Original Article

VALIDATING THE 3D AND 2D MANDIBULAR PLANE TO THE FRANKFORT PLANE FOR CRANIOFACIAL MEASUREMENT

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Purpose: This study evaluated whether the three-dimensional (3D) plane-to-plane mandibular plane angle measurement method could be applied in clinical analysis in a manner similar to the application of conventional two-dimensional (2D) cephalometric measurement, regardless of whether patients had symmetrical planes.

Patients and methods: This retrospective study selected 30 patients who had undergone both lateral cephalometric radiography and cone-beam computed tomography (CBCT). The 2D measurement was manually traced from the lateral cephalometric radiographs for the Frankfort horizontal plane line and mandibular plane line (2D FMA). The 3D reconstructions for each patient in the CBCT were evaluated using 3D software and measured using two 3D measurement methods regarding the mandibular plane angle (3D FMA, 3D MP). The Kruskal–Wallis test was used to determine the differences among the three different methods. Dahlberg's formula was used to determine the intra-examiner reproducibility.

Results: The mandibular plane angle acquired from two-dimensional measurements was larger than that obtained from 3D methods in the two asymmetry groups, and measurements revealed a greater difference in the horizontal asymmetry + vertical asymmetry group compared with the other two groups. However, no statistically significant difference was observed.

Conclusion: The 3D plane-to-plane angle measurement method can be used for analysis in patients with symmetric and asymmetric planes. ***(Taiwanese Journal of Orthodontics. 31(3): 142-152, 2019)***

Keywords: three-dimensional (3D) cephalometry; mandibular plane angle; Frankfort horizontal plane.

INTRODUCTION

Two-dimensional (2D) cephalometric radiographs are crucial for orthodontic diagnosis and treatment planning. Several measurement methods have been developed for evaluation of dental, skeletal, and soft tissues. However, 2D cephalometric radiograph measurement demonstrates limitations with respect to size, shape, volume, direction,

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and landmark identification.

Currently, three-dimensional (3D) cephalometric methods are widely used for orthodontic diagnosis and surgical evaluation because they are more accurate and can provide more information than 2D cephalometry.[1] Identifying measurement points in 2D cephalometric radiography is difficult when the landmarks overlap. The errors of landmark identification are lower in 3D cephalometry than in 2D radiography.[2,3]

Diagnosis of facial divergence is critical for orthodontic treatment planning. Several measurement methods have been developed to facilitate the classification of vertical facial types.[4,5] Mandibular plane angle (MPA) is one of the diagnostic criteria used in the analysis of facial pattern in orthodontic patients. Conventional 2D cephalometry usually uses the sella-nasion (S-N) line as the reference line for mandibular plane measurement. However, the sella turcica is difficult to mark in 3D because it is located in the center dot of the pituitary gland. Therefore, 3D cephalometry usually uses the Frankfort horizontal (FH) plane instead of SN for MPA measurement.

In terms of 3D cephalometric measurement, mandibular plane is defined differently. Line-to-line, line-to-plane, or plane-to-plane were used in 3D cephalometry to measure the MPA.[6–13] Its difference between 2D and 3D cephalometric measurements were compared between 2D MPA to 3D line-to-line MPA,[10,11,13,14] or to line-to-plane MPA,[11] or to MPA formed by a landmark projected onto the midsagittal plane (Table 1).[15]

Table 1. *Landmarks and reference planes of a 3D craniofacial model, frontal view. Or, orbitale; Ba, basion; Go, gonion.*

Author, Year	Patients	Study type	Measurement	3D MPA	Result
Yitschaky et al. **2011**	10 Human dry skulls	2D LCR vs 3D CT reconstruction	SNA, SNB, FMA, Gonial angle, SN-MP, U1-SN, U1-FH, IMPA, U1-L1, ANS-PNS, Co-Gn, Co-A, LAFH and so on	FMA (3D line to plane) SN-MP (3D line to line)	The compatibility of using most of the common orthodontic examined cephalometric measurements on 3D volume rendered image was proven except for the angular measurements that included sella anatomic landmark.
Jaime Gateno et al. **2011**	1 baseline model 10 different asymmetric 6 maxillas 4 mandible	2D LCR vs 3D CT reconstruction	Gonial angle (Co-Go-Me), ANS-PNS, SNA, Ricketts convexity, Interincisal angle (U1-L1) and so on	Gonial angle (Co-Go-Me) (3D line to line)	Facial asymmetry affects both 2D and 3D cephalometric measurements
Zamora et al. **2011**	8 patients (4M4F)	2D LCR vs 3D CBCT	SNA SNB SN-Palatal plane Angle SN-Mandibular plane Interincisal angle U1-SN, IMPA, and so on	SN-MP (3D line to line)	No statistically significant differences were found between the angular and linear measurements taken with the LCR and those taken with the CBCT.
Suseok Oh et al. **2014**	20 patients (12M8F)	2D LCR vs 3D CT	Gonial angle, Palatal angle, MPA, SNA, SNB, U1OPA, UOPA	SN-MP (3D line to line)	Results showed no significant difference among for FH planes defined on 3D CT.
Jung et al. **2015**	50 patients (12M/38F) no facial deformity (Me deviation<2mm)	2D LCR vs 3D projection (CBCT)	ANB, AB to FH, IMPA, FMA, Co-Gn, Go-Me, SN to FH, interincisal angle, FMIA, S-Go, Co-ANS	FMA (3D project to midsagittal plane)	No clinically significant difference was observed between CBCT analysis using the midsagittal plane and conventional LCR analysis, regardless of the reorientation methods
Hariharan et al. **2016**	30 patients	2D LCR vs 3D CBCT	SNA, SNB, FMA, Gonial angle, SN-MP, U1-SN, U1-NA, IMPA, and so on	FMA (3D line to line measure in lateral view)	we found that the 2D images generated by CBCT, like the half-skull, were competent in performing cephalometric analysis. Five angular measurements did not show any level of significance between the observers (FMA, IMPA, NAPog, ABN, and SNA).

LCR: Lateral cephalometric radiograph, CBCT: Cone-beam computed tomography
MPA: Mandibular plane angle FMA: Frankfort mandibular plane angle, SN-MP: Sella-nasion mandibular plane angle

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Several studies have reported that using plane-to-plane angle method for mandibular plane measurements in 3D cephalometry.[6,7,16] Plane-to-plane angle is the easiest to design and does not require projection in 3D cephalometry. It is faster and easier while using 3D software to identify MPA. The 3D plane-to-plane mandibular plane angle is formed by the FH plane and mandibular plane. These planes are composed of bilateral structures and are influenced by asymmetry.[17] However, no research has proposed a method for plane-to-plane MPA measurement in asymmetric cases. Therefore, this study evaluated whether the 3D plane-to-plane MPA measurement method could be applied in clinical analysis of patients similar to the conventional 2D cephalometric measurement, regardless of asymmetry.

PATIENTS AND METHODS

This retrospective study used the records of patients between 2016 and 2018, which were retrieved from the database of Chang Gung Craniofacial Center, Taipei and Taoyuan, Taiwan. Thirty adult Taiwanese patients (10 men and 20 women) were included. All of these patients had undergone cone-beam computed tomography (CBCT) and lateral cephalometric radiography (LCR) for diagnosis or surgical evaluation. The present study followed the Declaration of Helsinki on medical protocols and ethics, and the Institutional Review Board of Chang Gung Memorial Hospital approved this study (No. 201900751B0).

The inclusion criteria were Taiwanese adult patients (≥18 years old) who had an absence of craniofacial anomalies (cleft lip and palate, hemifacial microsomia, or congenital muscular torticollis), complete records with clear resolution that were available for evaluation, no history of facial surgery or trauma, and no pathological lesions or severe inflammation.

The three groups were classified according to the 3D image and following criteria (n = 10 patients each): relative symmetry group (menton deviation < 4 mm; gonion discrepancy < 3 mm), horizontal asymmetry group (menton deviation > 4 mm; gonion discrepancy < 3 mm), and horizontal asymmetry (menton deviation > 4 mm) + vertical asymmetry (gonion discrepancy > 3 mm) group.

LCR and CBCT

Head and neck LCR (lateral cephalometric radiograph) and CBCT images were obtained. The resolution of CBCT images was 0.4 × 0.4 × 0.4 mm in voxel size. The patient's head was positioned with the Frankfort horizontal plane parallel to the ground. Patients were instructed to avoid swallowing, keep their mouth closed, and maintain centric occlusion throughout the scan.

3D model construction and measurement methods

All CBCT images were stored in digital imaging and communication in medicine format and then imported to Simplant® O&O software (Materialise Dental, Leuven, Belgium) to construct 3D skull images for analysis. Each landmark and reference plane were identified and set for this study (Table 2, 3, Figure 1).

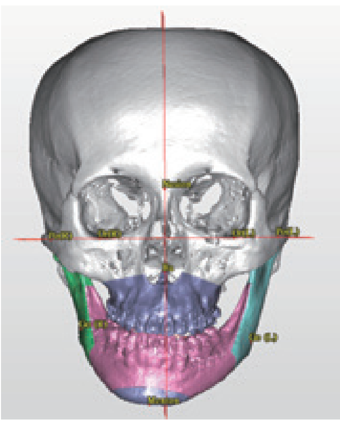

Figure 1. *Landmarks and reference planes of a 3D craniofacial model, frontal view. Or, orbitale; Ba, basion; Go, gonion.*

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Setting of measurement methods after 3D model construction

Every image was measured using the following three methods (Table 4):

(1) 2D FMA (2D Frankfort mandibular plane angle)

The 2D FMA is formed by the 2D Frankfort horizontal (FH) plane line and 2D mandibular plane line in lateral cephalometry.

Table 2. *Definition of cephalometric landmarks used in the present study.*

Landmarks	Definition
orbitale (Or)	The inferior point of the infraorbital rim
porion (Po)	The superior point of the external auditory canal
basion (Ba)	The anterior point of the foramen magnum
gonion (Go)	The midpoint between the most inferior and most posterior point in the mandibular angle region
menton (Me)	Most inferior point of the symphyseal outline
Gonion project	The point formed by the gonion point projected on the midsagittal plane
Gonion mid-project	The midpoint between the bilateral gonion projected points
Menton project	The point formed by the menton point projected on the midsagittal plane

Table 3. *Definition of cephalometric references.*

References	Definition
Frankfort horizontal plane (FH plane)	The plane formed by the bilateral orbitale (Or) and midpoint of the bilateral porion (Po)
Frankfort horizontal plane line (2D)	The line formed by the midpoint of the bilateral orbitale (Or) and midpoint of the bilateral porion (Po) in 2D lateral cephalometry
Frankfort horizontal plane line (midsagittal)	The line intersection between FH plane and Midsagittal plane
Midsagittal plane (MSP)	The plane perpendicular to the FH plane and passing through the nasion (Na) and basion (Ba)
Mandibular plane line (2D)	Line through menton (Me) and midpoint between bilateral Gonions (Go) in 2D lateral cephalometry
Mandibular plane (3D)	The plane passing through the menton (Me) and bilateral gonion (Go)
Mandibular plane projection line (midsagittal)	The line through gonion (Go) mid-projected point and projected menton (Me)

Table 4. *Definition of the measurements.*

Measurements	Definition
2D FMA	The angle between FH plane line (2D) and mandibular plane line (2D)
3D FMA	The angle between the midsagittal FH plane line and midsagittal mandibular plane project line
3D MP	The angle between the FH plane and mandibular plane
menton deviation	The distance between the menton and midsagittal plane

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(2) 3D FMA (3D projected on the midsagittal plane)

The 3D FH plane was formed by the bilateral orbitale (Or) and the midpoint of the bilateral porion (Po). The midsagittal plane was constructed by connecting the nasion (Na) and basion (Ba) and perpendicular to the FH plane. The FH plane line in this measurement was formed by the 3D FH plane projecting to the midsagittal plane. The 3D bilateral gonion and menton were projected on the midsagittal plane. The 3D FMA (projected on the midsagittal plane) was formed by FH plane line (on midsagittal plane) and projected mandibular plane line (Figure 2, 3).

(3) 3D MP (plane-to-plane)

The angle between the 3D FH plane and 3D mandibular plane, which was formed by connecting bilateral gonion (Go) and menton (Me) (Figure 4, 5).

Statistical analysis

The Kruskal–Wallis test was used to compare the FMA measurements. For the inter-examiner error assessment, all data were measured twice by the same observer after an interval of 3 weeks. The measurement errors were calculated using the Dahlberg's formula.[18] Statistical analysis was performed using SPSS software (version 23.0; IBM).

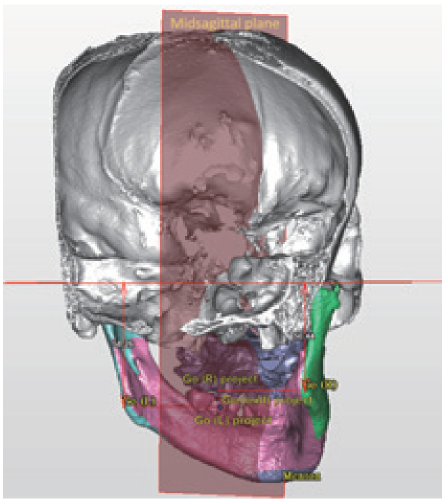

Figure 2. *Bilateral gonion (Go) projecting to the midsagittal plane.*
Gonion project (blue point), The point formed by the gonion point projected on the midsagittal plane; Gonion (mid) project (red point), The midpoint between the bilateral gonion projected points; Midsagittal plane, the plane perpendicular to the Frankfort horizontal plane andpassing through the nasion (Na) and basion (Ba).

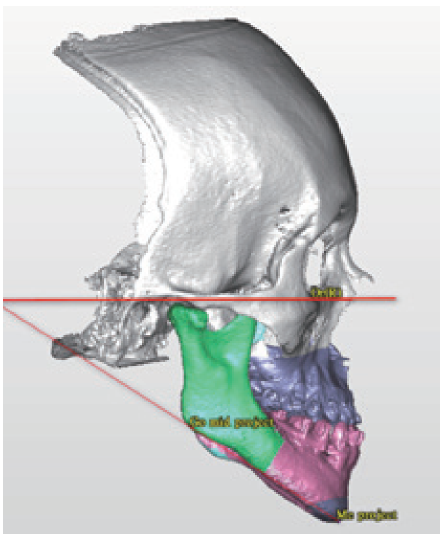

Figure 3. Lateral view of 3D FMA.
*The 3D bilateral gonion and menton were projected on the midsagittal plane. The 3D FMA was formed by projecting FH plane and mandibular plane line on the midsagittal plane. Mandibular plane was formed by connecting **Go mid project** to **Me project.***

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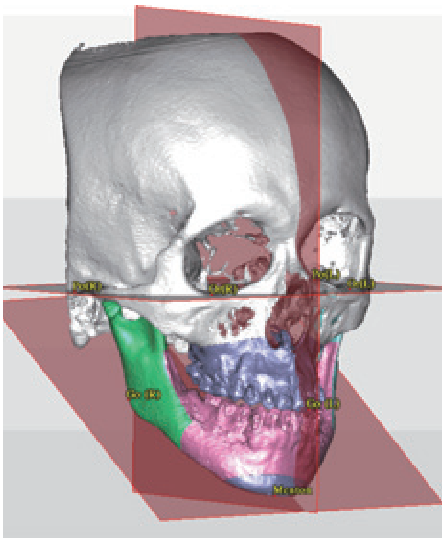

Figure 4. *Antero-posterior view of 3D MP. 3D MP, the angle formed between the FH plane and mandibular plane; Frankfort plane, the plane formed by the bilateral orbitale (Or) and midpoint of the bilateral porion (Po); Mandibular plane, the plane passing through the menton (Me) and bilateral gonion (Go).*

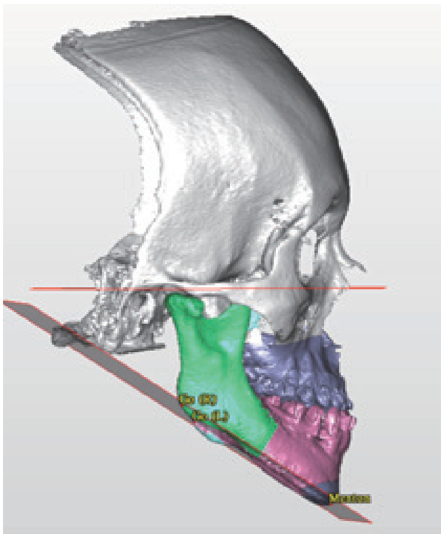

Figure 5. *Lateral view of 3D MP.*
3D MP, the angle between the FH plane and mandibular plane; FH plane, the plane formed by the bilateral orbitale (Or) and midpoint of the bilateral porion (Po); Mandibular plane angle, the plane passing through the menton (Me) and bilateral gonion (Go).

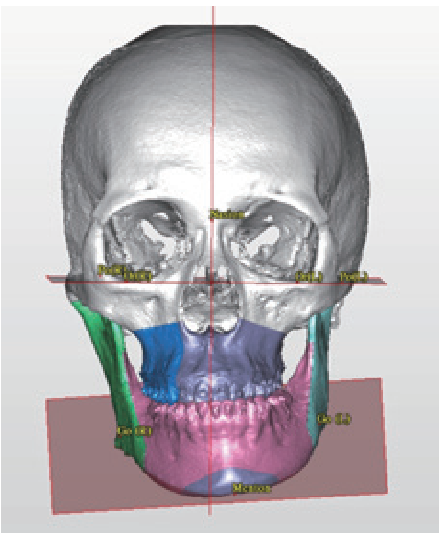

Figure 6. *An example of case with extreme asymmetry (menton deviation: 10.8 mm, bilateral Go discrepancy: 7.1 mm).*

RESULTS

This study recruited 30 patients (each group had 10 patients). Characteristics of the three groups are listed in Table 5. The mean menton deviation was 1.88 mm (SD, 1.18 mm) in the relative symmetry group, 7.03 mm (SD, 1.56 mm) in the horizontal asymmetry group, and 8.59 mm (SD, 2.31 mm) in the horizontal asymmetry + vertical asymmetry group. The mean gonion discrepancy was 1.70 mm (SD, 1.02 mm) in the relative symmetry group, 1.04 mm (SD, 0.95 mm) in the horizontal asymmetry group, and 5.58 mm (SD, 1.00 mm) in the horizontal asymmetry + vertical asymmetry group.

The results of a comparison of different MPA measurements are presented in Table 6. The MPA acquired from 2D measurements (2D FMA group) was larger than that obtained from 3D measurements (3D FMA and 3D MP groups) in the two asymmetry groups. However, a comparison of MPA measurement methods did not reveal any statistically significant difference. When the two 3D measurements were compared, they appeared to be similar in the relative symmetry and horizontal asymmetry groups. Although the measurements revealed a greater difference in the horizontal asymmetry + vertical asymmetry group compared with the other two groups, the difference was not statistically significant. A case of horizontal asymmetry + vertical asymmetry group was illustrated in Figure 6. The MPA measurement of this extreme asymmetry case (menton deviation: 10.8mm, Go discrepancy: 7.3mm) was 20.26° in 2D FMA, 19.29° in 3D FMA, and 19.61° in 3D MP (Table 7).

To evaluate the reproducibility of the measured values, the Dahlberg formula was used for measuring error; the 2D FMA group demonstrated a larger measurement error compared with those of the two 3D measurement method groups (3D FMA, 3D MP). However, no error exceeded 0.5 mm for any measurement (Table 8).

Table 5. *Characteristics of the three groups.*

Landmarks	Menton Deviation (mm)		Go discrepancy (mm)	
	Mean	SD	Mean	SD
Relative symmetry (menton deviation < 4 mm)	1.88	1.18	1.70	1.02
Horizontal asymmetry (menton deviation > 4 mm)	7.03	1.56	1.04	0.95
Horizontal asymmetry (menton deviation > 4 mm) +vertical asymmetry	8.59	2.31	5.58	1.00

Gonion (Go) discrepancy: Difference in distance between the bilateral gonions and 3D Frankfort plane.
Menton deviation: Distance from the menton to the 3D midsagittal plane; SD: Standard deviation.

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Table 6. *Descriptive and statistical comparison of 3D and 2D Frankfort mandibular plane angle measurement methods in different groups.*

Landmarks	2D FMA (N=10)		3D FMA (N=10)		3D MP (N=10)		Kruskal–Wallis p
	Mean	SD	Mean	SD	Mean	SD	
Relative symmetry (menton deviation < 3 mm)	30.11	5.80	30.37	5.85	30.37	5.85	0.980
Horizontal asymmetry (menton deviation > 5 mm)	28.37	4.21	28.00	4.02	27.99	4.03	0.923
Horizontal asymmetry (menton deviation > 5 mm) +vertical asymmetry	30.27	4.88	29.64	4.82	29.49	4.90	0.889

Table 7. *Characteristics and measurements of the example of an extreme asymmetry case, as presented in Figure 6.*

Menton Deviation (mm)	Go Discrepancy (mm)	2D FMA (degree)	3D FMA (degree)	3D MP (degree)
10.8	7.1	20.26	19.29	19.61

Table 8. *Mean measurement error according to the Dahlberg formula.*

	Menton Deviation	Go discrepancy	2D FMA	3D FMA	3D MP
Measure error	0.421	0.317	0.492	0.370	0.357

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DISCUSSION

This was a pilot study designed to estimate the feasibility of measuring plane-to-plane MPA on a 3D image. Several studies have reported no significant difference and high concordance between 3D and 2D cephalometry. In a comparison of the 2D and 3D CBCT methods, Nalçaci et al. reported no statistically significant difference for the measurements of 12 angles (SNA, SNB, ANB, SND, NA-Pog, AB-NPog, Ns-Ba, IMPA, FMIA, SN Ans-Pns, L1-APog, and L1- NB) but did note a significant difference in the measurements of two angles (U1-NA , U1-SN).[19] Yitschaky et al. reported high compatibility between 2D and 3D CT cephalometry in linear and angular measurements, excluding angular measurements that included the sella turcica anatomic landmark.[11] Oh et al. compared the angle measurements of 3D reconstructed computed tomography and 2D conventional LCR images. This study discovered that the MPA measured from 2D images was larger than the line-to-line MPA measured on 3D reconstructed computed tomography images for all patients; however, high concordance was still noted.[10] Zamora also reported that no statistically significant differences were observed between the angular and linear measurements obtained through LCR and those obtained through CBCT.20 Jung et al. compared 2D and 3D CBCT midsagittal projection cephalometric measurements. Their study noted no significant difference between 3D projected midsagittal plane measurements and 2D cephalometric measurements in patients with plane asymmetry (menton deviation < 2 mm). Although measurements differed after reorientation, these differences were not clinically significant.[15] However, the aforementioned studies did not consider the 3D plane-to-plane MPA for measurement and did not conduct comparisons with the facial asymmetry group.

Gateno et al. reported that facial asymmetry affected both 2D and 3D cephalometric measurements. In their study, line-to-line gonial angle (condylion-gonion-menton) measurement was distorted when it was measured using 2D cephalometry, but this distortion was not observed in the 3D measurements. Plane-to-plane occlusal plane-Frankfort horizontal angle measurements were distorted in planes with asymmetry in both 2D and 3D cephalometry, although the magnitude of the distortion was larger in 2D cephalometry. In the study conducted by Gateno et al., the 3D occlusal plane-Frankfort horizontal plane-to-plane angle was more distorted in roll rotation than in yaw rotation (0.34° distortion in 10° yaw rotation).[14]

In our study, 3D MP measurement revealed higher compatibility with the symmetry and asymmetry groups compared with 2D FMA and 3D FMA measurements. In a comparison between asymmetry groups, the horizontal asymmetry + vertical asymmetry group exhibited more considerable difference in measurement results than did the horizontal asymmetry group. This result is similar to the findings of the study by Gateno et al., which revealed that the plane-to-plane angle in 3D cephalometry was more distorted in roll rotation asymmetry than was that in yaw rotation asymmetry.

In this study, no significant difference was observed between the measurement values of 2D FMA, 3D FMA and 3D MP, and the difference in mean values between the groups was <0.8°. In extreme case that demonstrated in Figure 6, the difference between 3D FMA and 3D MP was 0.32 mm. According to study of Kamoen et al., the clinical significance error of FMA is 0.8o.[21] The amount of error has no clinical significance at all. Therefore, the differences in our results fall within the clinically acceptable range of measurement error in the range of menton deviation up to 12 mm and Go discrepancy up to 8 mm. Thus, the 3D MP measurement method could be used to analyze patients with symmetric and asymmetric planes.

Our study has several limitations. First, the sample in this pilot study was relatively small and included only 10 patients in each group. Second, patients with facial

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deformities, such as cleft lip or palate, and a history of facial surgery or trauma were excluded to reduce the identification errors of 2D-LCR tracing. Finally, in the asymmetry group, only menton deviation and bilateral gonion discrepancy were used for classification. More cases could be included in future study to confirm the factors that may affect the methods of 3D MP measurement in asymmetry patients.

CONCLUSION

The mandibular plane angle acquired from 2D FMA was larger than in 3D FMA and 3D MP groups in asymmetry patients though the differences did not reach statistical significance. The 3D MPA measurement was influenced by vertical asymmetry rather than horizontal asymmetry. However, the difference was not statistically significant. Therefore, the 3D plane-to-plane angle measurement method can be used for analysis in patients with symmetric and asymmetric facial structures when the asymmetry is confined at a certain range.

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