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Landmark validation for a mandibular horizontal plane for analysing facial asymmetry: Mental foramen versus Gonion

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Objectives: This study aimed to compare the validity of the mental foramen (MF) and gonion (Go) as landmarks for a mandibular horizontal plane by assessing their vertical positions and line angulations.
Methods: Ninety cone-beam computed tomography scans of skeletal Class III adult patients were included. The patients were divided into two main groups: symmetry (n=30) and asymmetry groups (n=60). The asymmetry group was subdivided into the roll (n=30) and non-roll types (n=30). A three-dimensional co-ordinate system was established using the best-fit mirroring superimposition of the mandibular body. Landmark positions of the MF and Go were analysed and line angulations were calculated using their coordinates.
Results: The Go line angulation relative to the x-axis in the mandibular co-ordinate system was significantly greater than the MF line angulation in both groups and asymmetry types ($P<0.05$). The difference between the Go line and the MF line angulations was significantly greater in the roll type than in the non-roll type. The bilateral vertical discrepancy in Go position was significantly greater than that of MF for both groups and asymmetry types.
Conclusions: The bilateral vertical discrepancy of the MF was significantly smaller than that of Go in symmetrically positioned mandibles. The mandibular roll may be assessed differently when using MF-based versus Go-based mandibular planes.
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Introduction

In recent years, the accuracy and reliability of treatment for patients with facial asymmetry have improved through the use of three-dimensional (3D) diagnostic data.[1–5] To obtain reliable skeletal and dental measurements during 3D diagnosis, a valid reference plane is required using stable landmarks. For this reason, cranial reference planes have been proposed and investigated.[6–9]

As facial asymmetry is primarily relevant to mandibular deviation,[10] accurate mandibular repositioning is essential for achieving facial symmetry. This requires dental decompensation and surgical adjustment based on a reliable mandibular reference plane. Conventionally, the mandibular horizontal plane has been defined using gonion (Go) and menton (Me), as these landmarks are easily identifiable and facilitate plane construction.[2,3,11] However, the validity of Go and Me as reference points is limited due to their position on the inferior or marginal regions of the mandible.[12,13] As an alternative, the mental foramen (MF) has been

proposed in previous studies as a valid additional landmark.[14–17] The MF is a relatively stable structure, located along the inferior alveolar nerve canal.[12,13] Its well-defined outer rim helps straightforward landmark identification, thus providing high reproducibility.[18,19] To date, few studies have dealt with the difference in landmark validity for a mandibular reference plane between the Go and MF, particularly for asymmetric mandibles.

Therefore, the present study aimed to evaluate the validity of Go and MF as reference landmarks for a mandibular horizontal plane in skeletal Class III patients with and without facial asymmetry.

Materials and methods

Study samples

The study was approved by the institutional review board (IRB) of Kyungpook National University Dental Hospital (IRB No. KNUDH-2021-07-02-00).

The sample size was determined based on previous studies on skeletal and dental measurements of cone-beam computed tomography (CBCT) images in patients with facial asymmetry using G*power (version 3.1.9.7; Heinrich Heine Universität, Düsseldorf, Germany).[14] The power was set at 0.80 with a two-sided significance level of $P<0.05$, and the effect size was set at 0.75. Therefore, a sample of 30 patients was required for the groups or types assigned to the study.

The study included 90 patients diagnosed with skeletal Class III relationships (ANB <0°) from January 2010 to December 2020 at the Department of Orthodontics, Kyungpook National University Dental Hospital, Daegu, Korea. The exclusion criteria were patients with (1) one or more dental prosthetic implants, (2) a congenitally missing tooth, (3) dental spacing, (4) dental crowding ≥3 mm, (5) a previous history of orthodontic treatment or orthognathic surgery, and (6) a craniofacial disorder or trauma. The patients were divided into two main groups based on the level of Me deviation relative to the midsagittal plane. The symmetry group (n=30; 17 males, 13 females; mean age, 21.34±2.42 years; range, 16.6–30.6 years) had <2 mm Me deviation, while the asymmetry group (n=60; 45 males, 15 females; mean age, 22.31±3.71 years; range, 15–29.2 years) showed >4 mm Me deviation. To compare the Go and MF landmarks using different asymmetry types, the asymmetry group was further divided into two subgroups (two asymmetry types) based on the ramus height difference between the non-deviated (NDv) and deviated (Dv) sides (ΔNDv–Dv; subtracting the value of Dv from that of NDv). Two subgroups were thereby defined: a roll type (n=30; 24 males, six females) with >3 mm bilateral ramus height difference and a non-roll type (n=30; 21 males, nine females) with <1.5 mm bilateral ramus height difference.

Data acquisition and measurements

CBCT data were acquired for diagnosis using a dental computed tomography scanner, CB MercuRay (Hitachi, Osaka, Japan; 120kVp, 15 mA, 19-cm field of view, 0.377 mm voxel size, 9.6-second scan time). After exporting the data, 3D images were reconstructed using Invivo 5 Anatomy imaging software (Anatomage Inc., San Jose, CA, USA).

All landmarks and reference planes used in the study are defined in Table I and Figure 1. The midsagittal and FH planes were used as cranial reference planes. The mandible was assessed using linear and angular measurements, and cephalometric measurements were acquired to assess the skeletal relationships (Table II).

A 3D best-fit mirroring superimposition of the mandibular body was performed to determine symmetry of the mandible (Figure 2).[14] Initially, a temporary horizontal plane was set which passed through the midpoint of the mandibular central incisor edges (LI_mid) and the central fossae of both mandibular first molars (LM). The orientation of the original image was then adjusted to achieve a best-fit superimposition between the original and mirrored mandibular bodies which focused on the area mesial to both first molars. This alignment was achieved using voxel-based superimposition, followed by manual refinement. The origin of the co-ordinates was set at the lowest point of the mandible in the mandibular midsagittal plane used for self-mirroring. By applying the mandibular co-ordinate system, the x-, y-, and z-coordinates of Go and MF were acquired for both Dv and NDv. To compare their vertical positions, scattergrams were plotted on the XZ plane, and the Go line and MF line angulations relative to the x-axis were calculated (with positive values

Table I. Definitions of landmarks, reference planes, and measurements

Landmark	Definition
Cg	The most superior point on the crista galli
Op	The middle point of the posterior border of the foramen magnum
Or	The most inferior point of the lower orbital margin
Po	The most superior point of the external auditory meatus
Me	The most inferior point on the symphyseal outline
Go	The most inferior point of gonial angle on the lateral view
MF	The most inferior point of the mental foramen
PM	The point where the curvature changes from concave to convex on the most anterior symphyseal border
Cd	The most superior point of the condyle head
LM	The central fossa of the mandibular first molar
LI_mid	The midpoint between the mandibular central incisor edges of both sides
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 FH plane
Measurement	Definition
Skeletal	
Menton deviation	The distance between menton and midsagittal plane
Body length	The distance between menton and Go
Ramus height	The distance between Go and Cd
Ramus inclination	The angle between the ramus axial line (Cd-Go) and midsagittal plane
Landmark line angulation	
Line angulation relative to the x-axis of the mandibular coordinate system	
Go line to the x-axis	The angle between the Go line (right-left Go) and the x-axis
MF line to the x-axis	The angle between the MF line (right-left MF) and the x-axis
Line angulation relative to the FH plane	
Go line to the FH plane	The angle between the Go line (right-left Go) and FH plane
MF line to the FH plane	The angle between the MF line (right-left MF) and FH plane
LM line to the FH plane	The angle between the LM line (right-left LM) and FH plane

Cd, condylion; Cg, crista galli; FH, Frankfort horizontal; Go, gonion; LI, mandibular incisor; LM, mandibular first molar; Me, menton; MF, mental foramen; Op, opisthion; Or, orbitale; PM, protuberance menti; Po, porion.

indicating that the line at the NDv canted down) (Figure 2E). In addition, to compare the extent of the transverse cant of the line based on the cranium, the LM line, Go line, or MF line angulation was calculated relative to the FH plane.

Statistical analysis

All measurements were performed by a single investigator (HJK) who also re-measured variables in 15 randomly selected patients after an interval of 4 weeks. The intraclass correlation coefficient exceeded 0.90, indicating high reliability. According to Dahlberg's formula, the method error value in the linear measurements was 0.62 mm (mean; range 0.05-1.53 mm) and 0.49° (mean; range 0.03-1.68°) in the angular measurements.

The Kolmogorov–Smirnov test confirmed that all groups followed a normal distribution. Therefore, an independent *t*-test was conducted to compare the symmetry and asymmetry groups and between the roll and non-roll types. A Chi-square test was used to

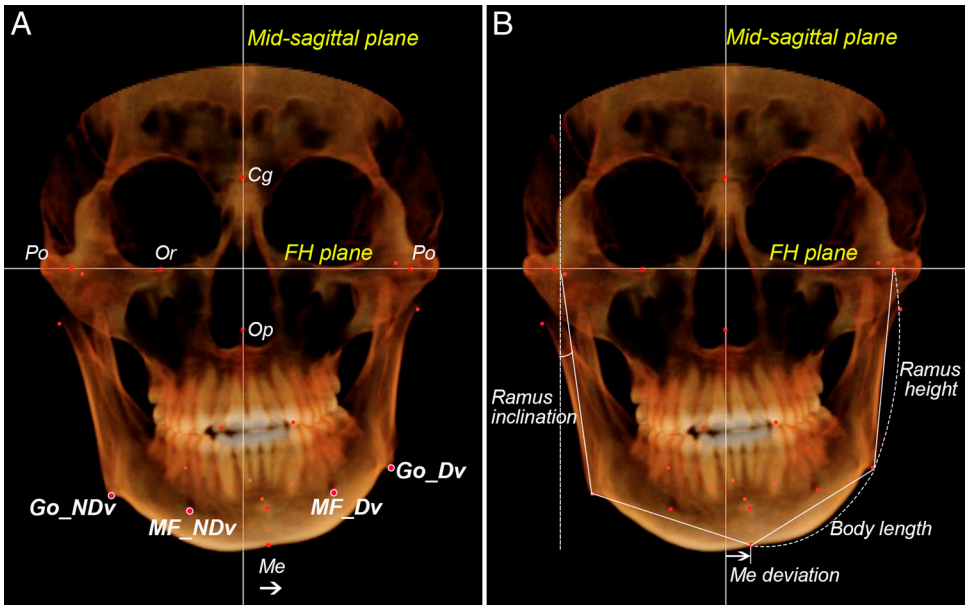

Figure 1. A, Landmarks and reference planes. B, Mandibular measurements. Cg, crista galli; Dv, deviated side; FH, Frankfort horizontal; Go, gonion; LM, mandibular first molar; Me, menton; MF, mental foramen; NDv, non-deviated side; Op, opisthion; Or, orbitale; Po, porion.

compare the gender distribution between the groups or asymmetry types. A comparison of the variables at Dv and NDv or the Go line and MF line angulations relative to the x-axis was performed within each group by using the paired *t*-test. To compare the LM line, MF line, and Go line angulations relative to the FH plane, a repeated-measures one-way analysis of variance with a Bonferroni correction was conducted. If data violated the sphericity assumption, the Greenhouse-Geisser correction was applied. Significance levels of all measurements were set at $P<0.05$ using SPSS (version 22; IBM, Chicago, IL).

Results

Sample distribution and cephalometric and CBCT skeletal measurements

No significant differences in the sample distribution (age and gender) and cephalometric measurements

Table II. Sample distribution (age and sex) and cephalometric measurements

	Symmetry (n=30)	Asymmetry (n=60)	*P*-value	Roll type (n=30)	Non-roll type (n=30)	*P*-value
Sex			0.077			0.371
Male (n)	17	45		24	21	
Female (n)	13	15		6	9	
Age (y)*	21.34±2.42	22.31±3.71	0.200	21.02±2.14	21.66±2.67	0.308
Cephalometric measurement*						
SNA (°)	82.57±3.41	81.72±2.91	0.219	81.36±2.99	82.08±2.82	0.344
SNB (°)	85.67±3.39	84.24±3.17	0.052	83.58±3.23	84.91±3.01	0.104
ANB (°)	−3.10±2.33	−2.52±2.04	0.230	−2.21±1.62	−2.83±2.37	0.247
FMA (°)	25.02±1.45	25.70±5.49	0.368	25.88±4.66	25.52±6.29	0.804

*Values are mean±standard deviation. Roll type, asymmetry patients with > 3 mm bilateral ramus height difference; Non-roll type, asymmetry patients with<1.5 mm bilateral ramus height difference. No significant difference was found between the symmetry and asymmetry groups and between the roll and non-roll types.

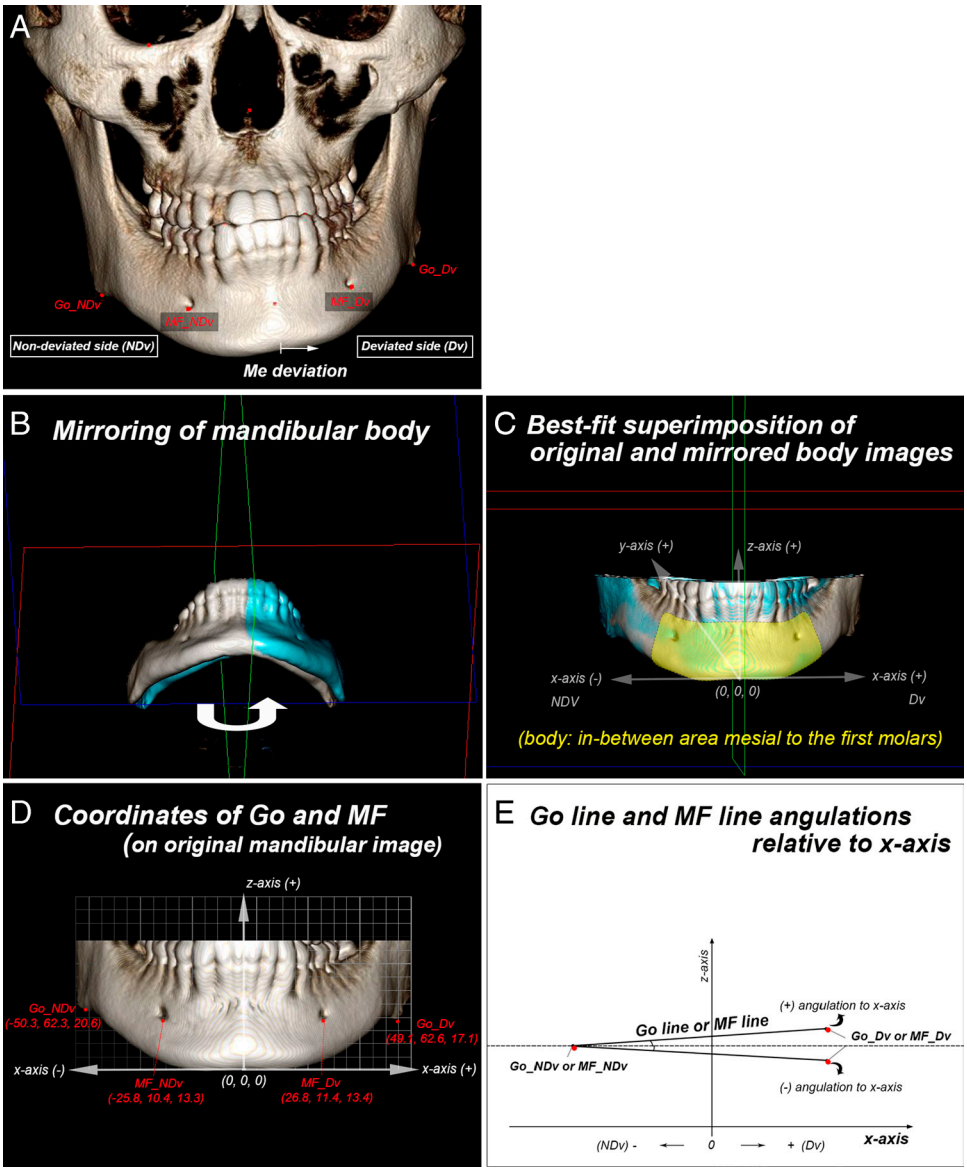

Figure 2. Workflow of the best-fit mirroring superimposition of the mandibular body and mandibular co-ordinate system. A, Three-dimensional CBCT image. B, Self-mirroring of the original mandibular body image (original, white; mirrored, blue). C, Best-fit superimposition of the original and mirrored body images (yellow area). D, Go and MF co-ordinates. E, Go line and MF line angulations relative to the x-axis. Dv, deviated side; Go, gonion; Me, menton; MF, mental foramen; NDv, non-deviated side.

between the groups and between the asymmetry types were observed (Table II).

The mean Me deviation differed significantly between the symmetry and asymmetry groups (P<0.001; Table III). Furthermore, the asymmetry group demonstrated a significant difference in all skeletal measurements between the sides (P<0.001), while no difference was detected in the symmetry group.

When comparing the roll and non-roll types (Table III), a significant difference in the ramus height at Dv (P<0.01) was observed. However, the Me deviation, body length, and ramus inclination was not significantly different.

Comparison of Go and MF positions

In the mandibular co-ordinate system set to allow best-fit mirroring superimposition of the mandibular body, the scattergram of the mandibular midsagittal plane (XZ plane) demonstrated different vertical distributions for Go and MF (Figure 3). When

Table III. Three-dimensional skeletal measurements in the symmetry and asymmetry groups and the roll and non-roll types

	Symmetry group			Asymmetry group			Roll type			Non-roll type		
	Dv	NDv	*P*-value	Dv	NDv	*P*-value	Dv	NDv	*P*-value	Dv	NDv	*P*-value
Me deviation (mm)	1.06±0.53†††	—	—	7.90±3.23	—	—	8.15±3.74	—	—	7.65±2.66	—	—
Body length (mm)	82.56±4.06	82.49±4.28†	0.865	81.72±4.68	85.21±5.01	0.000***	81.57±5.10	84.71±5.24	0.000***	81.87±4.29	85.72±4.81	0.000***
Ramus height (mm)	70.99±4.48	71.44±4.91	0.178	68.74±6.03	71.52±5.42	0.000***	66.31±5.76††	72.17±5.81	0.000***	71.17±5.35	70.87±5.01	0.247
Ramus inclination (°)	11.46±3.68††	12.14±3.29	0.074	8.20±5.51	12.70±4.48	0.000***	7.67±5.16	11.94±3.98	0.001**	8.73±5.88	13.47±4.88	0.000***

Values are mean±standard deviation.

Dv, deviated side; NDv, non-deviated side.

Paired t-test was performed to compare the Dv and NDv. Independent t-test was performed to compare the groups or the types.

***Significant difference at $P<0.001$ between the Dv and NDv.

†Significant difference at $P<0.05$ between the groups or the types.

††Significant difference at $P<0.01$ between the groups or the types.

†††Significant difference at $P<0.001$ between the groups or the types.

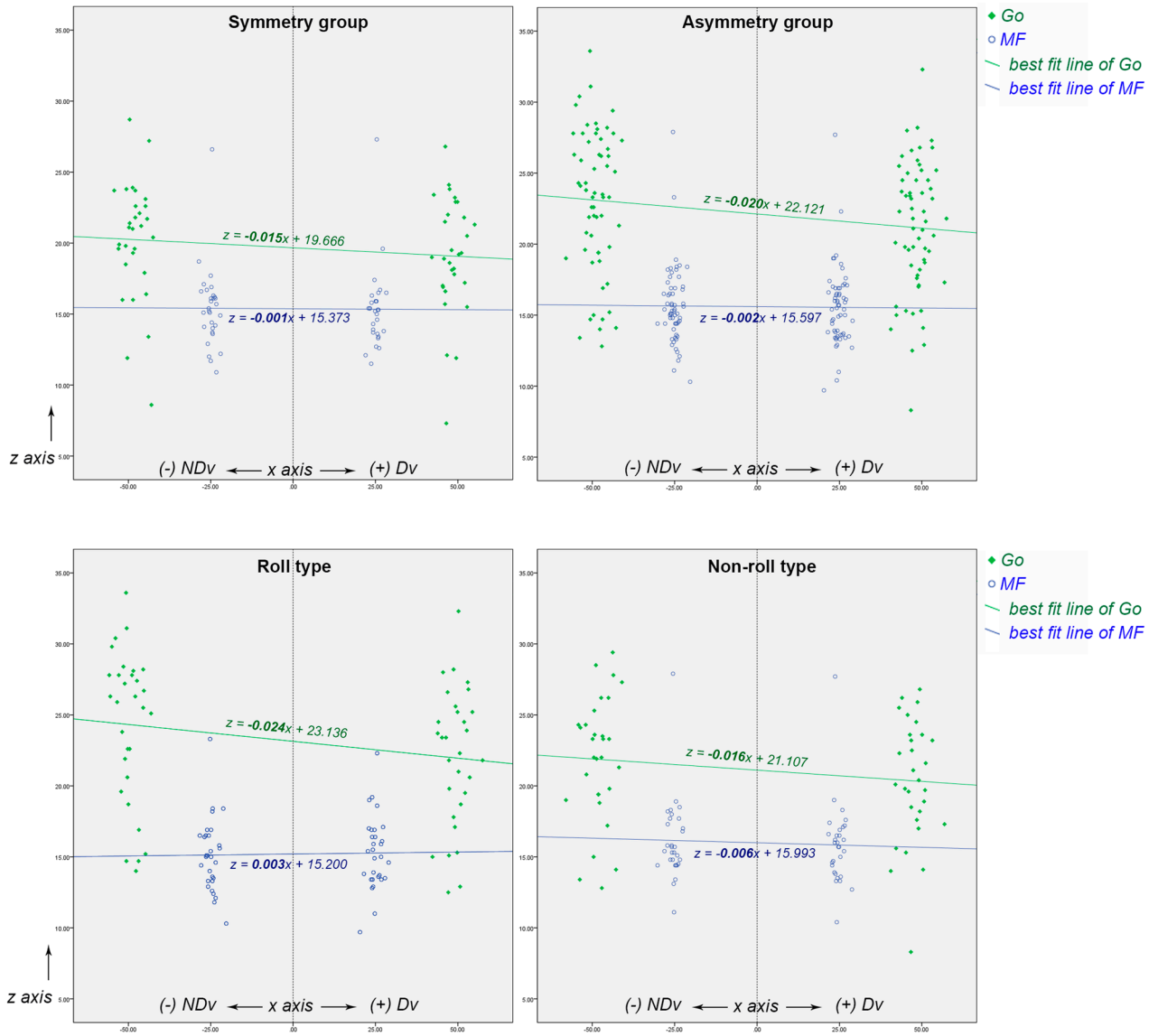

Figure 3. Scattergrams of Go and MF positions on the XZ plane of the mandibular co-ordinate system. Dv, deviated side; Go, gonion; MF, mental foramen; NDv, non-deviated side.

setting the best-fit lines by the least square method, the best-fit line of the MF was more parallel to the x-axis than that from Go. In addition, the Go line angulation relative to the x-axis was significantly greater than that of the MF line, indicating that the Go line exhibited a greater downward cant at Dv (Table IV and Figure 4). In particular, the difference was significantly higher in the roll type than in the non-roll type (roll type: -1.48±1.61°; non-roll type: –0.62±1.52°; *P*=0.036).

Regarding bilateral differences in 3D landmark positions within the mandibular coordinate system, Go exhibited significantly greater bilateral differences in the vertical positions than the MF in both groups and in both asymmetry types (Table V). The bilateral vertical difference in Go position was greater in the roll type than in the non-roll type (roll type: 2.30±2.36 mm; non-roll type: 1.60±1.87 mm). In the anteroposterior direction, the bilateral Go difference was significantly greater than that of the MF in the asymmetry group and the subtypes, indicating that Go at NDv was positioned more posteriorly than Go at Dv. However, in the transverse direction, the bilateral positional difference between Go and MF

Table IV. Transverse cant of Go and MF lines relative to the x-axis on the mandibular coordinate system

	Symmetry (n=30)	Asymmetry (n=60)	*P*-value (between the groups)	Roll type (n=30)	Non-roll type (n=30)	*P*-value(between the types)
Go line angulation (°)	−0.66±1.11	−1.14±1.27	0.080	−1.31±1.36	−0.97±1.17	0.303
MF line angulation (°)	−0.07±0.64	−0.09±0.87	0.893	0.17±0.78	−0.35±0.89	0.019†
ΔGo-MF line angulation (°)	−0.59±1.30	−1.05±1.61	0.175	−1.48±1.61	−0.62±1.52	0.036†
P-value (between the line angulations)	0.020*	0.000***		0.000***	0.034*	

Values are mean±standard deviation.

Go, gonion; MF, mental foramen; Go-line, line of the bilateral Go; MF-line, line of the bilateral MF; ΔGo-MF line, difference in Go and MF line angulations relative to the x-axis.

Paired *t*-test was performed to compare the Go and MF lines.

Independent *t*-test was performed to compare the symmetry and asymmetry groups or between the roll and non-roll types.

*Significant difference at $P<0.05$ between the Go line and MF line angulations.

***Significant difference at $P<0.001$ between the Go line and MF line angulations.

†Significant difference at $P<0.05$ between the symmetry and asymmetry groups or between the roll and non-roll types.

was not significant in any of the groups/asymmetry types.

Comparison of the Go, MF, and LM line angulations relative to the FH plane

Relative to the FH plane, the MF line showed significantly greater angulations than those of the LM line and the Go line in the roll type (Table VI and Figure 5). Conversely, the line angulations did not differ significantly in the symmetry group. All line angulations relative to the FH plane were significantly greater in the asymmetry group than in the symmetry group and greater in the roll type than in the non-roll type ($P<0.001$). These findings suggest that the bilateral vertical position discrepancies of the Go, MF, and LM relative to the cranium are more pronounced in the case of roll-type asymmetry.

Discussion

A reference plane should be representative of an asymmetric mandible and ensure symmetrical mandibular position after jaw surgery. Since facial asymmetry is primarily attributed to a deviant mandible,[10] accurate surgical repositioning of the mandible based on a reliable reference plane is crucial to achieve satisfactory facial symme. In this regard, the present study employed a 3D self-mirroring superimposition of the mandibular body to evaluate the suitability of Go and MF as mandibular reference landmarks. The method had been validated in previous studies to assess morphologic asymmetry and identify reliable reference planes and landmarks.[7,14,20] A bilateral positional similarity of landmarks indicates symmetrical mandibular morphology and positioning, which supports their use in constructing mandibular reference planes.

In reference to the mandibular co-ordinate system used in the present study, the MF line was more parallel to the x-axis than that of the Go line, and the difference in line angulation between the Go and MF lines increased in the roll type group. Accordingly, the MF-based mandibular plane might be more effective in achieving a symmetrical mandibular body morphology. This finding aligns with previous research which demonstrated that the MF-based mandibular plane yields superior bilateral similarity in mandibular body inclination.[21] Moreover, as patients with craniofacial disorders or trauma history were excluded from this study, the asymmetry observed is most likely attributable to asymmetric skeletal growth between the sides. Previous research reported that the bone surrounding

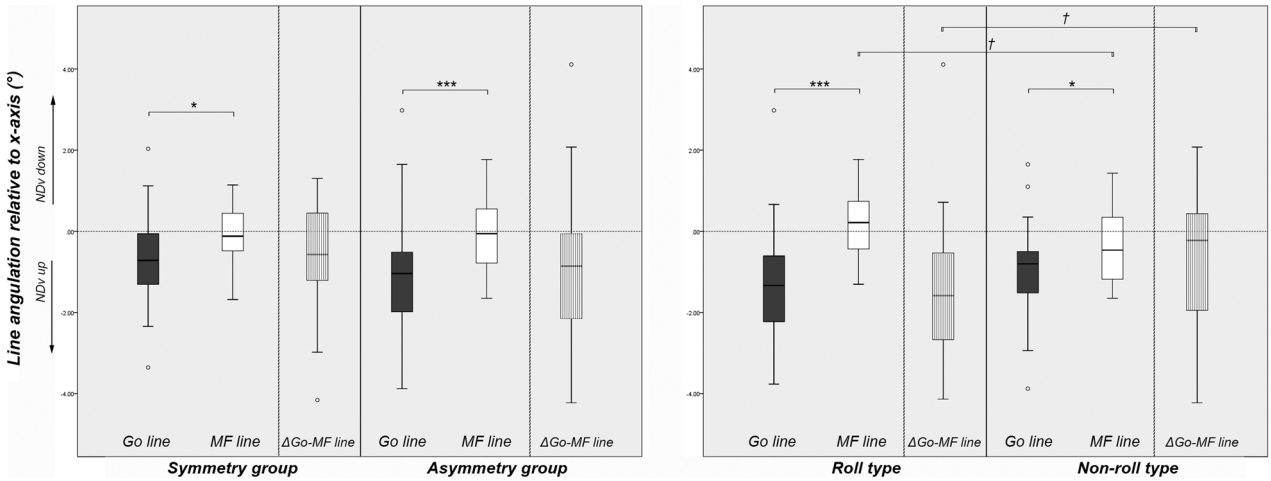

Figure 4. Box plots of the Go line and MF line angulations relative to the x-axis of the mandibular co-ordinate system. Go, gonion; MF, mental foramen; ΔGo–MF line, the difference of the Go line and MF line angulations. Significant differences between the lines at *P<0.05, ***P<0.001. Significant differences between the groups or between the asymmetry types at P<0.05.

the inferior alveolar nerve, considered the core of the mandible, is relatively stable and less susceptible to remodelling compared to the external mandibular regions, such as the gonial angle and the inferior border of the symphysis.[12,13,22–25] In addition, Damstra *et al.*[3] indicated that the accuracy of the reference planes constructed from stable landmarks remains unaffected by asymmetric bone deformities. Therefore, the observed discrepancies between the planes using Go and MF may be attributed to differential bone apposition and resorption at the gonial regions.

Relative to the FH plane, the MF line showed a greater angulation than the Go line in the roll type group, indicating that the MF landmark more accurately reflects mandibular body rolling.[21] According to these findings, the MF-based mandibular plane may be particularly beneficial for achieving better facial symmetry when surgically repositioning the mandible, especially in patients with roll-dominant asymmetry. In contrast, the mandibular plane using Go may not appropriately reflect mandibular body deviation because of the compensatory bone remodelling in the gonial region. In addition, the MF line angulation was greater than the LM line angulation in the roll type group, suggesting that the mandibular molars compensated by extrusion at NDv. Therefore, for effective correction of mandibular roll asymmetry using the MF-based mandibular plane, intrusion of the mandibular molars at NDv might be required before jaw surgery.

In the asymmetry group, Go on the non-deviated side (NDv) was positioned more superiorly than Go on the deviated side (Dv) relative to the x-axis of the mandibular co-ordinate system, as shown in Figure 2D. This finding may be attributed to differential bone remodelling associated with muscle activity. Previous studies on mandibular asymmetry have highlighted that increased masseter muscle volume and bite force at the Dv can lead to enhanced bone mineralisation at that site.[26,27] These findings suggest that altered functional activity may cause differential bone remodelling in the gonial region with increased bone apposition at the Dv. Furthermore, as Hendricksen *et al.*[28] reported, a more superiorly positioned Go at the NDv can translate into enhanced gonial resorption due to the elongation of the masseter muscle on the corresponding side.

The present study assessed the validity of Go and MF as reliable landmarks in the construction of a mandibular reference plane. The findings suggest that the mandibular horizontal plane using the MF may better ensure symmetrical mandibular body position compared to using Go. Notably, the MF-based mandibular plane more accurately reflects roll-type deviations of the mandibular body, which are often underestimated when using Go due to compensatory bone remodelling in the gonial region. The enhanced accuracy may improve treatment planning, especially for mandibular dental decompensation. Therefore, employing the MF as a reference landmark for surgical repositioning of the mandible is likely to

Table V. Bilateral difference in landmark position using the coordinate component on the mandibular coordinate system

	Symmetry			Asymmetry			Roll type			Non-roll type		
ΔNDv–Dv	Go	MF	*P*-value	Go	MF	*P*-value	Go	MF	*P*-value	Go	MF	*P*-value
x-component	–0.25±1.77	–0.12±1.10	0.741	0.53±2.49	0.38±1.32	0.677	0.48±2.40	–0.01±1.39	0.340	0.58±2.61	0.76±1.15	0.726
y-component	0.29±2.66	0.06±1.03	0.657	2.69±3.10	0.54±1.30	0.000§§§	1.95±2.13	0.41±1.30	0.002§§	3.43±3.72	0.67±1.29	0.000§§§
z-component	1.13±1.86	0.06±0.57	0.005§§	1.95±2.14	0.08±0.76	0.000§§§	2.30±2.36	–0.15±0.66	0.000§§§	1.60±1.87	0.31±0.79	0.001§§

Values are mean±standard deviation. ΔNDv–Dv, difference between the NDv and Dv; Go, gonion; MF, mental foramen. Paired *t*-test was performed to compare the Go and MF. §§Significant difference at $P<0.01$ between the Go and MF. §§§Significant difference at $P<0.001$ between the Go and MF.

Table VI. Transverse cant of Go, MF, and LM lines relative to the Frankfort horizontal plane

	Symmetry	Asymmetry	*P*-value (between the groups)	Roll	Non-roll	*P*-value (between the types)
LM line angulation (°)	0.44±1.49^{A}	2.08±2.09 ^{AB}	0.000†††	2.77±2.34^{A}	1.40±1.57 ^{B}	0.000†††
Go line angulation (°)	–0.00±1.10^{A}	1.35±2.04 ^{A}	0.000†††	2.80±1.56 ^{A}	–0.11±1.27 ^{A}	0.000†††
MF line angulation (°)	0.31±1.19 ^{A}	2.70±2.90 ^{B}	0.000†††	4.60±2.46 ^{B}	0.79±1.88 ^{AB}	0.000†††

Values are mean±standard deviation. LM, mandibular first molar; Go, gonion; MF, mental foramen; LM-line, line of the bilateral LM; Go-line, line of the bilateral Go; MF-line, line of the bilateral MF. Repeated-measures one-way analysis of variance with Bonferroni correction was performed to compare the LM line, Go line, and MF line angulations. Independent *t*-test was performed to compare the symmetry and asymmetry groups or between the roll and non-roll types. The values with different superscript letters in a column are significantly different between the line angulations ($P<0.05$).

†††Significant difference at $P<0.001$ between the symmetry and asymmetry groups or between the roll and non-roll types.

optimise postoperative facial symmetry, particularly in patients with roll-dominant mandibular asymmetry. If the residual asymmetry remains at the mandibular border or gonial region after surgical jaw movement, a supplementary border osteotomy can further enhance facial symmetry.[29,30]

The landmarks of the mandibular reference planes were validated using the symmetry and asymmetry groups, as well as roll and non-roll type asymmetries. However, the present study did not investigate the long-term clinical outcomes based on these landmarks and mandibular planes. Future research comparing surgical outcomes between the mandibular planes defined by different landmarks would provide valuable clinical insights.

Conclusions

The MF demonstrated smaller differences in vertical and anteroposterior positions between the Dv and NDv than Go in the mandibular co-ordinate system based on the best-fit mirroring superimposition of the mandibular body.

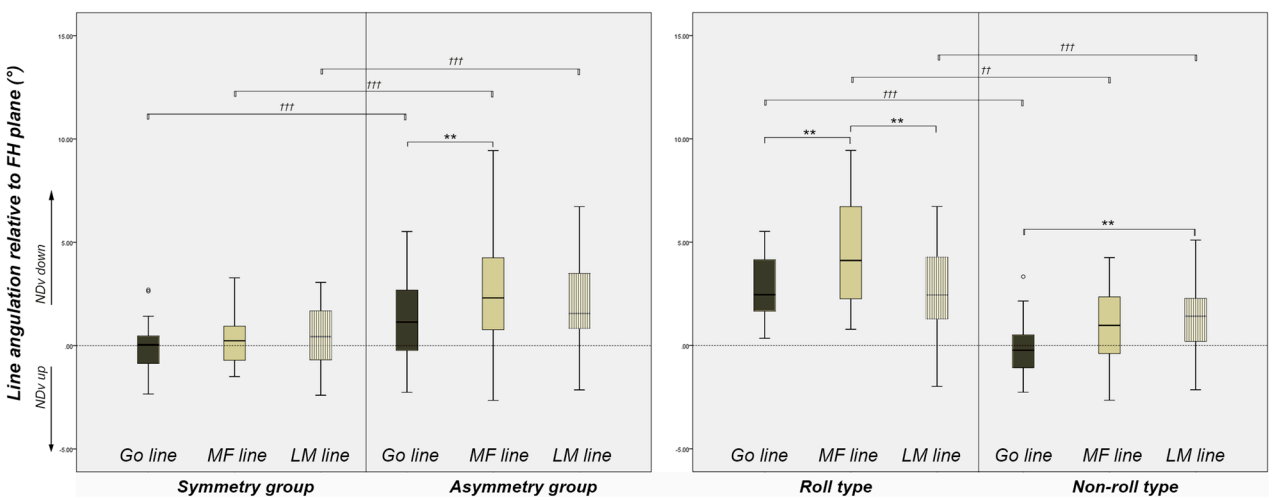

Figure 5. Box plots of the Go line, MF line, and LM line angulations relative to the FH plane. Dv, deviated side; Go, gonion; FH, Frankfort horizontal; LM, mandibular first molar; MF, mental foramen; NDv, non-deviated side. Significant differences between the lines at $^{**}P<0.01$. Significant differences between the groups or between the asymmetry types at $^{\dagger\dagger\dagger}P<0.001$.

The mandibular horizontal plane using the MF may suggest a better symmetrical mandibular position with appropriate mandibular roll correction compared to the plane generated using Go in roll-type asymmetry patients.

Conflicts of interest

The authors declare no conflict of interest.

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