

Article

Preoperative Anatomical Variables Affecting the Outcome of Surgical Correction in Class III Face Asymmetry

Yi-Ting Li ¹, Ying-An Chen ^{2,3}, Cheng-Hui Lin ^{2,3} and Ellen Wen-Ching Ko ^{1,3,4,*} 

- ¹ Graduate Institute of Dental and Craniofacial Science, Chang Gung University, Taoyuan 333, Taiwan; eatinglei@gmail.com
² Department of Plastic and Reconstructive Surgery, Chang Gung Memorial Hospital, Taoyuan 333, Taiwan; dr.yachen@gmail.com (Y.-A.C.); 3344@cgmh.org.tw (C.-H.L.)
³ Craniofacial Research Center, Chang Gung Memorial Hospital, Linkou, Taoyuan 333, Taiwan
⁴ Department of Craniofacial Orthodontics, Chang Gung Memorial Hospital, Taipei 105, Taiwan
* Correspondence: ellenko.wc@msa.hinet.net

Abstract: *Objective:* The study investigated the preoperative anatomical variables that affect the outcome of surgical correction in patients with Class III facial asymmetry. *Methods:* The study recruited 37 consecutive patients with facial asymmetry who had 2-jaw orthognathic surgery. They were divided into two groups based on the surgical outcome: symmetrical (S group) or asymmetrical (A group), according to the asymmetry index. The CBCT images were obtained before surgery (T0) and after debond (T1). The 3D dentofacial measurements were compared between groups S and A by the Mann–Whitney test. Spearman correlation analysis was performed to examine the relationship of all dentoskeletal variables in T0 with the facial symmetry outcome. *Results:* Significant between-group differences were observed in preoperative time, including maxillary anterior occlusal canting, maxillary posterior occlusal canting, the gonion–Frankfort horizontal plane (FHP) distance, the mandibular ramus axis–FHP distances, and sagittal and transverse of condyle position. *Conclusions:* For patients with severe skeletal Class III asymmetry, preoperative anatomical variables, particularly preoperative “roll” and “yaw” discrepancies and anatomical limitations of the mandible, should be considered for favorable asymmetry correction. Based on the anatomic variables that affect the outcomes of facial asymmetry correction, prognosis and treatment limitation could be predicted before treatment.

Keywords: virtual surgical planning; 3D imaging; oral maxillofacial surgery



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1. Introduction

Patients with Class III malocclusion with mandibular prognathism have a high prevalence of facial asymmetry [1–4]. The prevalence of skeletal Class III face asymmetry has been reported to range from 47.9% to as high as 85% in Asian cohorts [3,4]. The lower face, particularly the chin, deviates more frequently than the upper face [2,3]. The occurrence of facial skeleton asymmetry may result from variations in the morphology of bony structures and the positional deviation of the maxillomandibular complex, or only the mandible [5,6].

For patients with severe skeletal jaw discrepancy and facial asymmetry, a combination of orthodontic treatment and orthognathic surgery (OgS) is considered the only viable treatment option for improving facial appearance and restoring normal occlusal function [5]. The goal of 2-jaw OgS is to correct the overall dentofacial asymmetry regarding dental occlusion, align maxillary midline and chin to the facial midline, level the oral commissure and occlusal plane cant, and correct vertical and sagittal discrepancy [6]. Adjunctive surgeries or treatments, such as bone shaving, bone grafting, and soft tissue grafting, can improve contour asymmetry and enhance harmony of the face form [7,8]. With the

development of 3D images, cone-beam computed tomography (CBCT), and computer-assisted surgical simulation, 2-jaw OgS can be precisely planned, assisting surgeons to achieve similar treatment outcomes to correct facial asymmetry [9–11].

In many cases, however, residual asymmetry persists postoperatively [12]. Lin et al. reported that mandibular asymmetry persisted in 45 patients with facial asymmetry undergoing OgS, even though the center point of the mandible was well aligned with the facial midline [13]. According to the previous study from our team, Lin et al. analyzed 24 patients with skeletal Class III malocclusion with double-jaw OgS, who were classified according to the outcome of subjective visual perception scores [14]. The findings demonstrated that midline parameter deviation, shape of the mandibular border, and contour of menton morphology influenced the visual perception of postoperative asymmetry.

Chen et al. categorized mandibular asymmetry into three groups according to the amount and direction of ramus asymmetry relative to menton deviation in 3D-CBCT analysis [15,16]. They concluded that ramus asymmetry was less predictable. However, no specific factors were found to contribute to residual facial asymmetry.

The study aims to explore the preoperative anatomical variables affecting the outcome of surgical correction in facial asymmetry in patients with skeletal Class III malocclusion. The null hypothesis was that the anatomical factors are not different between the surgical outcome of good facial symmetry and residual asymmetry.

2. Materials and Methods

2.1. Patients

This retrospective study evaluated 37 consecutive adult Taiwanese patients with skeletal Class III facial asymmetry, who received bimaxillary OgS from 2014 to 2016 at the Chang Gung Memorial Hospital, Taipei, Taiwan.

The inclusion criteria were as follows: (1) having skeletal Class III dentofacial deformities with preoperative menton deviation >4 mm from the midsagittal plane (MSP); (2) undergoing bimaxillary OgS (Le Fort I osteotomy and BSSO); (3) having complete preoperative and posttreatment CBCT data; and (4) receiving treatment from the same orthodontist and the same group of surgeons.

The exclusion criteria of the subjects were: (1) craniofacial anomalies, such as cleft lip and palate, hemifacial microsomia; (2) craniofacial trauma; and (3) untreated temporomandibular joint disorder.

The sample size was calculated using G*Power (version 3.1.9.4; Universität Kiel, Kiel, Germany) [17]. On the basis of the difference in Go to FHP, significance of 95%, and power of 80%, the minimum sample size required for the two-sample *t*-test was 36.

This study followed the guidelines of the Declaration of Helsinki. The research protocol was approved by the Institutional Review Board and medical ethics committee of the Chang Gung Memorial Hospital.

2.2. Data Collection

The patients' 3D craniofacial images were taken in the natural head position with maximum intercuspation, by using an i-CAT scanner (Image Sciences International, Hatfield, PA), with the following settings: 120 kVp; 36.9 mA; field of view, 22×16 cm; scanning time, 40 s; and voxel size, $0.4 \times 0.4 \times 0.4$ mm. All data were obtained 1 month before surgery (T0) and on completion of orthodontic treatment (T1).

The DICOM format from the CBCT scanner was imported into the Simplant O&O software (Materialise Dental NV, Leuven, Belgium) to reconstruct the 3D skull models, including the cranium with maxilla and mandible. Maxillary and mandibular dental casts were digitized by a 3D scanner (3Shape, Copenhagen, Denmark) and integrated into the CBCT model by surface matching.

2.3. Presurgical 3D Surgical Simulation

The guidelines and procedures for 3D surgical simulation were reported in a previous study [11]. Both clinical facial and 3D cephalometric measurements were incorporated into the development of the 3D surgical plan.

The surgical stent for the 2-jaw OgS was fabricated according to the surgical occlusion setup in the maxillary and mandibular dental casts. An intermediate stent was fabricated with a 3D-printed technique to guide the surgery.

2.4. Surgical Technique

All patients underwent double-jaw OgS. The maxillo-mandibular complex (MMC) was completely mobilized with LeFort I osteotomy and BSSO. The sequence of surgery was based on the designated intermediate stent. The final 2-jaw movement was guided by the final occlusion stent with temporary intermaxillary fixation during surgery. The surgeons finalized the MMC pitch rotation according to the 3D surgical simulation and final assessment of the facial symmetry and profile. Next, the MMC was fixed to the maxillary base and mandibular proximal segments with rigid fixation. Genioplasty surgeries were conducted to enhance the chin contour as a last step if required.

The BSSO technique conducted at our center was modified from the Hunsuck technique, with a more anteriorly extended anterior osteotomy cut [18,19]. This technique facilitates later intraoral placement of the plates and screws, and allows for a greater amount of mandibular repositioning with good long-term stability.

For Asian women, simultaneous mandibular angle contouring is a common adjunct procedure to improve the “square face” [20]. The medial cortex of the mandibular angle on the proximal segment can be harvested for a high-quality bone graft, if necessary [21].

2.5. 3D Dentoskeletal Measurements

The 3D skull models at T0 and T1 were superimposed on the anterior cranial base, and frontal and periorbital surface. The deviation values were calculated, and a value of 0.5 mm was considered acceptable to ensure that the corresponding reference areas had the highest possible accuracy.

The 3D reference planes were constructed using the landmarks identified on the preoperative objects (Figure 1). Table 1 lists the definition of the 3D landmarks, and depicts the linear and angular measurements of each landmark relative to the reference planes (Figures 2–7). The deviated side was defined as the side of the face, including the skeletal menton, and the opposite side was the contralateral half (Figure 2). All landmarks were identified by the same investigator.

Table 1. Definition of 3D dentoskeletal landmarks and variables for measurement.

Landmark	Definition
Orbitale (Or)	The inferior point on the infraorbital rim
Porion (Po)	The superior point of the external auditory canal
Nasion (Na)	The junction of the nasal and frontal bones at the most medium point
Basion (Ba)	The anterior margin of the foramen magnum
ANS	The most anterior midpoint of the anterior nasal spline of the maxilla
A point	The most posterior point in the concavity of maxillary apical base in lateral view
B point	The most posterior point in the concavity of the mandibular apical base in lateral view
Pogonion (Pg)	The anterior point on the MSP of the mandible
Gnathion (Gn)	The most anterior and inferior point on the MSP of the mandible
Menton (Me)	The most inferior point on the MSP of the mandible
Medial condylar pole (CoM)	The most medial point of the condylion
Lateral condylar pole (CoL)	The most lateral point of the condylion

Table 1. *Cont.*

Condylion (Co)	The midpoint between the medial and lateral mandibular condylar poles at the most posterior superior surface edge
Glenoid fossa (GF)	The superior point of the glenoid fossa
Gonion (Go)	The most inferior, posterior and lateral point on the mandibular angle region
Upper contour point	Point in the middle of the lateral pole of condylion and gonion along the ramus
Lower contour point	Point in the middle of the lateral pole of gonion and menton along the mandibular body
U1	The midpoint of two upper central incisor edges
U3	The cusp tip of the upper canine
U6	The mesiobuccal cusp tip of the upper first molar
L1	The midpoint of the two lower central incisor edges
L4	The buccal cusp tip of the lower first premolar
L6	The mesiobuccal cusp tip of the lower first molar
Linear and angular variable	Definition
Ramus height (mm)	The distance between Co and Go
Mandibular body length (mm)	The distance between Go and Gn
Gonial angle	Angle between the tangent line of mandibular border and the Go–Me line
Condylar axis	The line connecting the CoM and CoL landmarks
Ramus axis	The line connecting the Co and Go landmarks
Mandibular axis	The line connecting the Go and Gn landmarks
Planar variable	Definition
Frankfort horizontal plane (FHP)	The plane formed by the bilateral orbitale (Or) and midpoint of bilateral porion (Po)
Midsagittal plane (MSP)	The plane perpendicular to the FHP and passing through the nasion (Na) and basion (Ba) landmark
Coronal plane (CP)	The plane perpendicular to the FHP and MSP and passing through basion (Ba)

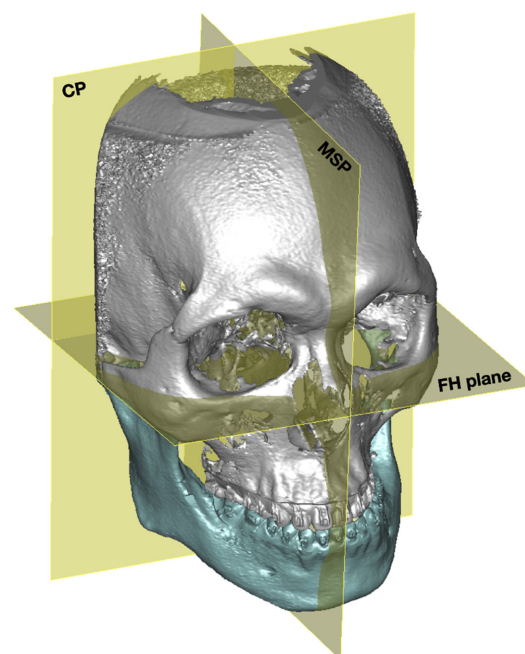


Figure 1. Three reference planes for 3D analysis. The 3D reference planes were constructed by the landmarks identified on the preoperative objects. The Frankfort horizontal plane (FHP) was determined by the bilateral orbitale and the midpoint of the bilateral porion. The midsagittal plane (MSP) was defined as the plane perpendicular to the FHP and passing through the nasion. The coronal plane (CP) was the plane perpendicular to the FHP and the MSP, and passing through the basion.

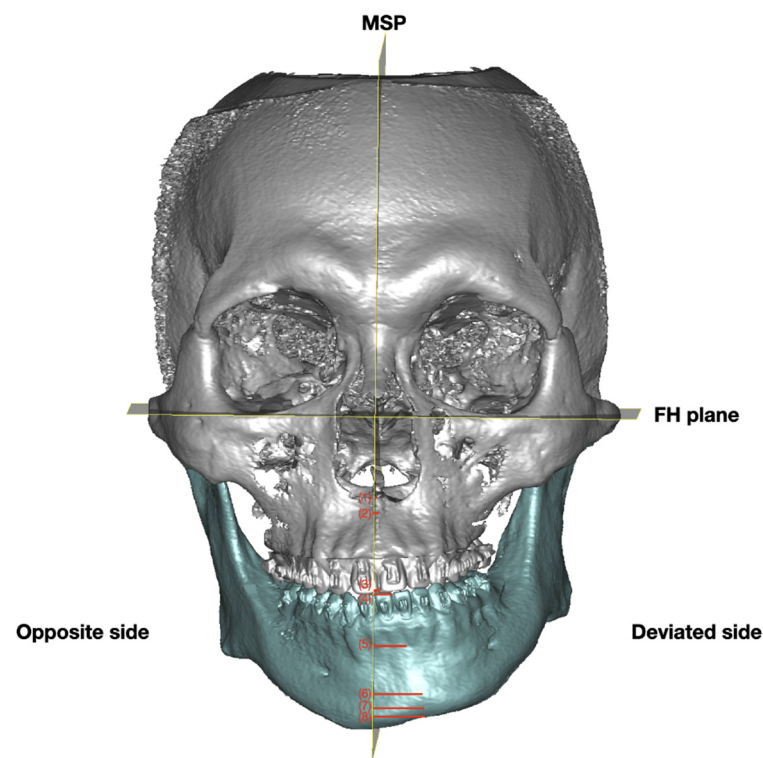


Figure 2. Midline measurements in the frontal view. The MSP separated the face into deviated and opposite sides. The deviated side was defined as the side of the face, including the skeletal menton, and the opposite side was the contralateral half. (1) ANS to MSP, (2) A point to MSP, (3) U1 to MSP, (4) L1 to MSP, (5) B point to MSP, (6) Pog to MSP, (7) Gn to MSP, (8) Me to MSP.

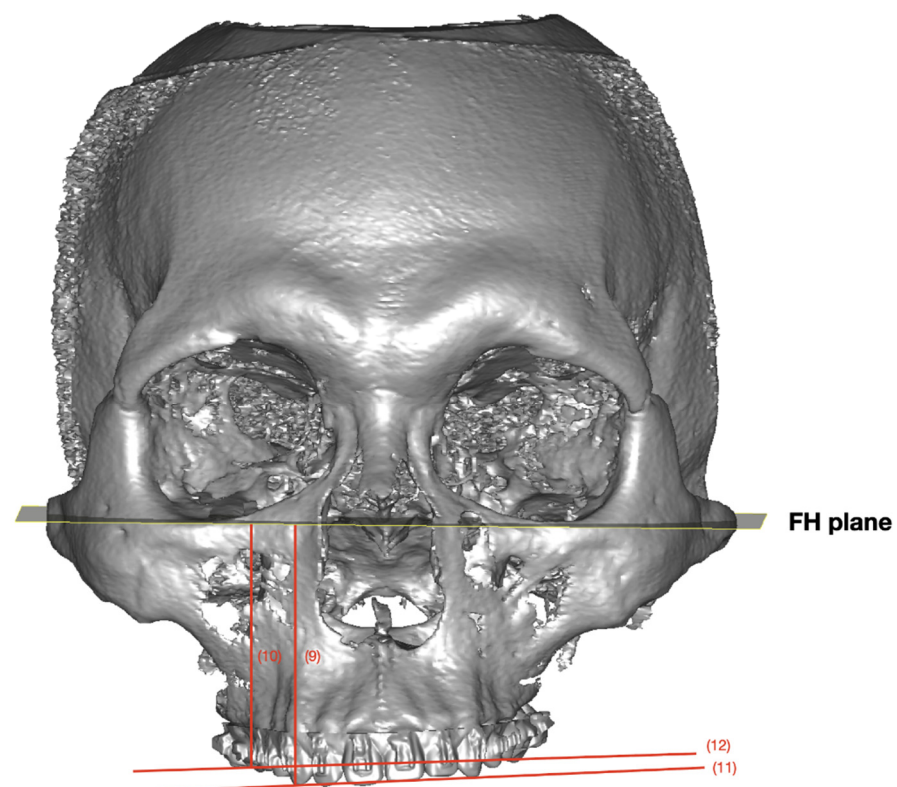


Figure 3. Maxillary bilateral variables. (9) U3 to the FHP, (10) U6 to the FHP, (11) maxillary anterior canting (Δ U3 to FHP), (12) maxillary posterior canting (Δ U6 to FHP).

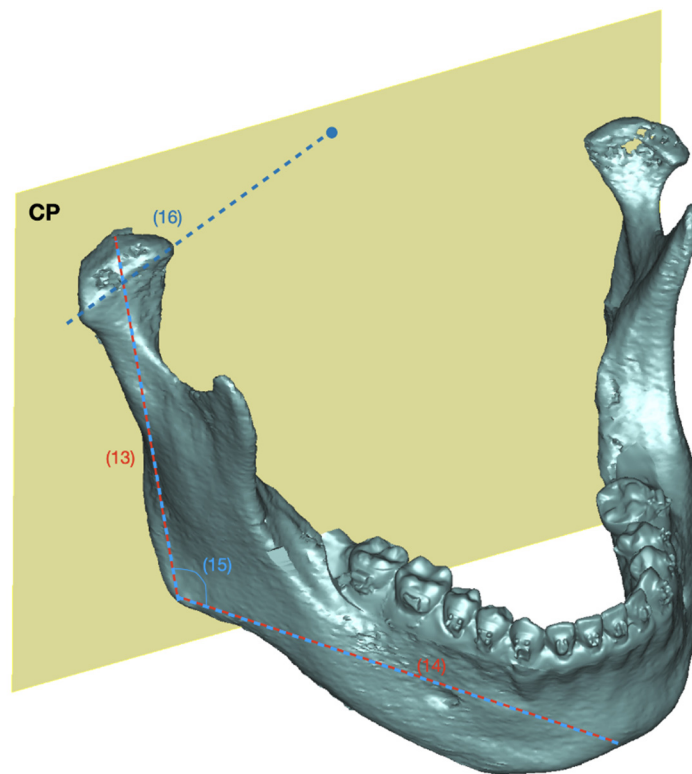


Figure 4. Mandibular linear and angular measurements. (13) Ramus height, (14) body length, (15) gonial angle, (16) condyle axis to CP.

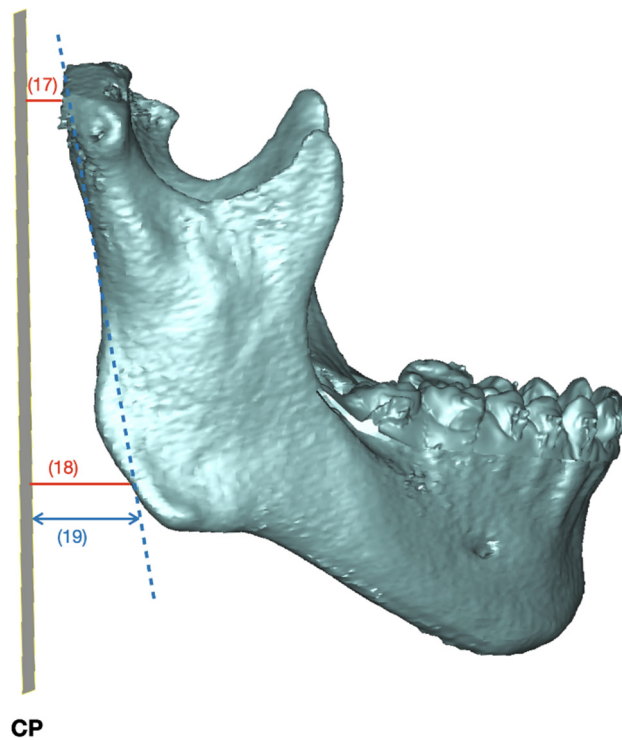


Figure 5. Mandibular measurements in sagittal view. (17) Co to CP, (18) Go to CP, (19) ramus axis to CP.

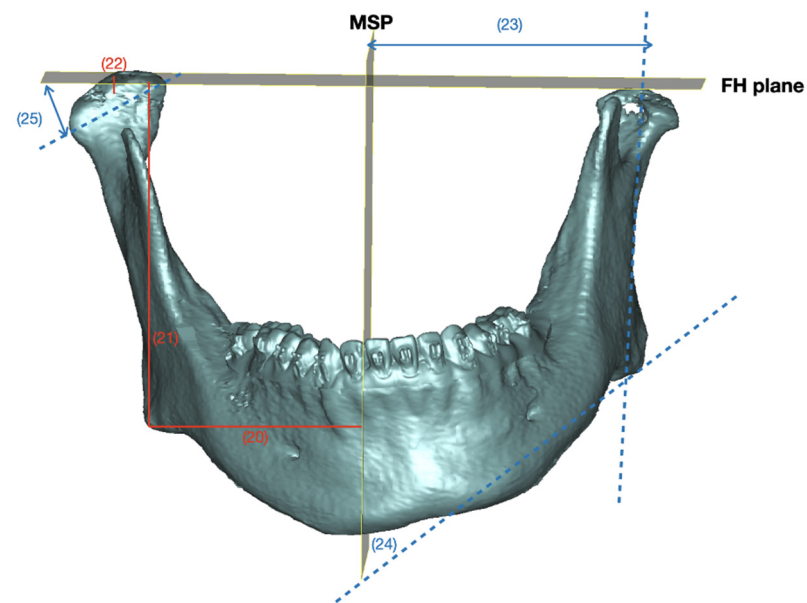


Figure 6. Mandibular measurements in frontal view. (20) Go to MSP, (21) Go to the FHP, (22) Co to the FHP, (23) Ramus axis to MSP, (24) Md axis to MSP, (25) condyle axis to the FHP.

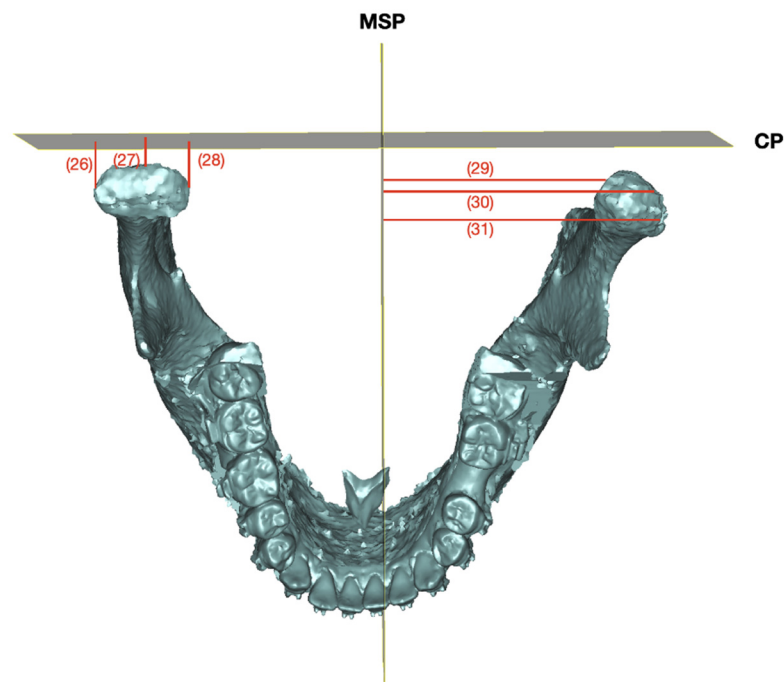


Figure 7. Mandibular condyle position measurements. (26) Medial condylar pole to CP, (27) Co to CP, (28) lateral condylar pole to CP, (29) medial condylar pole to MSP, (30) Co to MSP, (31) lateral condylar pole to MSP.

2.6. Classification of Patients after Treatment Completion (T1)

The distances from each landmark to the three reference planes were measured and used to calculate the asymmetry index: dx, dy, and dz represent the distance from the landmark to the MSP, FHP, and CP, respectively.

For bilateral asymmetry index, asymmetry index = $\sqrt{((d_{dx} - [d_{ox}])^2 + (d_{dy} - [d_{oy}])^2 + (d_{dz} - [d_{oz}])^2)}$,

where ddx, ddy and ddz represent the distance from the landmark on the deviated side to the MSP and dox, doy and doz represent the distance from the landmark on the opposite side to the MSP.

According to the asymmetry index after treatment completion, patients were categorized into the relative symmetry outcome group (group S) and the relative asymmetry outcome group (group A). One median was excluded, and each group had 18 patients. Figure 8 illustrates the study flowchart.

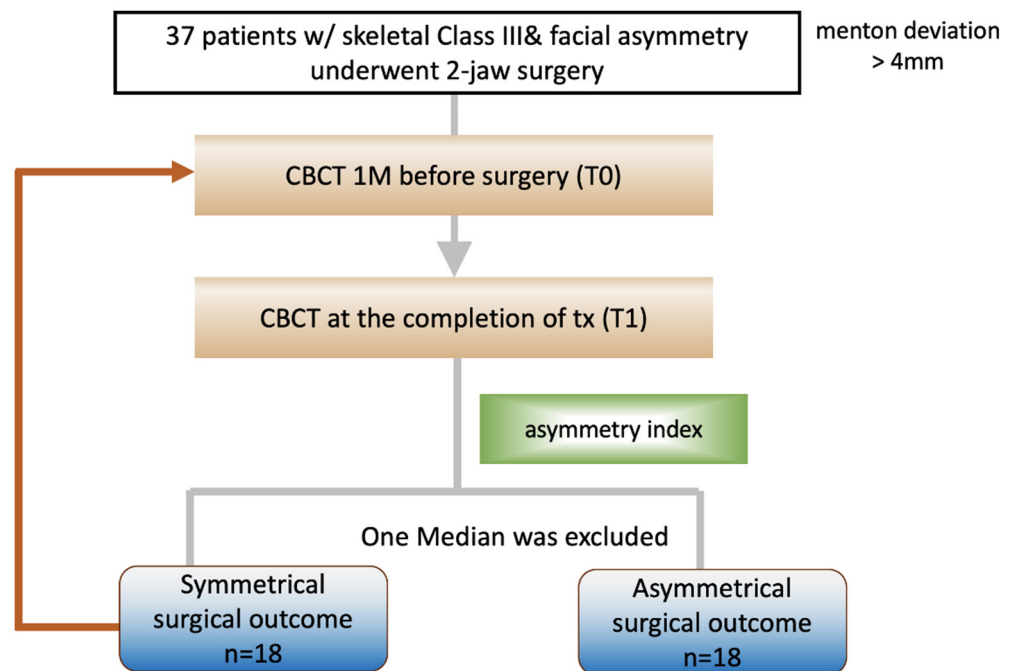


Figure 8. Flow chart for research design.

2.7. Statistical Analyses

The Mann–Whitney U test was used to compare the between-group differences in preoperative anatomical variables. $p < 0.05$ was set as statistically significant. Spearman correlation analysis was performed to examine the relationship of all dentoskeletal variables in T0 with the facial symmetry outcome—asymmetry index (T1)—for all patients.

For error study, 10 randomly selected cases were re-landmarked and measured within 3 weeks. The intraexaminer reliability test was conducted using intraclass correlation (ICC) [22] and Dahlberg’s formula [23].

3. Results

We enrolled 37 consecutive patients (21 women and 16 men), with an average age of 23.6 years (18.0–33.0 years, SD 4.6 years). Among them, 27 (72.9%) and 10 (27%) had preoperative chin deviation toward the left and right sides, respectively. Table 2 presents the descriptive data for the patients in the two groups.

Table 2. Descriptive data of the two groups of patients.

Group	Number	Sex		Age, Years		
		Female	Male	Minimum	Maximum	Mean
Symmetry	18	13	5	18	31	23.3
Asymmetry	18	8	10	18	33	24.2
Total	37	21	16	18	33	23.6

3.1. Error Study

The ICC for linear measurements was 0.91, and the measurement error determined using Dahlberg's formula was 0.21 mm. Both results indicate excellent intraexaminer reliability.

3.2. Comparison of Preoperative 3D Measurements between Groups S and A

For all midline variables, the amount of the ANS, A, U1, L1, B, Pog, Me, and Gn deviation from the MSP exhibited more discrepancy in group A than in group S, but none of these parameters indicated a significant between-group difference before surgery (Table 3).

Table 3. Comparison of 3D preoperative (T0) measurements of midline variables between groups S and A.

PreOP Midline Variables (mm)		Symmetry		Asymmetry		<i>p</i>
		Mean	SD	Mean	SD	
Maxilla	ANS to MSP	1.11	0.78	1.18	1.03	0.987
	A to MSP	1.07	0.72	1.21	0.99	0.800
	U1 to MSP	1.66	1.40	2.15	1.64	0.289
Mandible	L1 to MSP	3.97	3.29	4.32	2.11	0.887
	B to MSP	5.01	4.11	5.77	2.93	0.268
	Pog to MSP	6.36	5.07	8.03	3.94	0.117
	Gn to MSP	6.62	5.31	8.27	4.14	0.174
	Me to MSP	6.52	5.36	8.15	4.19	0.217

SD, standard deviation; Mann–Whitney U test was used for group comparison.

A significant between-group difference was detected in maxillary anterior canting and maxillary posterior canting before surgery (Table 4). The extent of anterior and posterior canting was significantly larger in group A.

Table 4. Comparison of 3D preoperative (T0) measurements of bilateral variables between symmetry and asymmetry outcome groups.

Bilateral Variables	Symmetry				Asymmetry		<i>p</i>
	ΔS		ΔA				
	Mean	SD	Mean	SD			
Maxilla							
U3 to FHP	mm	1.07	0.93	1.83	1.22	0.004 ***	
U6 to FHP	mm	1.90	1.91	2.95	1.81	0.040 *	
Mandible							
Ramus height	mm	3.90	4.16	5.98	5.23	0.235	
Body length	mm	3.64	3.11	2.22	1.54	0.195	
Gonial angle	°	8.53	18.09	2.54	1.67	0.062	
Go to MSP	mm	4.34	4.14	6.25	4.71	0.217	
Go to CP	mm	4.66	3.23	5.07	3.35	0.681	
Go to FHP	mm	1.88	1.77	5.25	4.51	0.015 *	
GF to MSP	mm	1.52	1.01	2.08	1.64	0.517	
GF to CP	mm	1.46	1.07	2.52	2.52	0.569	

Table 4. *Cont.*

Bilateral Variables		Symmetry		Asymmetry		<i>p</i>
		ΔS		ΔA		
		Mean	SD	Mean	SD	
GF to FH	mm	1.19	0.99	1.04	0.66	0.899
Co to MSP	mm	1.89	0.96	2.62	1.88	0.255
Co to CP	mm	1.89	1.27	2.72	2.26	0.527
Co to FHP	mm	1.38	1.07	1.51	1.22	0.899
CoL to MSP	mm	1.75	1.02	2.48	2.12	0.486
CoL to CP	mm	2.06	1.54	3.65	2.65	0.064
CoL to FHP	mm	1.56	1.41	2.64	1.66	0.056
CoM to MSP	mm	1.43	0.85	2.36	1.46	0.058
CoM to CP	mm	1.86	1.22	2.64	1.86	0.223
CoM to FHP	mm	2.03	2.06	1.83	1.62	0.728
Con axis to MSP	°	6.78	4.31	7.40	6.99	0.704
Con axis to CP	°	4.73	3.84	5.84	6.90	0.658
Con axis to FH	°	6.02	3.27	8.30	7.31	0.681
Ramus axis to MSP	°	4.44	2.66	5.93	4.26	0.327
Ramus axis to CP	°	4.11	2.93	3.80	1.90	0.704
Ramus axis to FH	°	11.61	20.80	4.75	3.28	0.635
Md axis to MSP	°	6.77	5.21	8.33	5.27	0.359
Md axis to CP	°	6.17	4.55	5.89	3.82	0.924
Md axis to FH	°	1.58	1.42	3.73	3.23	0.050 *

ΔS , the sum of the differences between the deviated-side and opposite-side absolute values of all patients in group S; ΔA , the sum of the differences between deviated-side and opposite-side absolute values of all patients in group A; SD, standard deviation; the Mann–Whitney U test was used for group comparison; * $p < 0.05$; *** $p < 0.01$.

In the mandible, the Go–FHP distance exhibited a discrepancy between the two sides (Δ Go to the FHP), which was 1.88 ± 1.77 mm in group S and 5.25 ± 4.51 mm in group A ($p = 0.015$). The discrepancy in the axis of the mandibular border to FH was also significantly different between the two groups ($p = 0.05$) (Table 4).

A significant difference was detected in five mandible variables at the deviated side in the distance between the coronal plane and the gonion, condyle, medial condylar pole, lateral condylar pole, and glenoid fossa (Table 5).

Table 5. Comparison of 3D preoperative (T0) measurements of bilateral variables between groups S and A (deviated side).

Deviated Side		Symmetry		Asymmetry		<i>p</i>
		Mean	SD	Mean	SD	
Maxilla						
U3 to FHP	mm	51.26	4.29	52.77	4.54	0.282
U6 to FHP	mm	47.56	4.30	48.47	4.07	0.506

Table 5. Cont.

Deviated Side	Symmetry			Asymmetry		<i>p</i>
		Mean	SD	Mean	SD	
Mandible						
Ramus height	mm	64.85	9.45	61.70	7.28	0.591
Body length	mm	85.31	5.37	87.64	4.15	0.164
Gonial angle	°	121.64	6.29	122.50	5.45	0.8
Go to MSP	mm	49.34	3.93	52.13	5.21	0.129
Go to CP	mm	24.01	4.53	19.83	4.49	0.019 *
Go to FHP	mm	62.57	7.61	60.40	7.27	0.384
GF to MSP	mm	49.84	3.69	51.15	2.91	0.174
GF to CP	mm	13.73	2.85	10.31	3.24	0.005 *
GF to FH	mm	2.66	1.67	3.18	1.57	0.393
Co to MSP	mm	53.20	3.69	54.30	4.25	0.613
Co to CP	mm	11.12	2.70	7.70	3.59	0.005 *
Co to FHP	mm	1.71	1.33	1.78	1.06	0.658
CoL to MSP	mm	61.07	3.22	62.19	4.15	0.488
CoL to CP	mm	17.01	2.78	14.18	4.39	0.034 *
CoL to FHP	mm	7.66	3.16	5.80	2.77	0.164
CoM to MSP	mm	42.13	3.10	43.54	3.29	0.242
CoM to CP	mm	13.53	3.02	9.75	2.86	0.001 ***
CoM to FHP	mm	4.25	3.74	4.08	2.52	0.776
Con axis to MSP	°	73.28	7.98	73.48	7.64	0.95
Con axis to CP	°	10.15	5.59	13.05	7.42	0.268
Con axis to FH	°	11.80	8.05	8.31	5.76	0.206
Ramus axis to MSP	°	11.58	21.53	3.09	2.73	0.069
Ramus axis to CP	°	10.57	4.64	11.37	5.30	0.776
Ramus axis to FH	°	74.23	15.24	77.88	5.25	0.613
Md axis to MSP	°	29.95	3.68	30.15	3.62	0.849
Md axis to CP	°	52.64	5.71	50.60	5.50	0.296
Md axis to FH	°	19.73	5.00	22.49	4.57	0.255

SD, standard deviation; the Mann–Whitney U test was used for group comparison; * $p < 0.05$; *** $p < 0.01$.

A significant difference was observed in two opposite-side mandible variables, in the distances between the MSP and lateral condylar pole ($p = 0.012$) and medial condylar pole ($p = 0.043$) (Table 6).

Table 6. Comparison of 3D preoperative (T0) measurements of bilateral variables between groups S and A (opposite side).

Opposite Side		Symmetry		Asymmetry		<i>p</i>
		Mean	SD	Mean	SD	
Maxilla						
U3 to FHP	mm	51.89	3.99	54.30	4.60	0.141
U6 to FHP	mm	49.06	4.33	51.07	4.32	0.195

Table 6. Cont.

Opposite Side	Symmetry			Asymmetry		<i>p</i>
		Mean	SD	Mean	SD	
Mandible						
Ramus height	mm	67.36	10.15	67.04	7.55	0.548
Body length	mm	88.38	5.18	89.05	4.48	0.825
Gonial angle	°	123.82	5.25	124.04	5.71	0.937
Go to MSP	mm	45.48	3.36	46.99	3.66	0.217
Go to CP	mm	26.43	7.10	24.37	5.27	0.174
Go to FHP	mm	63.24	7.52	64.91	7.59	0.448
GF to MSP	mm	50.30	2.60	52.17	3.22	0.066
GF to CP	mm	13.03	3.56	11.72	2.57	0.229
GF to FH	mm	3.41	2.05	3.05	1.47	0.635
Co to MSP	mm	53.73	3.28	56.05	3.82	0.107
Co to CP	mm	10.64	3.08	8.89	2.41	0.076
Co to FHP	mm	1.79	1.08	2.07	1.52	0.937
CoL to MSP	mm	60.99	2.69	63.61	3.70	0.012 *
CoL to CP	mm	17.18	3.09	16.23	2.85	0.393
CoL to FHP	mm	7.53	2.91	6.93	3.36	0.658
CoM to MSP	mm	42.45	2.71	44.56	3.14	0.043 *
CoM to CP	mm	12.69	3.01	11.36	2.93	0.235
CoM to FHP	mm	3.81	3.10	3.37	2.64	0.635
Con axis to MSP	°	69.43	6.64	70.10	9.96	0.359
Con axis to CP	°	12.96	4.94	13.88	5.92	0.527
Con axis to FH	°	14.10	8.34	11.65	10.79	0.184
Ramus axis to MSP	°	14.31	20.49	7.73	4.39	0.548
Ramus axis to CP	°	13.16	6.29	13.45	5.01	0.95
Ramus axis to FH	°	70.49	14.28	73.50	3.67	0.899
Md axis to MSP	°	36.09	3.85	38.37	3.34	0.076
Md axis to CP	°	47.54	3.38	45.09	3.50	0.054
Md axis to FH	°	18.60	5.07	19.06	4.91	0.837

SD, standard deviation; the Mann–Whitney U test was used for group comparison; * $p < 0.05$.

3.3. Correlation of the Asymmetry Index with Presurgical Variables

The asymmetry index had positive low-to-moderate correlations with the six preoperative variables: $\Delta U3$ to the FHP ($r = 0.340$), $\Delta U6$ to the FHP (0.348), Δ mandibular border axis to the FHP ($r = 0.332$), CoL ($r = 0.422$)/CoM ($r = 0.342$) of the opposite side to MSP, and Δ Go to the FHP ($r = 0.409$) (Figure 9). The asymmetry index was negatively correlated with five preoperative variables: Co ($r = -0.476$), CoM ($r = -0.546$), CoL ($r = -0.358$), GF ($r = -0.471$), and Go of the deviated side to CP ($r = -0.396$). It showed that the distance of the deviated-side variables to the coronal plane in group A was negatively correlated with the asymmetry index, while the distance of the opposite side variables to the MSP was positively correlated with the asymmetry index. The bilateral discrepancies demonstrated a positive correlation with the asymmetry index.

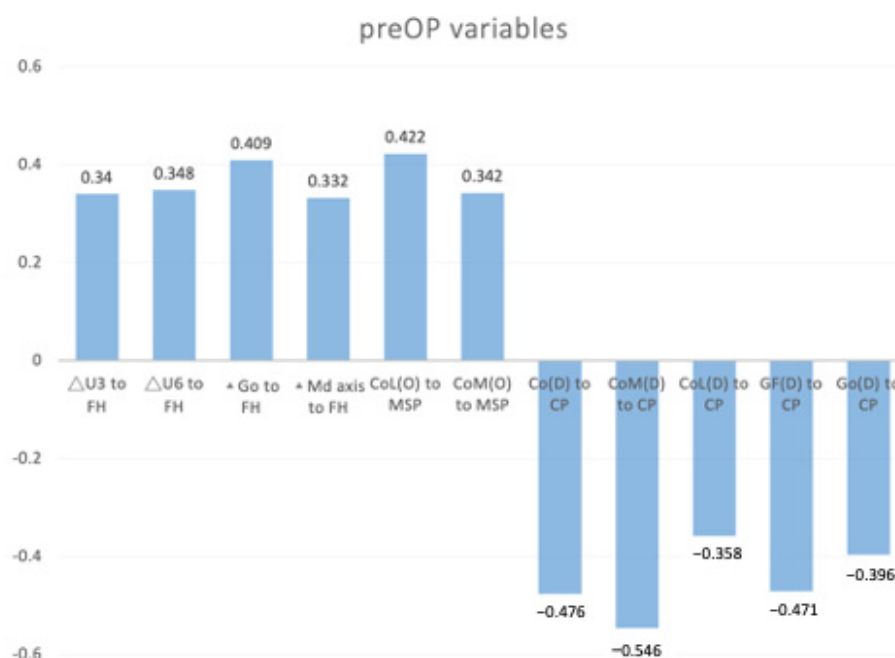


Figure 9. Significant correlation of the asymmetry index with preoperative variables. Spearman correlation was used for statistical analysis. The asymmetry index was positively correlated with the six preoperative variables and negatively correlated with five preoperative variables.

4. Discussion

This study used 3D linear and angular measurements to clarify the preoperative anatomical variables affecting the outcome of surgical correction in Class III facial asymmetry.

Patients with skeletal Class III malocclusion and facial asymmetry, with a menton deviation greater than 4 mm, were included in this study. According to Kwon et al., the perception of asymmetry of a chin deviation of 2 mm to the right and 4 mm to the left is not detected clinically [24]. Alongside that, most individuals, whether dental professionals or laymen, can notice a chin deviation of more than 4 mm [25]. Thus, it is acceptable to define 4 mm of menton deviation relative to MSP as facial asymmetry. The mean preoperative menton deviation in the two groups was 6.52 ± 5.36 mm in group S and 8.15 ± 4.19 mm in Group A (Table 3). The patients included in our study showed a severe deviation of menton, indicating a greater severity of facial asymmetry.

After treatment completion, facial asymmetry significantly improved in all patients, but did not completely resolve. Lin et al. reported that preoperative 3D dentoskeletal variables were not related to subjective visual perceptions of postoperative asymmetry [14]. In the present study, we used a more objective method to define postoperative asymmetry. However, the menton deviation decreased significantly after treatment, and the difference in midline deviation was not appropriate for defining postoperative symmetry and asymmetry. Currently, there is no objective 3D index to represent the degree of facial asymmetry. Therefore, we used the asymmetry index at treatment completion to classify patients into two groups and evaluate the preoperative variables.

We observed that only bilateral variables, and not midline variables, significantly affected the surgical outcomes. This may be because midline deviation is already corrected by surgeons with the aid of 3D surgical simulation [10,11]. For bilateral discrepancy, four variables were observed to significantly affect the surgical outcome: (1) maxillary anterior occlusal canting, (2) maxillary posterior occlusal canting, (3) Δ Go to the FHP, and (4) Δ mandibular axis to the FHP. These variables indicate the “roll asymmetry” of the maxilla and mandible.

For maxillary occlusal canting, the greater the preoperative discrepancy, the higher the possibility of residual asymmetry. However, maxillary occlusal canting was corrected well in both groups. Thiesen et al. found that the odds of presenting with mandibular asymmetry

were significantly higher in the presence of maxillary asymmetry [26]. The mandible is often associated with craniofacial asymmetries, with maxillary asymmetries often secondary to asymmetrical mandibular growth [27]. Severe maxillary canting might indicate more severe deviation of the mandible and more severe asymmetry of the whole face. The occlusal plane canting was usually the result of compensating growth to mandibular asymmetry. The reasons underlying the correlations are not certain and deserve future investigation.

Correction of bilateral gonion contour discrepancy is more difficult and relies more on the surgeon's decision-making during surgery. Trimming or contouring the gonion angle or adaptation of the proximal and distal segments all affect the surgical outcome. Presurgical ΔGo to MSP did not affect the surgical outcome, but ΔGo to the FHP and Go of the deviated side to CP showed a significant between-group difference. This might indicate that the preoperative roll (ΔGo to the FHP) and yaw (Go of the deviated side to CP) mandibular asymmetry affects the outcome. In Asia, most patients request mandibular angle reduction during surgery due to the preference for a slim and oval face [20]. Thus, the 3D gonion point would be altered after surgical contouring of the mandibular angle.

In mandibular variables on the deviated side, a significant difference was observed in the distances between the bilateral gonion, glenoid fossa, condyle, and medial and lateral condylar poles and the coronal plane between groups A and S. The distance of the deviated side variables to the coronal plane was smaller in group A than in group S. On the opposite side, the distances between the bilateral medial and lateral condylar poles to the MSP were significantly different between the two groups. The distance in group A is greater than that in group S. The different results between the deviated and opposite side variables indicate that the preoperative condyle position in the sagittal and transverse directions might relate to a higher asymmetry index after surgery. One reason is that the condyle and glenoid fossa might be anatomical limitations, because we could not move or change their original position during surgery. This should be considered during 3D planning. In clinical situations, when the distance of the CoL–MSP is greater in the opposite side than in the deviated side, the ramus axis is affected, causing facial asymmetry, even when the midline landmarks are perfectly aligned. In such cases, the patient should be informed preoperatively of a greater chance of residual asymmetry. The mandible border contouring or fat transplantation are choices for further asymmetry correction [8].

Some studies have discussed different surgical techniques to improve the outcome of ramus symmetry. The greatest advantage of intraoral vertical ramus osteotomy (IVRO) over BSSO is a lower incidence of injury to the inferior alveolar nerve [28,29]. Other advantages of IVRO include technical simplicity, shorter operation time, and less adverse effects related to the temporomandibular joint [30]. However, BSSO provides better bony interface with proximal and distal segments, and easier use of rigid fixation, thus minimizing the need for intermaxillary fixation [31]. Therefore, there is larger interference between the proximal and distal segments in IVRO during mandibular setback, resulting in a more significant increase of the total ramus angle, compared with that in BSSO [32]. However, Lee et al. had a different opinion: they reported a series of three cases with severe rotational asymmetry, using unilateral IVRO on the shorter side combined with sagittal split ramus osteotomies on the contralateral side for a greater setback [33]. They proposed that IVRO causes less rotational displacement of the proximal segment on the deviated side. The condylar segments that were displaced or rotated during surgery might return to their original physiologic position. The outcome and stability of the two different combined osteotomies on the mandible, in correction of face asymmetry, require further investigation.

Many factors are related to residual facial asymmetry, such as anatomical factors, surgical factors, surgical relapse, soft tissue response and adaptation, and asymmetric dynamic facial movement. However, in this study, we only discussed anatomical factors. This study also had the following limitations: first, we only discussed skeletal and dental variables, while the information of real facial soft tissue appearance was lacking. Second, the 3D reference planes were designed by skeletal landmarks; the setting of the 3D reference plane may be different from real patients. In clinical situations, the whole face,

including eyes and ears, should be considered when deciding the reference plane. Finally, considerable interindividual variation may exist in the etiology of facial asymmetry, and thus, variables accounting for each type of asymmetry classification. Further investigations might be needed to develop different surgical consideration and modification for outcome improvement in correction of facial asymmetry. Additionally, a larger sample size and soft tissue evaluation could provide more informative outcome assessment in the future study.

5. Conclusions

- Patients with severe skeletal Class III asymmetry, preoperative anatomical variables of the maxillary occlusal plane cant, bilateral gonion discrepancy to the FHP, bilateral mandibular axis discrepancy to the FHP, and sagittal and transverse of condyle position, were related to an achievement of favorable outcomes in asymmetry correction.
- In sagittal mandible dimension, a significant between-group difference was noted in the distances from the condyle, medial and lateral condylar poles, glenoid fossa, and gonion of the deviated side, to the coronal plane.
- In the transverse dimension, a significant between-group difference was noted in the distances from the medial and lateral condylar poles of the opposite side, to the MSP. In surgical correction of face asymmetry, “roll” and “yaw” discrepancies and anatomical limitations are critical factors affecting treatment outcomes.

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