skeletal variables were measured and differences in the variables between the sides (ΔNDv–Dv) were calculated (Table 2; Figure 2). To evaluate body morphologic similarities, body inclinations relative to each mandibular plane were measured and compared between the sides (Figure 3).

Regarding the mandibular dental variables (Table 2; Figure 4), the vertical distance and axial inclination of the canine and first molar, relative to the Border-MHP or Body-MHP, were measured to assess the dental compensation in the groups.

Cephalometric measurements were acquired to evaluate the sagittal (SNA, SNB, and ANB) and vertical skeletal relationships (FMA, FH plane to mandibular plane angle) of the groups (Table 3).

Statistical Analysis

A single investigator (HJK) measured all variables, which were remeasured for 15 randomly selected patients at an interval of 4 weeks. The intraclass correlation coefficient was 0.987 (mean; range, 0.967–0.995), indicating high reliability. According to Dahlberg's formula, the method error value was 0.55 mm (mean; range, 0.09–1.56 mm) in the linear measure-

Table 1. Definitions of Landmarks and Reference Planes[a]

Landmark	Definition
Cg	The superior-most point on the crista galli
Op	The middle point of the posterior border of the foramen magnum
Or	The inferior-most point of the lower orbital margin
Po	The superior-most point of the external auditory meatus
Me	The inferior-most point on the symphyseal outline
Go	The inferior-most point of gonial angle on the lateral view
MF	The inferior-most point of the mental foramen
PM	The point where the curvature changes from concave to convex on the anterior-most symphyseal border
Cd	The superior-most point of the condylar head
LM	The central fossa of the mandibular first molar
LM_axis	The long axis of the mandibular first molar, passing by the LM and midpoint of root furcation
LM_mid	The midpoint between the LM of both sides
LC	The cusp tip of the mandibular canine
LC_axis	The long axis of the mandibular canine, passing by the LC and root apex
LI_mid	The midpoint between the mandibular central incisor edges of both sides
Body_mid	The midpoint between the outermost points of the buccal and lingual body outline at the first molar apex level (on the section view of the mandibular frontal plane at LM)
Body_inf	The inferior-most point of the inner cortical line of the body (on the section view of the mandibular frontal plane at LM)

Reference Plane	Definition
Frankfort horizontal (FH) plane	The plane passing by bilateral Po and right Or
Midsagittal plane	The plane passing by Cg and Op, perpendicular to the FH plane
Conventional border mandibular horizontal plane (Border-MHP)	The plane passing by bilateral Go and Me
Conventional border mandibular frontal plane (Border-MFP)	The plane passing by bilateral Go, perpendicular to the Border-MHP
New body mandibular horizontal plane (Body-MHP)	The plane passing by bilateral MF and PM
New body mandibular frontal plane (Body-MFP)	The plane passing by bilateral MF, perpendicular to the Body-MHP
Mandibular occlusal plane	The plane passing by LI_mid and bilateral LM
Mandibular frontal plane at LM	The plane passing by bilateral LM, perpendicular to the mandibular occlusal plane

[a] Cg, crista galli; Op, opisthion; Or, orbitale; Po, porion; Me, menton; Go, gonion; MF, mental foramen; PM, protuberance menti; and Cd, condylion.

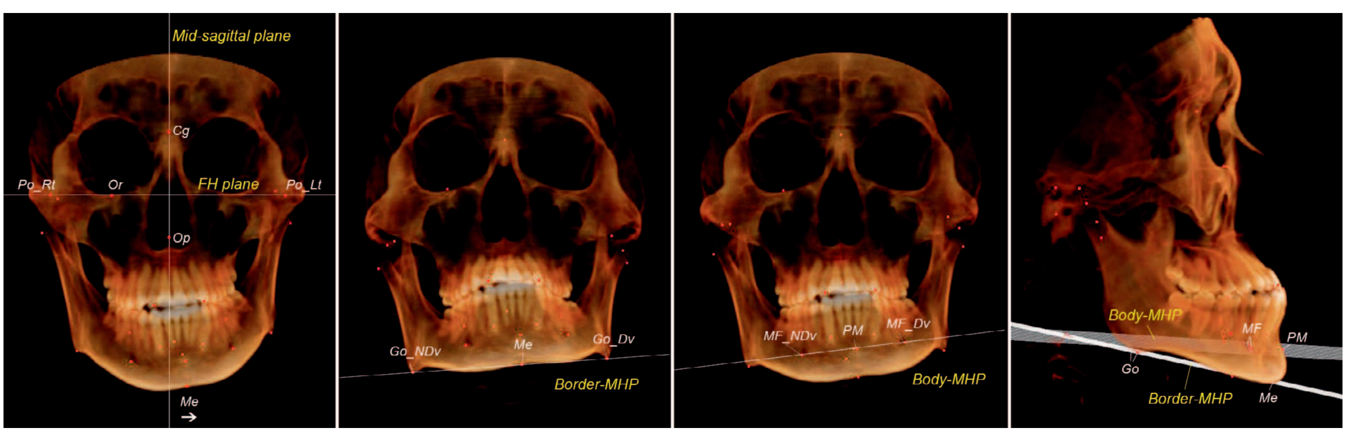

Figure 1. Landmarks and reference planes. Cg, crista galli; Op, opisthion; Or, orbitale; Po, porion; Me, menton; Go, gonion; Dv, deviated side; NDv, nondeviated side; MF, mental foramen; PM, protuberance menti; FH, Frankfort horizontal; Border-MHP, mandibular horizontal plane using bilateral Go and Me; Body-MHP, mandibular horizontal plane using bilateral MF and PM.

Table 2. Definitions of Skeletal and Dental Measurements[a]

Skeletal Measurement	Definition
Menton deviation	The distance between Me and midsagittal plane
Body length	The distance between Me and Go
Ramus height	The distance between Go and Cd
Body inclination	The angle between the body axial line (Body_mid-Body_inf) and Border-MHP or Body-MHP, projected on the mandibular frontal plane at LM
Ramus inclination	The angle between the ramus axial line (Cd-Go) and midsagittal plane
Go to Body-MHP	The distance between the Go and Body-MHP
Dental Measurement	**Definition**
LC to Border-MHP	The distance between the LC and Border-MHP
LC to Body-MHP	The distance between the LC and Body-MHP
LM to Border-MHP	The distance between the LM and Border-MHP
LM to Body-MHP	The distance between the LM and Body-MHP
∠LC_axis to Border-MHP	The angle between the LC_axis and Border-MHP, projected on Border-MFP
∠LC_axis to Body-MHP	The angle between the LC_axis and Body-MHP, projected on Body-MFP
∠LM_axis to Border-MHP	The angle between the LM_axis and Border-MHP, projected on Border-MFP
∠LM_axis to Body-MHP	The angle between the LM_axis and Body-MHP, projected on Body-MFP

[a] MF, mental foramen; PM, protuberance menti; Go, gonion; Me, menton; Cd, condylion; Body_mid, middle point of body; Body_inf, inferior point of body; LC, cusp tip of the mandibular canine; LC_axis, long axis of the mandibular canine; LM, central fossa of mandibular first molar; LM_axis, long axis of mandibular first molar; FH plane, Frankfort horizontal plane; Border-MHP, Border mandibular horizontal plane using Go and Me; Body-MHP, Body mandibular horizontal plane using MF and PM; Border-MFP, mandibular frontal plane perpendicular to Border-MHP; and Body-MFP, mandibular frontal plane perpendicular to Body-MHP.

ments and 0.66° (mean; range, 0.14–1.86°) in the angular measurements.

After confirming the normality of data with the Kolmogorov-Smirnov test, an independent *t*-test was conducted to compare the variables between groups. A chi-square test was used to compare the sex distribution of the sample between the groups. A comparison between the two reference planes or variables at Dv and NDv was performed within each group using a paired *t*-test. The statistical significance of all measurements was set at $P < .05$. SPSS statistical software (version 22; IBM, Chicago, Ill) was used.

RESULTS

Sample Distribution and Cephalometric and CBCT Skeletal Measurements in the Studied Groups

As described in Table 3, there were no significant differences in age and sex distribution of the sample or in any cephalometric measurement for sagittal and vertical skeletal relationships between the symmetry and asymmetry groups and between roll and non-roll type groups. There was a significant difference in the mean value of Me deviation between the symmetry and asymmetry groups ($P < .001$; symmetry group, 1.06 mm; asymmetry group, 7.90 mm) (Table 4). The asymmetry group showed a significant difference in all skeletal measurements between the Dv and NDv ($P < .001$), whereas the symmetry group did not.

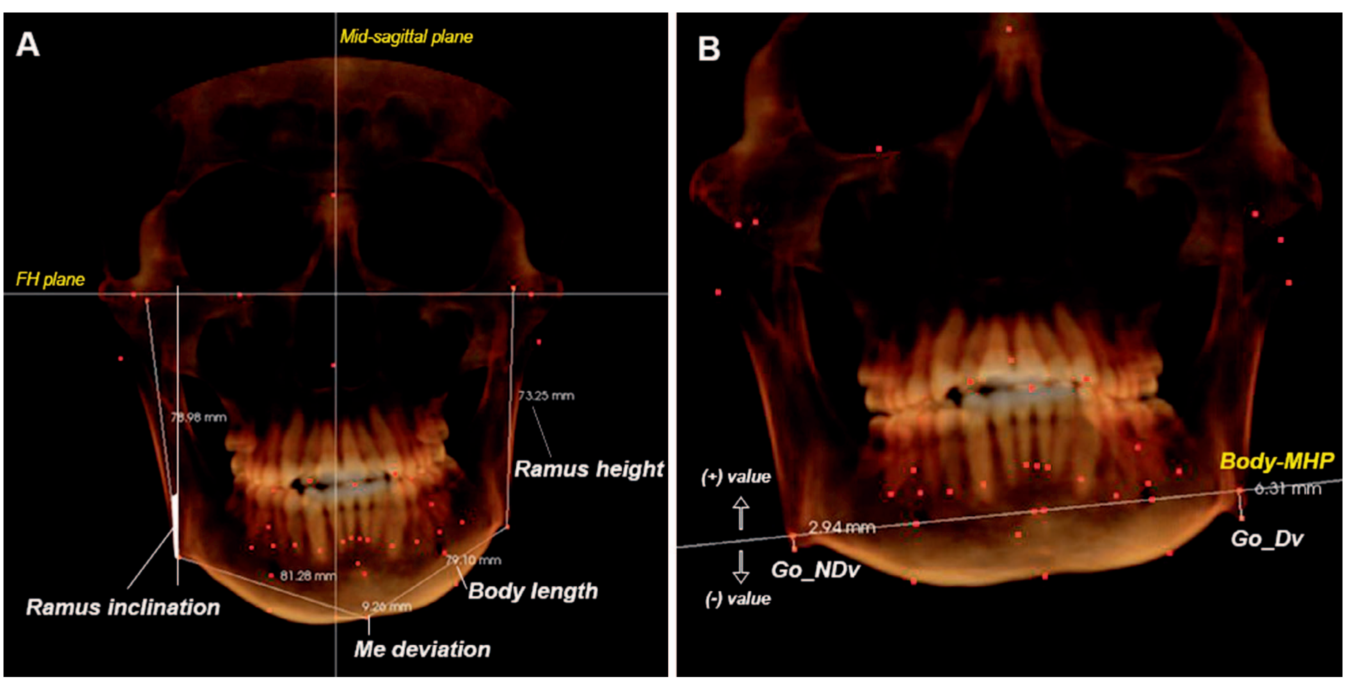

Figure 2. (A) Skeletal measurements. (B) Distance between the Go and Body-MHP. FH, Frankfort horizontal; Go, gonion; Dv, deviated side; NDv, nondeviated side; Body-MHP, mandibular horizontal plane using mental foramen and protuberance menti.

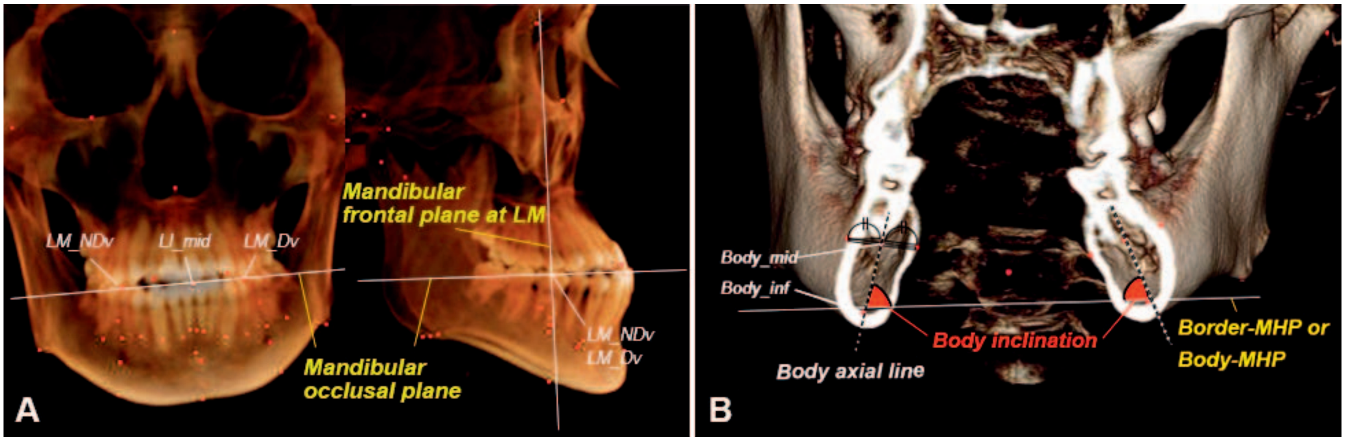

Figure 3. Body inclination measurements. (A) Construction of mandibular occlusal plane and mandibular frontal plane at LM. (B) Illustration of body inclination to the mandibular planes (coronal-sectioned view by the mandibular frontal plane at LM). LM, central fossa of the mandibular first molar; Dv, deviated side; NDv, nondeviated side; LI_mid, midpoint of the mandibular central incisor edges of both sides; Body_mid, midpoint of buccal and lingual body outlines at the first molar apex level; Body_inf, inferior-most point of the inner cortical line of the body.

In comparing the skeletal measurements between the roll and non-roll type groups (Table 5), a significant difference in ΔNDv–Dv of ramus height was observed ($P < .001$). No differences were observed in other skeletal measurements or in the mean value of Me deviation.

Skeletal and Dental Measurements Based on the Border-MHP or Body-MHP in Symmetry and Asymmetry Groups (Table 6)

In the symmetry group, the mandibular body inclinations relative to each mandibular plane did not show significant differences between the planes or the sides. In the asymmetry group, both planes demonstrated a significant difference in body inclination between the sides ($P < .001$); the amount of difference in the bilateral body inclinations (ΔNDv–Dv) to the Border-MHP (3.93°) was significantly greater than that to the Body-MHP (1.41°; $P < .001$). The Go distance to the Body-MHP in the asymmetry group was significantly greater at the NDv than at the Dv ($P < .001$), indicating that Go at the NDv was superiorly located relative to the Body-MHP compared to its location at the Dv.

For the linear dental measurements, none of the variables in the groups differed significantly between the planes. When comparing variables between Dv and NDv, only the distance of the mandibular canine cusp tip (LC) to the Border-MHP in the asymmetry

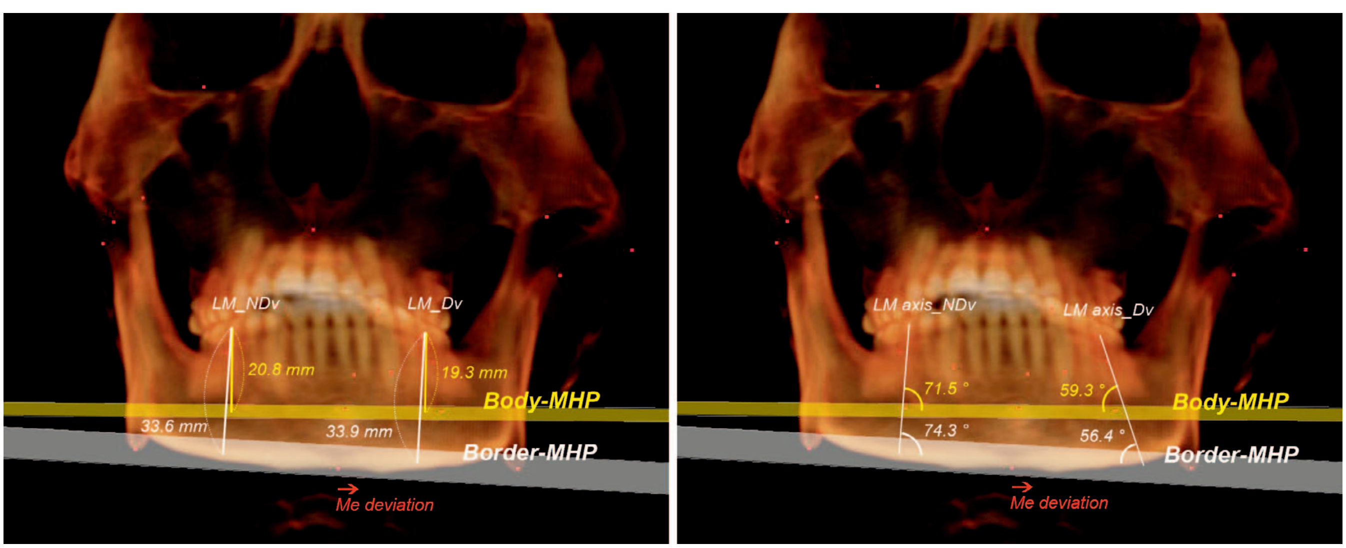

Figure 4. Dental measurements based on mandibular planes. Border-MHP, mandibular horizontal plane using gonion and menton; Body-MHP, mandibular horizontal plane using mental foramen and protuberance menti. LM, central fossa of the mandibular first molar; LM axis, long axis of the mandibular first molar; Dv, deviated side; NDv, nondeviated side.

Table 3. Sample Distribution and Cephalometric Measurements in the Symmetry and Asymmetry Groups and the Roll and Non-Roll Type Groups

	Symmetry (n = 30)	Asymmetry (n = 60)	*P*-Value	Roll Type (n = 30)	Non-Roll Type (n = 30)	*P*-Value
Sex			.077			.371
Male, n	17	45		24	21	
Female, n	13	15		6	9	
Age, y	21.34 ± 2.42	22.31 ± 3.71	.200	21.02 ± 2.14	21.66 ± 2.67	.308
Cephalometric measurement						
SNA, °	82.57 ± 3.41	81.72 ± 2.91	.219	81.36 ± 2.99	82.08 ± 2.82	.344
SNB, °	85.67 ± 3.39	84.24 ± 3.17	.052	83.58 ± 3.23	84.91 ± 3.01	.104
ANB, °	−3.10 ± 2.33	−2.52 ± 2.04	.230	−2.21 ± 1.62	−2.83 ± 2.37	.247
FMA, °	25.02 ± 1.45	25.70 ± 5.49	.368	25.88 ± 4.66	25.52 ± 6.29	.804

[a] Note: Values are mean ± standard deviation (SD). No significant difference was found between the symmetry and asymmetry groups and between the roll and non-roll type groups.

group showed a significant difference ($P < .001$); the other variables did not.

The difference in the angular dental measurement between the mandibular planes was not significant in either the symmetry or the asymmetry group. All angular variables in the asymmetry group showed significantly greater values at NDv than at Dv ($P < .001$); however, those in the symmetry group did not.

Skeletal and Dental Measurements Based on the Border-MHP or Body-MHP in the Roll and Non-Roll Type Groups

Comparing body inclination between the sides, the Border-MHP showed a significantly greater value at the NDv than at the Dv in the roll type group (NDv, 76.98°; Dv, 72.57°; $P < .001$), whereas the Body-MHP showed no significant difference between the sides (Table 7). Therefore, the ΔNDv–Dv of body inclination to the Border-MHP was significantly greater than that to the Body-MHP (Border-MHP, 4.42°; Body-MHP, 0.90°; $P < .001$). In the non-roll type group, both planes exhibited a significant difference in the body inclination between the sides (Border-MHP, $P < .001$; Body-MHP, $P = .001$); the Border-MHP showed a greater side-to-side difference in body inclination than did the Body-MHP (ΔNDv–Dv; Border-MHP, 3.45°; Body-MHP, 1.92°), although this difference was not statistically significant ($P = .066$). The Go distance to the Body-MHP at the NDv was significantly greater than at the Dv in both type groups. In addition, the ΔNDv–Dv of this distance was significantly greater in the roll type (3.04 mm) than in the non-roll type (1.17 mm; $P = .003$).

Regarding linear dental variables to reference planes, the ΔNDv–Dv of LC and LM (central fossa of the mandibular first molar) distances to the Border-MHP (LC, −0.66 mm; LM, 0.46 mm) was significantly less than than those to the Body-MHP (LC, −0.03 mm, $P = .041$; LM, 1.48 mm, $P = .022$) in the roll-type group. Conversely, no significant difference in the linear dental measurement between the planes was observed in the non-roll type group.

Regarding the ΔNDv–Dv of the mandibular first molar inclination, the Border-MHP showed a greater mean value than did the Body-MHP (Border-MHP, 7.19°; Body-MHP, 3.35°); however, this difference was not significant ($P = .075$). In addition, the Body-MHP exhibited a significant difference in that variable between the roll and non-roll type groups ($P = .04$; roll type, 3.35°; non-roll type, 7.39°), whereas the Border-MHP did not.

Table 4. Three-Dimensional Skeletal Measurements of the Mandible in the Symmetry and Asymmetry Groups[a]

	Symmetry Group (n = 30)				Asymmetry Group (n = 60)				*P*-Value (Between the Groups)		
	Dv	NDv	ΔNDv−Dv	*P*-Value (Between the Sides)	Dv	NDv	ΔNDv−Dv	*P*-Value (Between the Sides)	Dv	NDv	ΔNDv−Dv
Me deviation, mm	1.06 ± 0.53	–	–	–	7.90 ± 3.23	–	–	–	.000****	–	–
Body length, mm	82.56 ± 4.06	82.49 ± 4.28	−0.07 ± 2.17	.865	81.72 ± 4.68	85.21 ± 5.01	3.49 ± 2.46	.000*	.405	.013**	.000****
Ramus height, mm	70.99 ± 4.48	71.44 ± 4.91	0.45 ± 1.77	.178	68.74 ± 6.03	71.52 ± 5.42	2.77 ± 3.68	.000*	.050	.948	.000****
Ramus inclination, °	11.46 ± 3.68	12.14 ± 3.29	0.68 ± 2.00	.074	8.20 ± 5.51	12.70 ± 4.48	4.50 ± 5.18	.000*	.001***	.542	.000****

[a] Note: Values are mean ± standard deviation (SD). Dv, deviated side; NDv, nondeviated side; and ΔNDv–Dv, the difference between NDv and Dv. Paired *t*-test was performed to compare the Dv and NDv. An independent *t*-test was performed to compare the symmetry and asymmetry groups.

* Significant difference at $P < .001$ between the Dv and NDv.

** Significant difference at $P < .05$ between the symmetry and asymmetry groups.

*** Significant difference at $P < .01$ between the symmetry and asymmetry groups.

**** Significant difference at $P < .001$ between the symmetry and asymmetry groups.

Table 5. Three-Dimensional Skeletal Measurements of the Mandible in the Roll and Non-Roll Type Groups[a]

	Roll Type (n = 30)				Non-Roll Type (n = 30)				*P*-Value (Between the Groups)		
	Dv	NDv	ΔNDv−Dv	*P*-Value (Between the Sides)	Dv	NDv	ΔNDv−Dv	*P*-Value (Between the Sides)	Dv	NDv	ΔNDv−Dv
Me deviation, mm	8.15 ± 3.74	–	–	–	7.65 ± 2.66	–	–	–	.553	–	–
Body length, mm	81.57 ± 5.10	84.71 ± 5.24	3.14 ± 2.08	.000**	81.87 ± 4.29	85.72 ± 4.81	3.85 ± 2.78	.000**	.807	.440	.267
Ramus height, mm	66.31 ± 5.76	72.17 ± 5.81	5.85 ± 2.44	.000**	71.17 ± 5.35	70.87 ± 5.01	−0.31 ±1.43	.247	.001***	.357	.000****
Ramus inclination, °	7.67 ± 5.16	11.94 ± 3.98	4.27 ± 6.05	.001*	8.73 ± 5.88	13.47 ± 4.88	4.74 ± 4.23	.000**	.462	.189	.728

[a] Note: Values are mean ± standard deviation (SD). Dv, deviated side; NDv, nondeviated side; and ΔNDv–Dv, the difference between NDv and Dv. Paired *t*-test was performed to compare the Dv and NDv. An independent *t*-test was performed to compare the roll and non-roll type groups.

* Significant difference at $P < .01$ between the Dv and NDv.
** Significant difference at $P < .001$ between the Dv and NDv.
*** Significant difference at $P < .01$ between the roll and non-roll type groups.
**** Significant difference at $P < .001$ between the roll and non-roll type groups.

DISCUSSION

Treatment success in patients with facial asymmetry requiring surgical correction primarily depends on improving the asymmetric mandible, which contributes significantly to the recognition of facial asymmetry.[6,16] Hence, for precise improvement, the reference plane should first guarantee the morphologic symmetry of the mandible. Therefore, this study attempted to verify

Table 6. Skeletal and Dental Measurements Based on the Border-MHP or Body-MHP in the Symmetry and Asymmetry Groups[a]

	Symmetry (n = 30)				Asymmetry (n = 60)				*P*-Value (Between the Groups)		
	Dv	NDv	ΔNDv−Dv	*P*-Value (Between the Sides)	Dv	NDv	ΔNDv−Dv	*P*-Value (Between the Sides)	Dv	NDv	ΔNDv−Dv
Skeletal measurement											
Body inclination, °											
to Border-MHP	73.51 ± 5.15	74.11 ± 5.03	0.59 ± 2.17	.146	71.83 ± 5.29	75.77 ± 5.95	3.93 ± 3.28	.000*	.154	.195	.000***
to Body-MHP	73.72 ± 4.92	73.91 ± 5.10	0.20 ± 1.30	.411	73.09 ± 5.57	74.50 ± 5.58	1.41 ± 2.92	.000*	.606	.629	.008**
P-value (between the planes)	.879	.881	.397		.206	.233	.000****				
Distance, mm											
Go to Body-MHP	2.50 ± 6.79	3.06 ± 6.53	0.55 ± 2.45	.224	2.73 ± 7.88	4.83 ± 8.05	2.10 ± 2.49	.000*	.895	.267	.006**
Dental measurement											
Distance, mm											
LC to Border-MHP	41.12 ± 2.98	40.89 ± 2.91	−0.23 ± 0.79	.117	41.48 ± 3.43	40.86 ± 3.36	−0.61 ± 1.02	.000*	.628	.973	.077
LC to Body-MHP	28.40 ± 2.36	28.37 ± 2.35	−0.04 ± 0.66	.766	28.51 ± 2.92	28.22 ± 2.80	−0.29 ± 1.22	.075	.866	.808	.299
P-value (between the planes)	–	–	.298		–	–	.112				
LM to Border-MHP	32.32 ± 2.67	32.08 ± 2.57	−0.24 ± 1.30	.312	31.91 ± 3.02	31.89 ± 3.04	−0.02 ± 1.69	.923	.530	.773	.528
LM to Body-MHP	25.55 ± 3.01	25.52 ± 3.10	−0.03 ± 1.47	.910	25.13 ± 3.13	25.60 ± 3.43	0.47 ± 3.43	.062	.539	.921	.211
P-value (between the planes)	–	–	.553		–	–	.139				
Angle, °											
∠LC_axis to Border-MHP	91.77 ± 3.94	93.10 ± 3.78	1.33 ± 4.09	.085	89.57 ± 5.88	96.26 ± 6.31	6.69 ± 7.14	.000*	.068	.004**	.000***
∠LC_axis to Body-MHP	92.12 ± 4.02	92.83 ± 3.94	0.71 ± 4.43	.387	90.69 ± 6.04	95.21 ± 6.46	4.52 ± 7.62	.000*	.245	.068	.004**
P-value (between the planes)	.734	.788	.576		.306	.368	.110				
∠LM_axis to Border-MHP	74.89 ± 7.87	75.33 ± 6.26	0.44 ± 6.03	.695	69.82 ± 5.90	77.89 ± 5.51	8.07 ± 7.37	.000*	.001**	.051	.000***
∠LM_axis to Body-MHP	75.61 ± 7.08	75.50 ± 6.46	−0.11 ± 5.51	.914	71.60 ± 5.87	76.97 ± 5.63	5.37 ± 7.66	.000*	.005**	.270	.001**
P-value (between the planes)	.712	.917	.716		.099	.370	.051				

[a] Note: Values are mean ± standard deviation (SD). Dv, deviated side; NDv, nondeviated side; ΔNDv–Dv, the difference between NDv and Dv; Go, gonion; MF, mental foramen; Me, menton; PM, protuberance menti; LC, cusp tip of the mandibular canine; LC_axis, long axis of the mandibular canine; LM, central fossa of the mandibular first molar; LM_axis, long axis of the mandibular first molar; Border-MHP, Border mandibular horizontal plane using Go and Me; and Body-MHP, Body mandibular horizontal plane using MF and PM. Paired *t*-test was performed to compare the Border-MHP and Body-MHP or the Dv and NDv. An independent *t*-test was performed to compare the symmetry and asymmetry groups.

* Significant difference at $P < .001$ between the Dv and NDv.
** Significant difference at $P < .01$ between the symmetry and asymmetry groups.
*** Significant difference at $P < .001$ between the symmetry and asymmetry groups.
**** Significant difference at $P < .001$ between the Border-MHP and Body-MHP.

Table 7. Skeletal and Dental Measurements Based on the Border-MHP and Body-MHP in the Roll and Non-Roll Type Groups[a]

	Roll Type (n = 30)				Non-Roll Type (n = 30)				*P*-Value (Between the Types)		
	Dv	NDv	ΔNDv−Dv	*P*-Value (Between the Sides)	Dv	NDv	ΔNDv−Dv	*P*-Value (Between the Sides)	Dv	NDv	ΔNDv−Dv
Skeletal measurement											
Body inclination, °											
to Border-MHP	72.57 ± 5.56	76.98 ± 6.31	4.42 ± 3.19	.000***	71.10 ± 4.97	74.55 ± 5.39	3.45 ± 3.36	.000***	.285	.113	.257
to Body-MHP	74.33 ± 5.94	75.23 ± 5.86	0.90 ± 2.85	.094	71.86 ± 4.96	73.78 ± 5.28	1.92 ± 2.94	.001**	.087	.320	.178
P-value (between the planes)	.242	.268	.000§§§		.553	.580	.066				
Distance, mm											
Go to Body-MHP	3.67 ± 8.33	6.71 ± 8.17	3.04 ± 2.16	.000***	1.79 ± 7.44	2.96 ± 7.61	1.17 ± 2.48	.015*	.361	.071	.003††
Dental measurement											
Distance, mm											
LC to Border-MHP	41.42 ± 3.94	40.75 ± 3.83	−0.66 ± 1.08	.002**	41.54 ± 2.89	40.97 ± 2.88	−0.57 ± 0.98	.004**	.891	.803	.721
LC to Body-MHP	28.13 ± 3.14	28.09 ± 3.25	−0.03 ± 1.24	.887	28.88 ± 2.68	28.35 ± 2.30	−0.54 ± 1.16	.017*	.320	.731	.110
P-value (between the planes)	–	–	.041§		–	–	.917				
LM to Border-MHP	31.44 ± 3.03	31.90 ± 3.36	0.46 ± 1.65	.140	32.38 ± 2.99	31.88 ± 2.75	−0.50 ± 1.63	.104	.230	.988	.028†
LM to Body-MHP	24.86 ± 3.10	25.39 ± 3.18	1.48 ± 1.71	.000***	25.39 ± 3.18	24.86 ± 3.18	−0.54 ± 1.55	.067	.511	.096	.000†††
P-value (between the planes)	–	–	.022§		–	–	.925				
Angle, °											
LC_axis to Border-MHP	91.26 ± 5.90	97.34 ± 7.11	6.08 ± 7.90	.000***	87.89 ± 5.45	95.19 ± 5.31	7.30 ± 6.37	.000***	.025†	.189	.515
LC_axis to Body-MHP	92.90 ± 5.94	95.78 ± 7.50	2.88 ± 8.65	.078	88.49 ± 5.37	94.64 ± 5.28	6.15 ± 6.16	.000***	.004††	.500	.097
P-value (between the planes)	.289	.411	.140		.667	.692	.481				
LM_axis to Border-MHP	69.65 ± 6.78	76.84 ± 5.63	7.19 ± 8.25	.000***	69.82 ± 5.90	77.89 ± 5.51	8.07 ± 7.37	.000***	.826	.142	.359
LM_axis to Body-MHP	71.98 ± 6.66	75.33 ± 5.50	3.35 ± 8.16	.032*	71.22 ± 5.05	78.61 ± 5.36	7.39 ± 6.67	.000***	.620	.023†	.040†
P-value (between the planes)	.184	.299	.075		.343	.814	.358				

[a] Note: Values are mean ± standard deviation (SD). Dv, deviated side; NDv, nondeviated side; ΔNDv–Dv, the difference between NDv and Dv; Go, gonion; MF, mental foramen; Me, menton; PM, protuberance menti; LC, the cusp tip of the mandibular canine; LC_axis, the long axis of the mandibular canine; LM, central fossa of the mandibular first molar; LM_axis, the long axis of the mandibular first molar; Border-MHP, Border mandibular horizontal plane using Go and Me; Body-MHP, Body mandibular horizontal plane using MF and PM. Paired *t*-test was performed to compare the Border-MHP and Body-MHP or the Dv and NDv. An independent *t*-test was performed to compare the roll and non-roll type groups.

* Significant difference at $P < .05$ between the Dv and NDv.

** Significant difference at $P < .01$ between the Dv and NDv.

*** Significant difference at $P < .001$ between the Dv and NDv.

† Significant difference at $P < .05$ between the roll and non-roll type groups.

†† Significant difference at $P < .01$ between the roll and non-roll type groups.

††† Significant difference at $P < .001$ between the roll and non-roll type groups.

§ Significant difference at $P < .05$ between the Border-MHP and Body-MHP.

§§§ Significant difference at $P < .001$ between the Border-MHP and Body-MHP.

mandibular symmetry based on each plane using mandibular body inclination.

The Border-MHP demonstrated a significant side-to-side difference in the body inclination in the roll-type asymmetric mandible, whereas the Body-MHP did not show a significant difference in the corresponding values. In the surgical treatment of skeletal Class III patients with an asymmetric mandible, better mandibular symmetry can be achieved with coincident body inclination between the sides using the Body-MHP as a reference plane for roll-type asymmetry (Figure 5). As Go and the mandibular inferior border tend to have secondary compensating bone changes during mandibular growth and modeling,[17,18] subsequent supplementary osteotomy may be needed to enhance mandibular symmetry by trimming the remaining asymmetric contour in the gonial area or inferior mandibular border.[19,20] The bilateral difference in the Go distance to Body-MHP is likely usable as an indicator of the supplementary osteotomy (Figure 5C). On the other hand, the Border-MHP that is influenced by the marginal bone changes at Go might not provide sufficient rolling correction of the mandibular body toward the NDv. Thus, there is a remaining difference in the mandibular body inclination between the sides after surgery (Figure 5B).

Dental variables based on each mandibular plane in the symmetry group showed no significant difference between the reference planes. Conversely, the roll-type asymmetric mandible showed different dental compensations based on the planes: ΔNDv–Dv in the vertical tooth–distance to the Border-MHP was less than that to the Body-MHP; ΔNDv–Dv in tooth inclination to the Border-MHP was greater than that

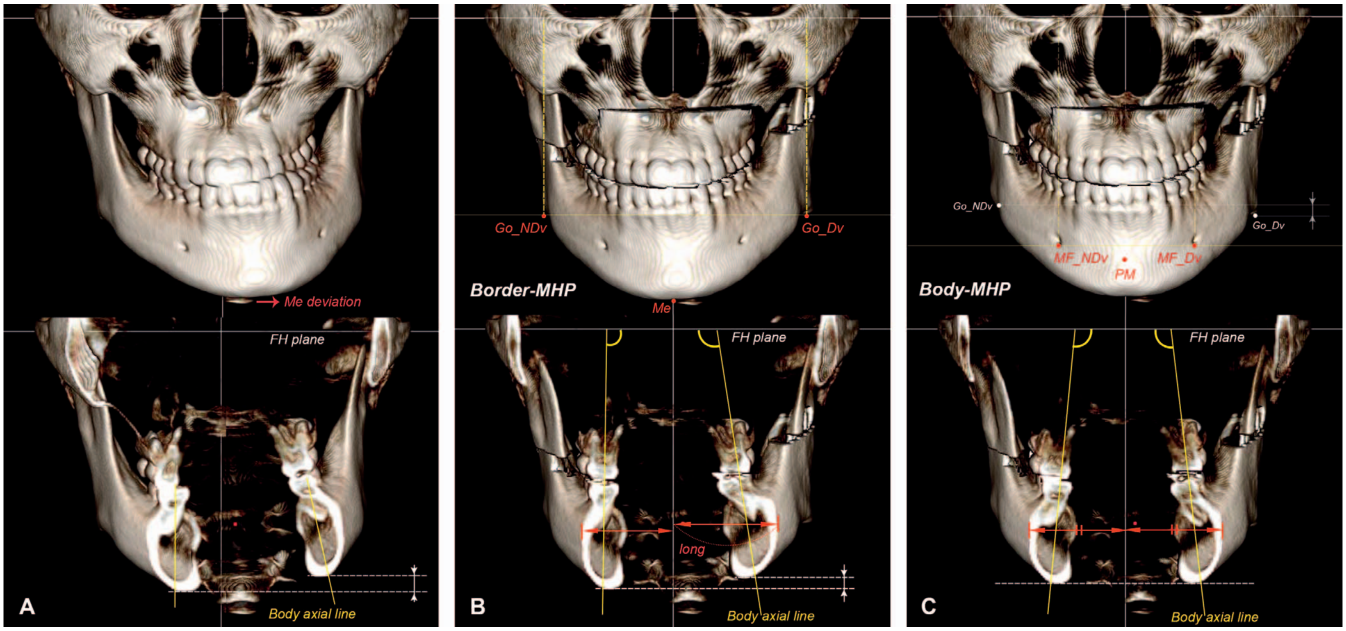

Figure 5. Virtual mandibular surgery for a patient with roll-type asymmetric mandible based on the two mandibular planes. (A) Preoperative frontal view and body axial line of the sides. (B) Postoperative (based on the Border-MHP) frontal view and body inclinations of the sides relative to FH plane (mean ± standard deviation [n = 30]; NDv, 103.03 ± 6.31°; Dv, 107.43 ± 5.56°; $P < .001$). (C) Postoperative (based on the Body-MHP) frontal view and body inclinations of the sides relative to FH plane (mean ± standard deviation [n = 30]; NDv, 104.78 ± 5.86°; Dv, 105.67 ± 5.94°; $P = .094$). FH, Frankfort horizontal; Border-MHP, mandibular plane using gonion (Go) and menton (Me); Body-MHP, mandibular plane using mental foramen (MF) and protuberance menti (PM); NDv, nondeviated side; Dv, deviated side.

to the Body-MHP, showing accentuated lingual tipping at the Dv and buccal tipping at the NDv. In other words, the Border-MHP overmeasured the side-to-side differences in tooth inclination compared with the Body-MHP (Figure 6).

The smaller vertical tooth–distance differences from the Border-MHP may produce less rolling movement of the mandible during surgery; higher tooth inclination differences may produce inappropriate lateral or yawing movement of the mandible as a result of the surgery if dental compensation is completely performed via this dental analysis. Therefore, less rolling movement of the mandible as a result of the surgery may cause a difference in body inclination between the sides even after surgery, eventually resulting in retained asymmetry.

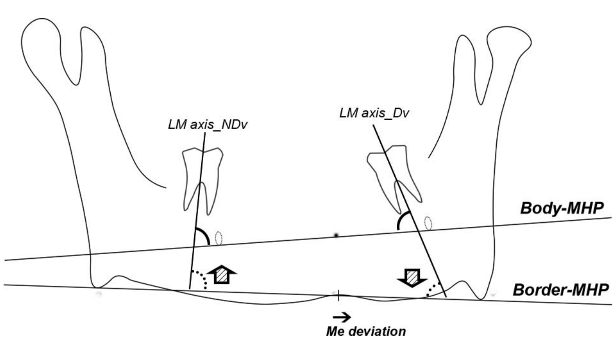

Figure 6. Schematic illustration of dental compensation on inclination; the Border-MHP tends to accentuate the molar lingual tipping on the Dv and buccal tipping on the NDv, compared with the Body-MHP. LM_axis, the long axis of the mandibular first molar; Dv, deviated side; NDv, nondeviated side; Me, menton; Border-MHP, mandibular horizontal plane using gonion and menton; Body-MHP, mandibular horizontal plane using mental foramen and protuberance menti.

This study provides important insights into establishing a reliable reference plane for the asymmetric mandible. Based on the current findings, the body mandibular plane can be alternatively used in patients with facial asymmetry, especially in the roll type. In asymmetric patient treatment, if dental decompensation and orthognathic surgery are completed after analysis with this body mandibular plane, the symmetric mandibular body position and inclination can be achieved. The remaining asymmetric contour may require additional border-trimming osteotomy. This will produce symmetry in the dentition, mandibular body, and border.

This study yielded good verification of the reliability of mandibular planes in the asymmetric mandible by measuring bilateral body inclinations. However, this research compared two planes by assessing linear and angular measurements, not including the 3D volumetric assessment of the mandibular symmetry. Therefore, a future study using the volumetric data from 3D images to directly evaluate the planes would be valuable. In addition, all samples in this study consisted of non-growing patients; thus, in future studies it may be important to further verify whether this novel plane is also applicable to patients undergoing growth changes.

CONCLUSIONS

- The null hypothesis of this study was rejected.
- In patients with roll-type facial asymmetry, the transverse position and body inclination between the sides were more symmetrical when a Body-MHP was used for analysis as compared to the conventional mandibular plane (Border-MHP).
- The novel body mandibular plane can ensure an accurate diagnosis for decompensating tooth movement and jaw surgery in patients with a roll-type asymmetric mandible.

REFERENCES

1. Noh HK, Park HS. Does maxillary yaw exist in patients with skeletal Class III facial asymmetry? *Am J Orthod Dentofac Orthop*. 2021;160:573–587.
2. Aljawad H, Kang N, Lee KC. Integration accuracy of craniofacial cone-beam computed tomography images with three-dimensional facial scans according to different registration areas [published online ahead of print July 27 2022]. *Angle Orthod*. doi:10.2319/021422-135.1
3. Hong M, Kim MJ, Shin HJ, Cho HJ, Baek SH. Three-dimensional surgical accuracy between virtually planned and actual surgical movements of the maxilla in two-jaw orthognathic surgery. *Korean J Orthod*. 2020;50:293–303.
4. Kim HJ, Hong M, Park HS. Analysis of dental compensation in patients with facial asymmetry using cone-beam computed tomography. *Am J Orthod Dentofac Orthop*. 2019;156: 493–501.
5. Santos RMGD, De Martino JM, Haiter Neto F, Passeri LA. Influence of different setups of the Frankfort horizontal plane on 3-dimensional cephalometric measurements. *Am J Orthod Dentofacial Orthop*. 2017;152:242–249.
6. Severt TR, Proffit WR. The prevalence of facial asymmetry in the dentofacial deformities population at the University of North Carolina. *Int J Adult Orthod Orthognath Surg*. 1997;12: 171–176.
7. Cevidanes LHS, Alhadidi A, Paniagua B, et al. Three-dimensional quantification of mandibular asymmetry through cone-beam computerized tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2011;111:757–770.
8. Leung MY, Leung YY. Three-dimensional evaluation of mandibular asymmetry: a new classification and three-dimensional cephalometric analysis. *Int J Oral Maxillofac Surg*. 2018;47:1043–1051.
9. Park SB, Park JH, Jung YH, Jo BH, Kim YI. Correlation between menton deviation and dental compensation in facial asymmetry using cone-beam CT. *Korean J Orthod*. 2009;39: 300–309.
10. Damstra J, Oosterkamp BC, Jansma J, Ren Y. Combined 3-dimensional and mirror-image analysis for the diagnosis of asymmetry. *Am J Orthod Dentofacial Orthop*. 2011;140: 886–894.
11. Björk A. Prediction of mandibular growth rotation. *Am J Orthod*. 1969;55:585–599.
12. Proffit WR. Later stages of development. In: Proffit WR, Fields HW, Larson BE, Sarver DM, eds. *Contemporary Orthodontics*. 6th ed. St Louis, Mo: Elsevier; 2019:84–106.
13. Lim BD, Choi DS, Jang I, Cha BK. Application of the foramina of the trigeminal nerve as landmarks for analysis of craniofacial morphology. *Korean J Orthod*. 2019;49:326–337.
14. Pittayapat P, Jacobs R, Bornstein MM, et al. A new mandible-specific landmark reference system for three-dimensional cephalometry using cone-beam computed tomography. *Eur J Orthod*. 2016;38:563–568.
15. Chen G, Al Awadi M, Chambers DW, Lagravère-Vich MO, Xu T, Oh H. The three-dimensional stable mandibular landmarks in patients between the ages of 12.5 and 17.1 years. *BMC Oral Health*. 2020;20:1–10.
16. Ajmera DH, Hsung RT, Singh P, et al. Three-dimensional assessment of facial asymmetry in Class III subjects. Part 1: a retrospective study evaluating postsurgical outcomes. *Clin Oral Investig*. 2022;26(7):4947–4966.
17. Björk A. Facial growth in man, studied with the aid of metallic implants. *Acta Odontol Scand*. 1955;13:9–34.
18. Björk A. Variations in the growth pattern of the human mandible: longitudinal radiographic study by the implant method. *J Dent Res*. 1963;42:400–411.
19. Kim CH, Lee JH, Cho JY, Lee JH, Kim KW. Skeletal stability after simultaneous mandibular angle resection and sagittal split ramus osteotomy for correction of mandible prognathism. *J Oral Maxillofac Surg*. 2007;65:192–197.
20. Xiao Y, Sun X, Wang L, Zhang Y, Chen K, Wu G. The application of 3D printing technology for simultaneous orthognathic surgery and mandibular contour osteoplasty in the treatment of craniofacial deformities. *Aesthetic Plast Surg*. 2017;41:1413–1424.