Analysis of dental compensation in patients with facial asymmetry using cone-beam computed tomography

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Introduction: The purpose of this research was to evaluate dental compensation in facial asymmetry and its correlation with skeletal variables using cone-beam computed tomography. **Methods:** Sixty adult patients were retrospectively divided into asymmetry (mean age, 21.8 ± 5.4 years) and symmetry groups (mean age, 28.1 ± 4.1 years); both groups comprised 30 patients. Independent and paired *t* tests were used for comparisons between the asymmetry and symmetry groups and between deviated (Dv) and nondeviated (NDv) sides of the asymmetry group, respectively. Pearson correlation between dental and skeletal variables was performed. **Results:** The mean value of menton deviation was 9.4 mm in the asymmetry group. Compared with the symmetry group, the direction and amount of dental compensation of the asymmetry group were as follows: 2.5-mm extrusion of the maxillary first molar (UM6) at NDv ($P < 0.05$); 1.8-mm higher position of the mandibular canine (LC) from the mandibular horizontal plane using mental foramen (MHP_mf) at NDv ($P < 0.05$); 6°-more buccoversion of UM6 at Dv; 3.7°-more linguoversion of UM6 at NDv; 4.8°-more buccoversion of the maxillary canine (UC) at Dv; 4.9°-more buccoversion of the mandibular molar (LM6) at NDv; and 2.6°-more linguoversion of LC at Dv. Dental compensation correlated or marginally correlated with skeletal variables of the deviated mandible. **Conclusions:** Dental compensations, extrusion of the maxillary molars on the NDv, and buccal tipping of the maxillary teeth and lingual tipping of the mandibular teeth on the Dv, were observed. The mandibular body length was associated with linguoversion of the mandibular molars on the Dv. The ramal inclination was related to the extrusion of the maxillary molars on the NDv. (Am J Orthod Dentofacial Orthop 2019;156:493-501)

Facial asymmetry is a disharmony of facial features relative to the midsagittal plane (MSP)/facial midline.[1] Increased menton deviation and midline discrepancy of the maxilla and mandible are associated with higher patient perception of facial asymmetry.[2] The lower one-third of the face is affected in 74% of patients with asymmetry, indicating that facial asymmetry primarily depends on the presentation of the mandible.[3]

Most facial asymmetry can be corrected with orthognathic surgeries; however, in some cases, treatment outcome is not sufficient to satisfy patients. Insufficient dental decompensation is one of the reasons for this lack of satisfaction.[4-6] Dental compensation requires alteration of positions and axial inclinations of the teeth, relative to the deviant skeletal position, to achieve suitable occlusion.[7] Dental compensation in the deviated mandible manifests as buccolingual inclination, transversal cant of the occlusal plane, and tipping of the anterior teeth.

Although the skeletal asymmetrical pattern can be precisely analyzed in patients, it is hard to precisely correct each case of malocclusion without an understanding of dental compensation. Geometric magnification and distortion on postero-anterior (PA) cephalometry have caused inaccurate identification of structures and imprecise measurements, resulting in misdiagnosis.[8-12] Previous studies regarding dental compensation in PA cephalometry revealed limitations in obtaining an accurate diagnosis and treatment plan because of the inherent errors.[13-15] Through 3-dimensional (3D) reconstruction techniques, it is possible to rotate images,

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modify reference axes and planes, and measure values of interest. Accurate measurement of distance and angulation of the teeth to reference planes are available techniques that enable effective and accurate diagnosis.[16,17]

Studies of dental compensation in asymmetrical patients have primarily used PA cephalometry and scanned dental cast images[16-18]; a few studies have used computed tomography.[6,18-20] However, no studies have evaluated accurate manifestations of dental compensation in vertical position and axial inclination using cone-beam computed tomography (CBCT) and dental compensation relative to the deviant skeletal measurements of the mandible, such as menton deviation, mandibular body length, and ramus length and ramus inclination. The purpose of this study was to evaluate the patterns of dental compensation and the relationships between deviated mandibles and their dental compensation using CBCT to measure facial asymmetry.

MATERIAL AND METHODS

The asymmetry group consisted of 30 adult patients (17 men and 13 women; aged 21.8 ± 5.4 years with a range of 17.9-44.9) with facial asymmetry who visited the Department of Orthodontics of Kyungpook National University dental hospital, Daegu, South Korea. Each patient was confirmed to exhibit ≥5 mm menton deviation, relative to the maxillary MSP, via his or her diagnostic CBCT.

A total of 30 adult patients (16 men and 14 women; aged 28.1 ± 4.1 years with a range of 18.8-33.3) with ≤1.5 mm menton deviation relative to the MSP, as confirmed on CBCT images, were randomly selected for the symmetry group from the same department. In both groups, the exclusion criteria included a history of previous orthodontic treatment; the presence of cleft lip and palate; a history of other craniofacial syndrome and/or trauma; and local factors, such as crowding, spacing, missing teeth, and/or the use of a dental prosthesis, which might affect the position and inclination of the patient's dentition. The study was approved by the appropriate institutional review board.

CBCT scans were acquired using the dental cone-beam x-ray system, CB MercuRay (Hitachi, Osaka, Japan), with 15 mA, 120 kVp, 19-cm field of view, voxel size of 0.377 mm, and scan time of 9.6 seconds. CBCT scans were exported in Digital Imaging and Communications in Medicine file format, saved, and reconstructed to produce 3D images using Invivo 5 Anatomy imaging software (Anatomage Inc, San Jose, Calif). Landmarks and reference planes (Table I; Figs 1 and 2) were defined on the 3D images of CBCT. A horizontal reference plane of the maxilla (Frankfurt horizontal [FH] plane) was constructed by connecting the right orbitale with both sides of the porion. The MSP, which is a vertical reference plane of the maxilla, was constructed perpendicular to the FH plane, passing through the crista galli and opisthion.

Traditionally, a mandibular horizontal reference plane (MHP) has been constructed by connecting both sides of

Table I. Descriptions of landmark and reference planes

Landmark	*Description*
Cg	The most superior point on the crista galli
Op	The median point of the posterior border of the foramen magnum
Or	The midpoint of the infraorbital margin
Po	The most superior point of the external auditory meatus
Me	The most inferior point on the symphyseal outline on anterior view
Go	The most inferior point of curvature along the angle of mandible in lateral view
MF	The most inferior point of the mental foramen
PM	A point where the curvature of the anterior border of the symphysis changes from concave to convex on the mandibular vertical reference plane
Cd	The most posterior point of the condyle head on posterior view
UM6	Central fossa on the upper first molar occlusal surface
LM6	Central fossa on the lower first molar occlusal surface
UC	Cusp tip of the upper canine
LC	Cusp tip of the lower canine
Reference plane	*Description*
MSP	Perpendicular to FH plane, passing through Cg and Op
FH plane	The plane that passes through both sides of Po and right Or
MVP	The plane that exhibits the maximum degree of similarity between either side of the anterior mandibular body (anterior to right and left mental foramen) when superimposed in mirror-image analysis
MHP	The plane that passes through both sides of Go and Me
Mandibular horizontal plane (mental foramen, MHP_mf)	The plane that passes through both sides of MF and PM

Cg, crista galli; *Or*, orbitale; *Po*, porion; *Me*, menton; *Go*, gonion; *MF*, mental foramen; *Cd*, condylion.

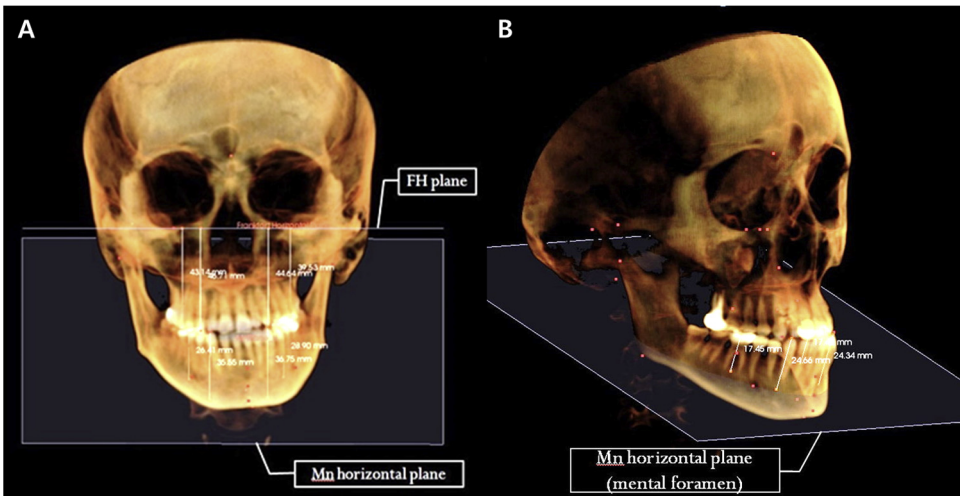

Fig 1. Horizontal reference planes and dental linear measurements. **A**, FH plane, mandibular horizontal plane, and dental linear measurements. **B,** Mandibular horizontal plane (mental foramen) and dental linear measurements.

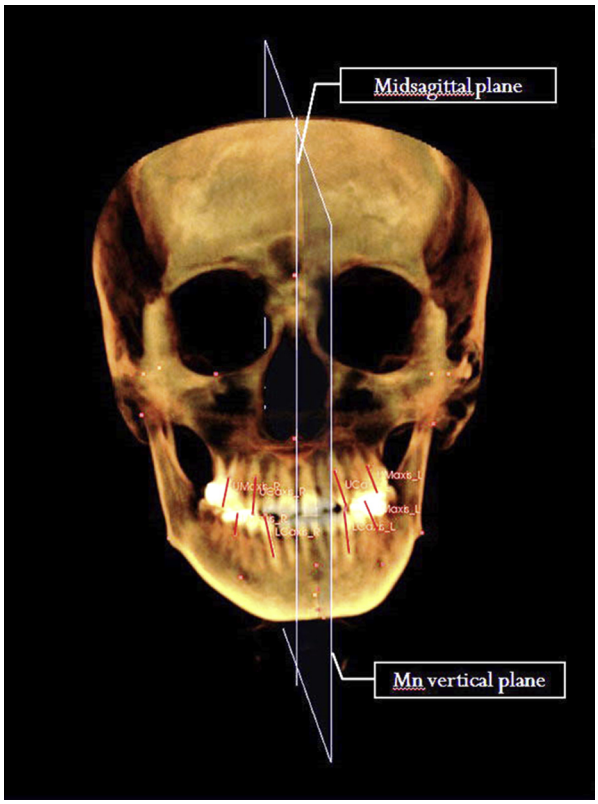

Fig 2. Vertical reference planes and dental angular measurements.

the gonion and menton, as in previous studies.[6,15,21,22] However, asymmetrical bony appositions or distortion at mandibular bodies, ramus, and gonial areas have typically been observed in patients with facial asymmetry, which may result in measurement errors.

According to Björk,[23] the mandibular canal is relatively stationary because bone remodeling does not occur in the canal to the same extent as the outer surface of the mandible. Because there is little alteration in the mandibular canal during bone remodeling and growth, the mandibular canal might be a stable structure to be used as the landmark for an MHP.[24] However, it is difficult to locate this as a landmark. Therefore, we have chosen the most inferior point of mental foramen of both sides and protuberance menti (PM) to construct the new reference plane. This plane may not be affected by bone apposition on gonion or the inferior mandibular border.

We have used 2 planes as mandibular reference planes, conventional MHP and the new mental foramen (MHP_mf). On reconstructed 3D images, the PM was redefined as the midpoint of pogonion and B-point, because of difficulty in determining landmark location. The step for vertical reference plane was as follows: the maximum overlapping image between original and mirror images of the mandible was constructed. The plane was constructed by dividing evenly the anterior portion of the overlapped mandibular body (between right and left mental foramen) (Fig 3).

Menton deviation, mandibular body length, ramus length, and ramus inclination were measured by delineation in mandibular skeletal measurements (Table II; Fig 4). In dental measurements, vertical distances from canine tips were measured using FH plane, MHP, and MHP_mf. The inclination of the canine was measured by the angle that included the long axis of the canines,

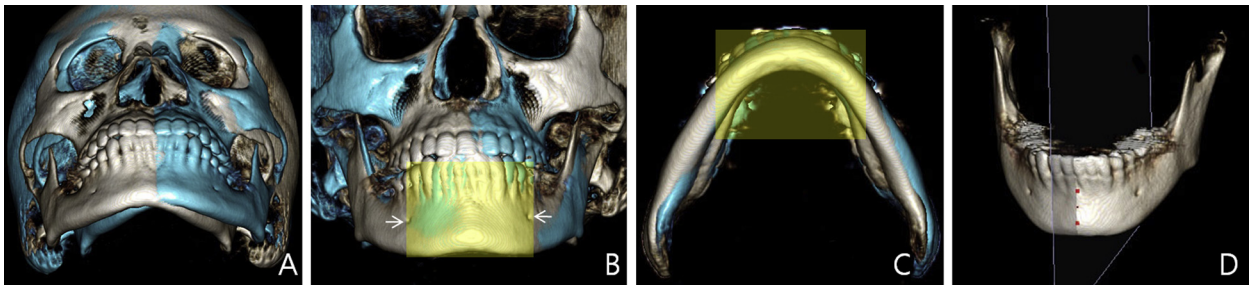

Fig 3. Construction of MVP using mirror image. **A,** Reconstruction of image (*white*) and mirror image (*blue*) by arbitrary plane. **B** and **C,** Maximum overlap with mirror image on anterior portion of mandibular body (*yellow areas* between 2 *arrows*; between 2 mental foramens) and construction of MVP by dividing this area evenly. **D,** MVP.

Table II. Skeletal variables for mandible

Skeletal variables	*Description*
Me deviation	The distance between Me and MSP
Mn body length	The distance between Me and Go
Ramus length	The distance between Go and Cd
Ramus inclination	The angle formed by ramus line (Go–Cd) to MSP

Me, menton; *Mn*, mandibular; *Go*, gonion; *Op*, opisthion; *Cd*, condylion.

MSP, and the mandibular vertical plane (MVP), respectively. Vertical distance of first molars was measured from the buccolingual midpoint on the occlusal surface to the same 3 horizontal planes. The inclination of first molars was measured by the angle formed by the line connecting the midpoint of first molar crown to root furcation, combined with vertical reference planes (Table III).

The intraclass correlation coefficient was calculated to assess the reliability of measurements on the 3D images. The same investigator re-measured all variables for 15 randomly selected subjects after a 2-week interval. The intraclass correlation coefficient was 0.985 (mean; range 0.946-0.997) for the maxilla and 0.989 (mean; range 0.981-0.994) for the mandible, indicating high reliability. Using Dahlberg's formula, the method error value for linear measurement was 0.16 mm (mean; range 0.10-0.23 mm) in the maxilla and 0.18 mm (mean; range 0.09-0.23 mm) in the mandible. For angular measurements, it was 0.95° (mean; range 0.45°-1.73°) in the maxilla and 0.61° (mean; range 0.49°-0.85°) in the mandible.

Because the data showed normal distribution, an independent *t* test was used for comparisons between the asymmetry and symmetry groups. In the asymmetry group, the difference between the deviated side (Dv) and the nondeviated side (NDv) was tested by paired *t* test. Pearson correlation coefficient was used to evaluate the degree of correlation between the skeletal measurements and dental measurements for both Dv and NDv. Statistical significance was evaluated at $P < 0.05$, using SPSS statistical software (version 22; IBM, Chicago, IL). As this clinical study is an exploratory research, adjustment for *P* value of multiple comparisons was not considered, considering both type 1 and type 2 errors.

RESULTS

Mandibular skeletal measurements

In the asymmetry group, the mean value of menton deviation (9.4 mm), mandibular body length difference (−4.4 mm), ramus length difference (−5.3 mm), and ramus inclination difference (−7.3°) between the Dv and NDv were significantly different from the corresponding measurements in the symmetry group ($P < 0.01$). The lengths of the mandibular body and ramus on the NDv were greater than those on the Dv, and ramus inclination on the NDv was greater than that on the Dv (Table IV).

Dental measurements

Regarding dental linear variables (Table III), in the asymmetry group, the mean values of all variables, except vertical distance of the mandibular first molar (LM6) and canine (LC) to MHP (LM6-MHP and LC-MHP), were statistically different between the Dv and NDv. The vertical distances of the maxillary first molar (UM6) and canine (UC) on the NDv were approximately 2 mm longer, relative to the corresponding distances on the Dv. Compared with their distances on the Dv, distances of LM6 and LC to the MHP_mf on the NDv were 0.8 mm and 0.4 mm longer, respectively. Therefore, both

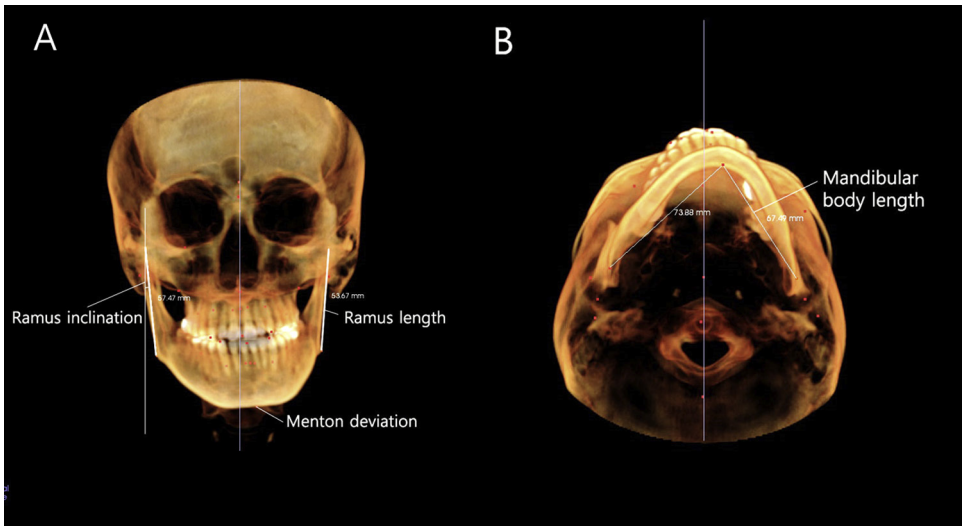

Fig 4. Mandibular skeletal measurements. **A,** Menton deviation, ramus length, and ramus inclination. **B,** Mandibular body length.

Table III. Dental linear and angular variables

Dental variables	*Description*
Linear measurements	
UM6-FH plane	The distance from the central fossa of the crown of the upper first molar to FH plane
UC-FH plane	The distance from the cusp tip of the upper canine to FH plane
LM6-MHP	The distance from the central fossa of the crown of the lower first molar occlusal surface to the MHP
LC-MHP	The distance from the cusp tip of the lower canine to the MHP
LM6-MHP_mf	The distance from the central fossa of the crown of the lower first molar to MHP_mf
LC-MHP_mf	The distance from the cusp tip of the lower canine to MHP_mf
Angular measurements	
∠UM6-MSP	The angle formed by the long axis of the upper first molar to the MSP
∠UC-MSP	The angle formed by the long axis of the upper canine to the MSP
∠LM6-MVP	The angle formed by the long axis of the lower first molar to the MVP
∠LC-MVP	The angle formed by the long axis of the lower canine to the MVP

canines and first molars on the NDv extruded vertically, compared with the contralateral teeth on the Dv.

The mean value of the UM6-FH on the NDv (51 mm) in the asymmetry group was significantly longer (by 2.5 mm) than the corresponding value in the symmetry group (P <0.05). Hence, the UM6 on the NDv in the asymmetry group extruded vertically, compared with the UM6 in the symmetry group. The mean value of the LC to MHP_mf on the NDv (27.4 mm) in the asymmetry group was significantly longer (by 1.8 mm) than the corresponding value in the symmetry group (P <0.01; Table V).

Regarding dental angular variables, in the asymmetry group, all angular variables on the Dv were significantly different from those on the NDv. The inclination of the UM6 on the Dv was 10° greater than that on the NDv. The inclination of the UC on the Dv was 6° greater than on the NDv. The inclination of the LM6 on the Dv was significantly smaller (7°) than on the NDv. The difference in the inclination of the LC between the Dv and NDv was −4°.

All values of inclination of the UM6 to the MSP of the asymmetry group in the Dv and NDv were statistically different from those of the symmetry group (P <0.01). The UM6 tipped buccally on the Dv and palatally on the NDv. The inclination of the UC to the MSP on the Dv (13.3°) revealed a statistically significant difference from that of the symmetry group (P <0.01), resulting in canine buccal tipping. The inclination of the LM6 to the MVP on the Dv in the asymmetry group (−14.7°) exhibited marginal significance (P = 0.069), whereas the same measurement on the NDv of the asymmetry group (−7.6°) showed a statistically significant difference compared with that of the symmetry group (P <0.01). Therefore, the LM6 tipped lingually on the Dv and buccally on the NDv. The inclination of the LC to the MVP on the Dv in the asymmetry group (1.4°) revealed a statistically significant difference from that of the

Table IV. Skeletal measurements in the mandible

	AG			SG		
Mandible	*Dv*	*NDv*	*Dv–NDv*	*Dv*	*NDv*	*Dv–NDv*
Me deviation (mm)	-	-	9.35 ± 3.65†	-	-	0.80 ± 0.47
Mn body length (mm)	76.93 ± 6.02*	81.35 ± 5.83†	−4.42 ± 3.45†	76.25 ± 3.55	76.45 ± 3.72	−0.25 ± 0.87
Ramus length (mm)	65.83 ± 6.33*	71.76 ± 6.54†	−5.32 ± 4.72†	68.11 ± 6.37	68.19 ± 6.00	−0.10 ± 1.51
Ramus inclination (°)	5.80 ± 4.20*,†	13.06 ± 3.45†	−7.26 ± 4.33†	10.10 ± 3.47	10.17 ± 3.16	0.10 ± 3.55

Note. Values are mean ± *SD*.
AG, asymmetry group; *SG*, symmetry group; *Dv–NDv*, the difference between Dv and NDv; *Mn*, mandibular.
*Significant difference at $P < 0.001$ between Dv and NDv in the asymmetry group; †Significant difference at $P < 0.05$ between the AG and SG.

Table V. Vertical distances and inclinations of the maxillary and mandibular canines and first molars

	AG			SG		
Variables	*Dv*	*NDv*	*Dv–NDv*	*Dv*	*NDv*	*Dv–NDv*
Dental linear measurements (mm)						
UM6-FH	48.61 ± 4.35*	50.96 ± 4.35†	−2.34 ± 1.53†	48.57 ± 3.39	48.49 ± 3.51	0.07 ± 1.15
UC-FH	53.56 ± 4.32*	55.09 ± 4.43	−1.53 ± 1.24†	54.08 ± 3.42	54.18 ± 3.34	−0.10 ± 0.70
LM6-MHP	31.96 ± 2.69	31.95 ± 3.11	0.01 ± 1.95	32.51 ± 3.15	32.15 ± 3.01	0.37 ± 1.16
LC-MHP	40.08 ± 3.78	39.79 ± 4.10	0.29 ± 1.09	39.76 ± 3.25	39.74 ± 3.23	0.02 ± 0.78
LM6-MHP_mf	23.11 ± 3.30*	23.93 ± 3.74	−0.81 ± 2.16†	23.99 ± 3.16	23.54 ± 3.03	0.45 ± 0.80
LC-MHP_mf	26.96 ± 2.92*	27.43 ± 2.71†	−0.46 ± 1.23	25.68 ± 2.20	25.67 ± 2.23	0.01 ± 0.59
Dental angular measurements (°)						
∠UM6-MSP	12.83 ± 4.76*,†	3.09 ± 4.76†	9.73 ± 4.27†	6.79 ± 3.39	6.80 ± 3.34	−0.01 ± 0.55
∠UC-MSP	13.25 ± 4.46*,†	7.16 ± 4.52	6.10 ± 4.43†	8.48 ± 3.09	8.62 ± 3.04	−0.14 ± 0.92
∠LM6-MVP	−14.70 ± 5.03*	−7.59 ± 3.82†	−7.11 ± 4.68†	−12.44 ± 4.37	−12.50 ± 4.29	0.05 ± 0.80
∠LC-MVP	1.37 ± 4.33*,†	5.71 ± 4.34	−4.33 ± 4.94†	3.99 ± 5.33	4.13 ± 5.27	−0.13 ± 0.64

Note. Values are mean ± *SD*.
AG, asymmetry group; *Dv–NDv*, the difference between Dv and NDv; *SG*, symmetry group.
*Significant difference at $P < 0.001$ between Dv and NDv in the asymmetry group; †Significant difference at $P < 0.05$ between the AG and SG.

symmetry group ($P < 0.05$), indicating lingual tipping (Table V).

Regarding Pearson correlation coefficient between dental and skeletal measurements of the mandible, in this study, there was no statistically significant correlation of dental measurements with the extent of menton deviation. However, the UM6-FH on the NDv exhibited marginally significant positive correlations with menton deviation ($P = 0.066$). The LM6 to the MVP on the Dv showed marginally significant negative correlation with menton deviation ($P = 0.074$).

The inclination of LM6 to the MVP on the Dv exhibited a statistically significant positive correlation with mandibular body length difference ($P < 0.01$).

The UM6-FH on the NDv showed a statistically significant negative correlation ($P < 0.05$) with ramus length difference. There was no statistically significant correlation between dental measurements and ramus inclination difference. However, the UM6-FH on the NDv showed a marginally significant negative correlation with ramus inclination difference (UM6-FH, $P = 0.057$; Table VI).

DISCUSSION

Overall, the social interest and perception of esthetics have resulted in a high demand for alleviating skeletal and dental malocclusion. The CBCT has become a crucial source for 3D volumetric data of maxillofacial structures because it enables quantification of the amount of asymmetry, which results in a more precise assessment for patients with asymmetry.[25-28]

This study used 3D CBCT to measure mandibular menton deviation, mandibular body length, ramus length, and ramus inclination for analysis of the patterns of asymmetry, and then calculated the differences in these values between the Dv and NDv in the asymmetry group. Furthermore, the extent of dental compensation was assessed by comparison between the asymmetry and symmetry groups.

A new reference plane, the MHP_mf, was proposed, which was constructed by the most inferior point of both mental foramen and PM.[6,15,21,22] This may minimize the influence from bone apposition on gonion or the mandibular inferior border.

Table VI. Pearson correlation between dental measurements and mandibular skeletal measurements

	Me deviation				*ΔMn body length (Dv–NDv)*				*ΔRamus length (Dv–NDv)*				*ΔRamus inclination (Dv–NDv)*			
	Dv		*NDv*		*Dv*		*NDv*		*Dv*		*NDv*		*Dv*		*NDv*	
	CC	*Sig*	*CC*	*Sig*	*CC*	*Sig*	*CC*	*Sig*	*CC*	*Sig*	*CC*	*Sig*	*CC*	*Sig*	*CC*	*Sig*
Dental linear measurement																
UM6-FH	0.191	0.313	0.339	0.066	−0.029	0.880	−0.039	0.837	−0.205	0.277	−0.428	0.018*	−0.223	0.236	−0.351	0.057
UC-FH	0.254	0.176	0.340	0.066	−0.013	0.946	−0.092	0.630	−0.275	0.142	−0.332	0.073	−0.263	0.161	−0.318	0.086
LM6-MHP	0.080	0.674	0.246	0.191	−0.113	0.552	−0.184	0.330	−0.087	0.649	−0.295	0.113	−0.072	0.703	−0.325	0.080
LC-MHP	0.252	0.179	0.252	0.180	−0.042	0.827	−0.005	0.977	−0.146	0.442	−0.169	0.373	−0.183	0.332	−0.231	0.220
LM6-MHP_mf	0.036	0.850	0.205	0.277	−0.003	0.986	−0.168	0.374	0.024	0.902	−0.157	0.407	−0.124	0.514	−0.331	0.074
LC-MHP_mf	0.032	0.869	0.091	0.632	0.132	0.487	0.061	0.750	−0.010	0.959	−0.084	0.660	0.108	0.572	−0.030	0.876
Dental angular measurement																
∠UM6-MSP	0.262	0.162	0.008	0.968	−0.181	0.339	−0.024	0.902	−0.127	0.503	0.087	0.649	−0.071	0.709	−0.041	0.831
∠UC-MSP	0.341	0.065	0.023	0.906	−0.356	0.053	−0.131	0.491	0.073	0.700	0.201	0.286	−0.057	0.764	−0.015	0.939
∠LM6-MVP	−0.330	0.074	0.175	0.354	0.570	0.001*	0.149	0.432	0.015	0.939	−0.156	0.410	0.069	0.716	−0.136	0.473
∠LC-MVP	0.303	0.104	0.035	0.855	0.229	0.223	−0.119	0.531	0.102	0.591	−0.062	0.744	0.069	0.719	−0.190	0.313

Me, menton; *Mn*, mandibular; *CC*, correlation coefficient; *Sig*, significance (*P* value).
*$P < 0.05$.

The MVP was defined as a plane, constructed by dividing evenly the area of maximum overlapping between anterior mandibular body (between right and left mental foramens) when the original image was superimposed with the mirror image. The menton and pogonion were used as landmarks to construct mandibular vertical reference planes in previous studies.[16,21] However, because they are too close to each other, a small error in identification may produce large errors on the vertical reference plane. Therefore, we used a new mandibular vertical reference plane, using the shape of the anterior portion of the mandibular body to reduce errors from landmark identification. These approaches may minimize previous errors related to asymmetrical bony apposition around landmarks, which occurred with conventional MVP construction.[21]

The extrusion of the maxillary first molar on the NDv and the occlusal plane canting toward the Dv are consistent with the results of previous studies (Fig 5, *A*).[15,16,18] In our study, the vertical position of the molar, relative to the FH plane, was measured at the midpoint of the occlusal surface. Clinically, posterior occlusal cant is greater than this value, as measured at the palatal cusps of the maxillary molar. Furthermore, the dental compensation pattern of inclination observed in our study is supported by previous studies.[15-19] Whereas the inclinations of both maxillary first molars in the asymmetry group were significantly different from those in the symmetry group ($P < 0.01$), the angular value of the UC on the Dv in the asymmetry group exhibited a significant difference compared with that of the symmetry group ($P < 0.05$). The direction and extent of dental compensation because of asymmetry are as follows: 6° buccoversion of the maxillary first molar on the Dv and 4° linguoversion of the maxillary first molar on the NDv. The UC on the Dv exhibited 5° buccoversion (Fig 5, *B*). The vertical position of the mandibular canine (LC to MHP_mf) on the NDv was significantly higher in the asymmetry group than in the symmetry group, indicating extrusion of the LC on the NDv in the asymmetry group. When measured relative to the MHP, there was no difference in the vertical distance of the mandibular first molar between the Dv and NDv, possibly because of the compensatory bony apposition on the gonion. Despite a report of vertical difference of mandibular molars in relation to the MHP, the difference was <1 mm, with no clinical significance.[15]

The inclination of the mandibular first molar on the NDv in the asymmetry group was significantly different compared with that of the symmetry group ($P < 0.01$). The mandibular molars were compensated by 2° linguoversion on the Dv and 5° buccoversion on the NDv, consistent with previous studies.[15-19] The 2.6°

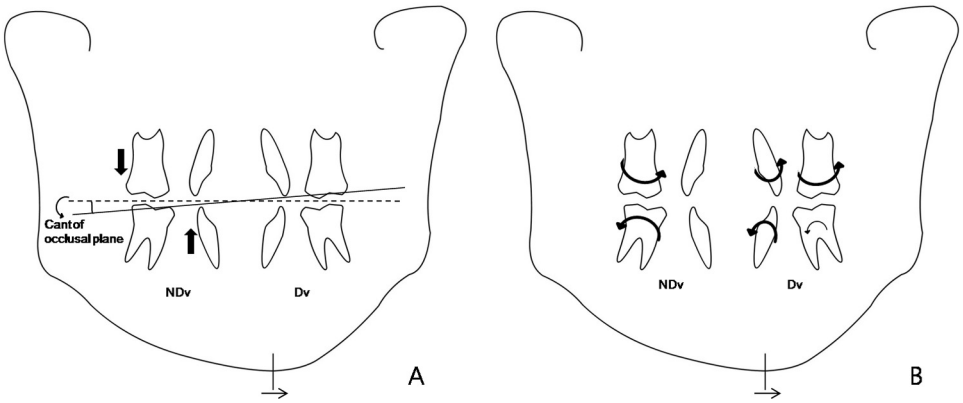

Fig 5. Schematic diagrams of patterns of dental compensation (first molar and canine; *black arrow*, significant difference between asymmetry and symmetry groups). **A,** Dental compensation on vertical position (linear variables) and cant of transverse occlusal plane. **B,** Dental compensation on buccolingual inclination (angular variables).

linguoversion of the LC on the Dv was the only significant anterior difference between the asymmetry and symmetry group ($P < 0.05$).

As the menton deviation increased, the maxillary molar and canine on the NDv showed compensatory extrusion without many changes in axial inclinations resulting in a downward occlusal cant, and the mandibular molar on the Dv showed linguoversion. Maxillary occlusal plane cant originated from maxillary vertical dental compensation, whereas the alteration of molar inclination comprised sequelae of mandibular transverse dental compensation.

The correlation of dental compensation with menton deviation is analogous to previous articles.[6,15,17-19] However, Park et al[15] underestimated the role of menton deviation in vertical distance in the canine and first molar and the inclination of the canine as a result of an anterior crossbite and anterior crowding. Our study excluded patients with crowding and anterior crossbite, leading to markedly different results. Hwang et al[20] suggested that chin deviation mostly resulted from differences in the length and inclination of the mandible, after analyzing factors of chin deviation including ramus length, ramus inclination from a frontal view, ramus inclination from a lateral view, mandibular body length, and mandibular body height.

The mandibular first molar inclination on the Dv showed a significant positive correlation with the mandibular body length difference between the Dv and NDv ($P < 0.01$). The mandibular body length difference was positively correlated with lingual tipping of the mandibular molar on the Dv. However, there was no correlation with either vertical linear measurement or occlusal plane cant. Therefore, differences in the right and left mandibular body length are considered to affect transversal mandibular asymmetry. Differences in ramus length and ramus inclination are marginally correlated with the extrusion of the maxillary molar on the NDv and transverse cant of the occlusal plane. The buccolingual tipping of molars, however, was barely correlated with ramus length and ramus inclination. Kusayama et al[18] reported that the cant of the plane passing through both gonia is correlated with the cant of occlusal plane, thus agreeing with our results. This suggests that ramus length difference affects the vertical portion of mandibular asymmetry by development of dental compensation. The ramus inclination correlated significantly with the cant of the occlusal plane, but not with the dental buccolingual inclination. Thus, dental compensation buccolingual inclination was more sensitive to differences in mandibular body length than to the differences in ramus length and ramus inclination.

There is a limitation in attributing the etiology of dental compensation to the ratio of related factors, such as ramus length difference or ramus inclination discrepancy. For further studies, analysis of dental compensation and its correlation with deviated mandible is required, after sorting subjects by contributing factors of facial asymmetry. The transverse factor of the mandibular asymmetry originates from the gap in right and left mandibular body length, which was responsible for buccolingual inclination of the mandibular molar. The vertical factor of the mandibular asymmetry is attributed to the differences in ramus length and ramus inclination, which resulted in vertical movement of the maxillary and mandibular molar.

CONCLUSIONS

It is critical to select reliable reference planes for quantifying the extent of skeletal asymmetry and dental compensation. Measurements based on these references can contribute to orthodontic dental decompensation and surgical correction. The dental compensation pattern on the NDv was extrusion of the upper molars, whereas on the Dv, buccal tipping of the maxillary teeth and lingual tipping of the mandibular teeth were present. The dental compensation on the posterior teeth was marginally correlated with skeletal variables of the deviated mandible. Differences in the mandibular body length between the NDv and Dv were associated with linguoversion of the mandibular molars on the Dv. Differences in inclination of the ramus were related to the extrusion of the maxillary molars on the NDv.

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