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ORIGINAL ARTICLE

Treatment outcome of bimaxillary surgery for asymmetric skeletal class II deformity

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Abstract

Objectives Facial asymmetry is one of the main concerns in patients with a dentofacial deformity. The aims of the study were to (1) evaluate the changes in facial asymmetry after bimaxillary surgery for asymmetric skeletal class II deformity and (2) compare preoperative and postoperative facial asymmetry of class II patients with normal controls.

Materials and methods The facial asymmetry was assessed for 30 adults (21 women and 9 men, mean age: 29.3 years) who consecutively underwent bimaxillary surgery for asymmetric skeletal class II deformity using cone-beam computed tomography before and at least 6 months after surgery. Thirty soft tissue and two dental landmarks were identified on each three-dimensional facial image, and the asymmetry index of each landmark was calculated. Results were compared with those of 30 normal control subjects (21 women and 9 men, mean age: 26.2 years) with skeletal class I structure.

Results Six months after surgery, the asymmetric index of the lower face and total face decreased significantly (17.8 ± 29.4 and 16.6 ± 29.5 mm, respectively, both $p < 0.01$), whereas the asymmetric index of the middle face increased significantly (1.2 ± 2.2 mm, $p < 0.01$). Postoperatively, 53% of the class II patients had residual chin asymmetry. The postoperative total face asymmetric index was positively correlated with the preoperative asymmetric index ($r = 0.37$, $p < 0.05$).

Conclusions Bimaxillary surgery for patients with asymmetric class II deformity resulted in a significant improvement in lower face asymmetry. However, approximately 50% of the patients still had residual chin asymmetry. The total face postoperative asymmetry was moderately related to the initial severity of asymmetry.

Clinical relevance These findings could help clinicians better understand orthognathic outcomes on different facial regions for patients with asymmetric class II deformity.

Keywords Orthognathic surgery · Facial asymmetry · Class II malocclusion · Asymmetry index

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Introduction

Facial symmetry is generally recognized as one of the features of attractive faces [1, 2]. Although some amounts of facial asymmetry are acceptable and are present on what are considered to be beautiful and attractive faces [3, 4], significant facial asymmetry might severely influence facial appearance and induce psychosocial distress to patients.

The causes of facial asymmetry include skeletal asymmetry, soft tissue asymmetry, and functional asymmetry or a combination [5, 6]. Of these, skeletal asymmetry involving the maxillofacial region is predominant. Orthognathic surgery (OGS) is the only procedure for correcting jaw asymmetry in adult patients. Although several studies have reported the outcome after bimaxillary OGS for facial asymmetry, the lack of normal controls in these studies prevents an objective assessment of whether the outcome is ideal [7–12]. Moreover, types of malocclusion in most of these studies were heterogenous; therefore, the outcome of class II asymmetry was unclear [7, 9–11]. Although Hajeer et al. reported the outcome of 12 patients with class II deformity, only two of them presented with facial asymmetry before surgery [8]. Furthermore, asymmetric class II patients undergoing bimaxillary OGS have never been systematically studied for outcomes on the areas (e.g., nose, cheek, lip, chin, contour, incisor), parts (midline, paramedian, contour), or zones (middle, lower) of the face. A better understanding of the OGS outcomes on facial areas, parts, or zones may have important clinical implications, including the development of more comprehensive surgical designs that consider facial asymmetry as well as improvements in consultations with patients for this surgical modality.

One of the best methods for assessing the three-dimensional structure of the face is cone-beam computed tomography (CBCT), which has been demonstrated to be a powerful research tool [12, 13]. Although CBCT provides untextured soft tissue data, it can also provide information regarding dental and hard tissue components. Incisors are directly visualized; therefore, they are important for development of a treatment plan and evaluation of the treatment outcome. In addition, because of their higher stability and reproducibility of landmark identification compared to soft tissues, hard tissues are essential for head orientation, registration of CBCT at different timings, and construction of a 3D coordinate system for each subject. Therefore, this CBCT study aimed to (1) evaluate the outcome of bimaxillary OGS in patients with asymmetric skeletal class II deformity and (2) compare the preoperative and postoperative facial asymmetry of class II patients with control subjects. The null hypotheses to be tested were (1) facial asymmetry after bimaxillary OGS is not different from pre-surgery, and (2) the facial asymmetry after bimaxillary OGS is not significantly different from that of normal controls.

Materials and methods

Patients with asymmetric class II deformity

Thirty Taiwanese adults (age ≥ 18 years) with class II deformity (A point–nasion–B point angle > 4°) and significant facial asymmetry (skeletal menton deviation ≥ 2 mm or lip cant ≥ 2 mm) were selected consecutively based on the following criteria: (1) Le Fort I osteotomy and bilateral sagittal split osteotomy (BSSO) advancement surgery by the attending surgeons supervised by one senior surgeon with more than 40 years of experience at the Chang Gung Craniofacial Center between 2010 and 2015, (2) no progressive or chronic temporomandibular joint disorder, (3) no history of craniofacial surgery, (4) no craniofacial deformity or genetic syndromes, and (5) CBCT evaluation at two time points: before surgery and at least 6 months after surgery (i.e., at orthodontic debonding). The hospital's institutional review board approved the study.

Control subjects

Control subjects were 30 Taiwanese adults with skeletal class I (0 < A point–nasion–B point angle < 4°) and dental class I occlusion. Control subjects were selected consecutively from patients who had undergone CBCT at the Chang Gung Dental Department between 2010 and 2014 for other dental indications (e.g., implant, third molars, dental crowding, or spacing). Controls were excluded based on the following criteria: (1) craniofacial anomaly, (2) anterior open bite, (3) severe dental crowding or spacing, (4) significant facial asymmetry, or (5) history of craniofacial surgery. These subjects were used to generate 3D norms.

Surgical technique

The BSSO was modified from Hunsuck [14] by extending the anterior cut of the osteotomy to the first molar [15, 16]. The Le Fort I osteotomy was performed with a technique similar to that popularized by Bell [17]. No additional surgical intervention other than genioplasty was performed. Rigid fixation was performed with bone plates or screws.

CBCT

CBCT of the head and neck was performed during wakefulness using an i-CAT 3D Dental Imaging System (Imaging Sciences International, Hatfield, PA) with the following parameters: 120 kVp, 0.4 mm × 0.4 mm × 0.4 mm voxel size, 40 s scan time, and 16 cm × 16 cm field of view. The patient's head was positioned with the Frankfort horizontal (FH) plane parallel to the ground. Throughout the scan, patients were asked not to swallow.

Images were stored in the Digital Imaging and Communications in Medicine (DICOM) format and then transferred to a workstation (Avizo v7.0.0 software, VSG, Bordeaux, France) where they were rendered into volumetric images, segmented, and analyzed by one single investigator (CYF) blinded to subjects' treatment histories. Before analysis, six skeletal landmarks were selected for registration of the 3D images in a 3D coordinate system (*x, y, z*) with nasion (N) as the zero point: N, bilateral porion (Po), bilateral orbitale (Or), and basion (Ba). The definition of skeletal landmarks [18] and reference planes are provided in Table 1. A positive coordinate value indicates the left, posterior, and superior side of the face, and a negative value indicates the opposite (Fig. 1). Cranial structures not affected by the surgery were selected to superimpose the CBCT images taken before and after surgery in order to register them in the same 3D coordinate system.

After registration of the 3D images, 30 soft tissue and 2 dental landmarks [13, 18] (Table 2 and Fig. 2) were located

Table 1 Definitions of skeletal landmarks and reference planes

Landmarks	Symbol	Definition
Nasion	N	The midpoint of the frontonasal suture
Porion	Po	The most superior point of each external acoustic meatus
Orbitale	Or	The most inferior point of each infraorbital rim
Basion	Ba	The most anterior point of foramen magnum
Reference planes		
Frankfort horizontal (FH) plane		The best-fit plane passing through bilateral porion and orbitale
Horizontal plane		A plane parallel with the FH plane and passing through nasion
Midsagittal plane		A plane perpendicular to the horizontal reference plane and passing through nasion and basion
Coronal plane		A plane perpendicular to the horizontal and midsagittal reference planes and passing through nasion

on the 3D surface model with coordinates (x, y, z) by the same investigator (CYF) in random order. Multiplanar reconstruction views were also used to identify the landmark when necessary.

Asymmetry index (AI)

To evaluate facial asymmetry, the distances of each landmark to three reference planes were measured as dx, dy, and dz in millimeters [19]. The values of dx, dy, and dz of the nasion were zero. For each paired bilateral landmark, the differences in dx, dy, and dz between the right side and left side indicated the discrepancy of the paired landmarks in three dimensions. For perfect symmetrical paired bilateral landmarks located in the paramedian part, the discrepancy in dx, dy, and dz must approach zero. For perfect symmetrical paired bilateral landmarks located in the contour part, the discrepancy in dx must approach zero because symmetry of facial contour is always perceived from the frontal view. In other words, it is not necessary to take the dy into account. Therefore, the perfect contour symmetry should fulfill the following criteria: no discrepancy in the distance of the bilateral most lateral points of the face from the facial midline on the same horizontal level.

Thus, an AI for each landmark was calculated and designated as follows:

AI of facial midline landmarks = dx;
AI of facial paramedian landmarks = $\sqrt{(Ldx - Rdx)^2 + (Ldy - Rdy)^2 + (Ldz - Rdz)^2}$, where L = left and R = right;
AI of facial contour landmarks = $\sqrt{(Ldx - Rdx)^2}$, where L = left and R = right.

To evaluate facial asymmetry, a total face AI was created, which is the sum of each landmark AI. In addition, every region AI was created, which is the sum of each landmark AI in that region (Table 3). For perfect symmetry, the AI must approach zero.

To define residual asymmetry in class II patients, a cutoff value derived from the normal controls (i.e., mean plus 2 standard deviations [SD]) was calculated [20, 21]. If the postoperative AI was higher than the cutoff value, the asymmetry was more severe than that of approximately 97.72% of the control subjects, which was considered as residual asymmetry (i.e., abnormal asymmetry).

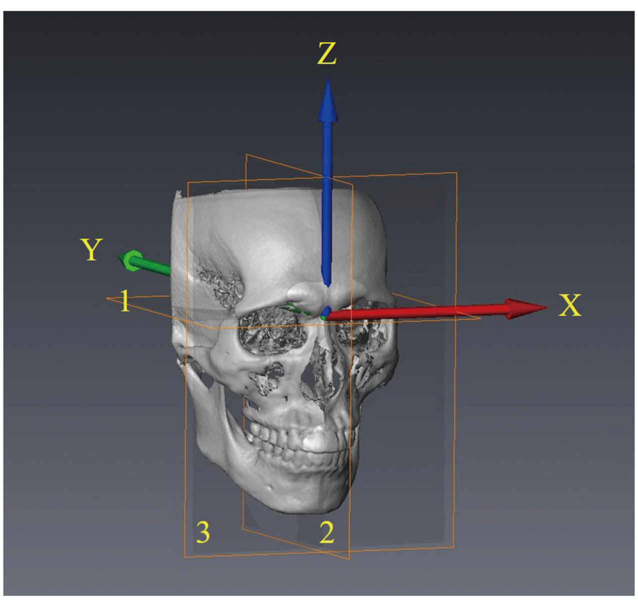


Fig. 1 Reference planes for the 3D coordinate system: X axis (right-left); Y axis (posterior-anterior); Z axis (up-down); 1, Horizontal plane; 2, Midsagittal plane; 3, Coronal plane

Reliability

To assess intra-examiner reliability, all CBCT measurements were repeated by the same investigator for ten randomly chosen patients 1 month after the measurements. Intra-examiner reliability, analyzed by the intraclass correlation coefficient (ICC), was excellent (mean ICC, 0.954; 95% confidence interval, 0.928 to 0.969).

Table 2 Definitions of landmarks used for asymmetry index calculation

Landmarks	Symbol	Definition
Soft tissue midline landmark		
Pronasale	Pn	The most anterior midpoint of the nasal tip
Subnasale	Sn	The midpoint on the nasolabial soft tissue contour between the columella crest and the upper lip
Labiale superius	Ls	The midpoint of the vermilion line of the upper lip
Stomion	Sto	The midpoint of the horizontal labial fissure
Labiale inferius	Li	The midpoint of the vermilion line of the lower lip
Soft tissue B point	B′	The most posterior midpoint on the labiomental soft tissue contour that defines border between the lower lip and the chin
Soft tissue pogonion	Pg′	The most anterior midpoint of the chin
Soft tissue menton	Me′	The most inferior midpoint on the chin located at the level of the 3D cephalometric hard tissue menton landmark
Soft tissue bilateral landmark		
Alare	Ala	The most lateral point on each alar contour
Cheek	Chk	The most prominent point of the cheek
Cupid's bow	Cu	The most prominent point of the vermilion border of the Cupid's bow of the upper lip
Cheilion	Ch	The point located at each labial commissure
Soft tissue lateral chin point	lC′	The most inferior and lateral point on each angle of the chin
Contour Sn point	cSn	The intersection point formed by the most lateral point on the face and the line parallel to the horizontal plane passing through Sn
Contour Ls point	cLs	The intersection point formed by the most lateral point on the face and the line parallel to the horizontal plane passing through Ls
Contour Sto point	cSto	The intersection point formed by the most lateral point on the face and the line parallel to the horizontal plane passing through Sto
Contour Li point	cLi	The intersection point formed by the most lateral point on the face and the line parallel to the horizontal plane passing through Li
Contour B′ point	cB′	The intersection point formed by the most lateral point on the face and the line parallel to the horizontal plane passing through B′
Contour Pg′ point	cPg′	The intersection point formed by the most lateral point on the face and the line parallel to the horizontal plane passing through Pg′
Dental landmark		
Upper incisal embrasure	UIE	The incisal embrasure between the upper central incisors
Lower incisal embrasure	LIE	The incisal embrasure between the lower central incisors

Statistical analysis

Statistical analyses were performed using the statistical software package SPSS version 17.0 for Windows (SPSS Inc., Chicago, USA). Patient clinical characteristics and CBCT-measured variables were compared before and after surgery using paired *t*, independent *t*, or chi-square test when indicated. Pearson correlation analysis was used to assess correlation between postoperative AI and preoperative AI. Probabilities of 0.05 or less were accepted as significant.

Results

Subject characteristics

We studied 30 patients with asymmetric class II deformity (mean age, 29.3 ± 5.6 years; range, 19.0–47.0) and 30 control subjects (mean age, 26.2 ± 4.5 years; range, 18.1–35.5). Patients with class II deformity were not significantly different from control subjects at baseline with respect to sex and overbite. The mean time after surgery was 20.6 ± 7.2 months (range 8.2 to 34.6 months) (Table 4).

Postsurgical changes in class II patients

The surgery was highly effective for class II deformity with significant improvement in the ANB angle (from 7.2 ± 2.0 to 3.7 ± 1.5°, $p < 0.001$) and overjet (from 4.8 ± 3.0 to 2.7 ± 0.6 mm, $p < 0.01$). After surgery, the AI of the lower face and total face decreased significantly, whereas the AI of the middle face increased significantly (all $p < 0.01$). The AI of the chin, lower contour, and lower incisor decreased significantly ($p < 0.001$, $p < 0.05$, and $p < 0.01$, respectively); however, the AI of the nose and upper incisor increased significantly ($p < 0.001$ and $p = 0.05$, respectively). The AI of the midline and paramedian parts decreased significantly (both $p < 0.01$) (Table 5).

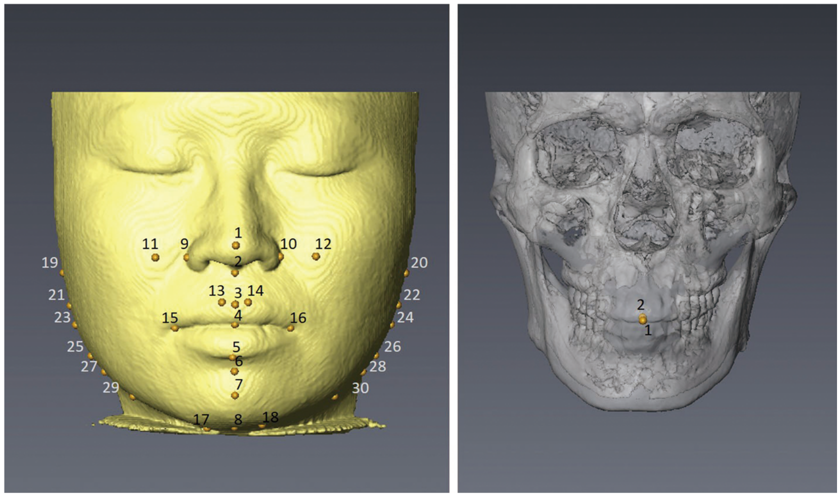


Fig. 2 Soft tissue and dental landmarks for calculation of asymmetry index. (Left) Soft tissue landmarks: 1, pronasale (Pn); 2, subnasale (Sn); 3, labiale superius (Ls); 4, stomion (Sto); 5, labiale inferius (Li); 6, soft tissue B point (B′); 7, soft tissue pogonion (Pg′); 8, soft tissue menton (Me′); 9, alare right (AlaR); 10, alare left (AlaL); 11, cheek right (ChkR); 12, cheek left (ChkL); 13, cupid's bow right (CuR); 14, cupid's bow left (CuL); 15, cheilion right (ChR); 16, cheilion left (ChL); 17, soft tissue lateral chin point right (lC′R); 18, soft tissue lateral chin point left (lC′L); 19, contour Sn point right (cSnR); 20, contour Sn point left (cSnL); 21, contour Ls point right (cLsR); 22, contour Ls point left (cLsL); 23, contour Sto point right (cStoR); 24, contour Sto point left (cStoL); 25, contour Li point right (cLiR); 26, contour Li point left (cLiL); 27, contour B′ point right (cB′R); 28, contour B′ point left (cB′L); 29, contour Pg′ point right (cPg′R); 30, contour Pg′ point left (cPg′L). (Right) dental landmarks: 1, upper incisal embrasure (UIE); 2, lower incisor embrasure (LIE)

Frequency of residual asymmetry in class II patients

After surgery, 66.7% of the Class II patients had residual face asymmetry which was major on the lower face (60%), the midline (80%), and the paramedian (66.7%) parts, or the areas of the nose, upper lip, chin, upper and lower incisors from seven midline landmarks (Sn, Ls, B′, Pg′, Me′, UIE, and LIE), and the transverse differences of two paramedian landmarks (Cu and lC′) (Table 5 through Table 6). Figures 3 and 4 show a patient before and after treatment.

Table 3 Definitions of regional and total face asymmetry index (AI)

	Asymmetry index (AI) summation
Area AI	
Nose	AIs of Pn, Sn, and Ala
Cheek	AI of Chk
Upper lip	AIs of Ls, Sto, and Cu
Lower lip	AIs of Li and Ch
Chin	AIs of B′, Pg′, Me′, and lC′
Upper contour	AIs of cSn, cLs, and cSto
Lower contour	AIs of cLi, cB′, and cPg′
Upper incisor	AI of UIE
Lower incisor	AI of LIE
Part AI	
Midline	AIs of Pn, Sn, Ls, Sto, Li, B′, Pg′, Me′, UIE, and LIE
Paramedian	AIs of Ala, Chk, Cu, Ch, and lC′
Contour	AIs of upper and lower contour
Zone AI	
Middle face	AIs of nose and cheek
Lower face	AIs of upper lip, lower lip, chin, upper contour, lower contour, upper incisor, and lower incisor
Total Face AI	AIs of middle and lower face

For definition of landmarks, please refer to Table 2

Correlation between postoperative AI and preoperative AI

Postoperative AI was positively correlated with preoperative AI in five areas: nose, cheek, upper lip, chin, and lower incisor ($r = 0.38$–0.81, $p < 0.05$ for cheek, chin, and lower incisor and $p < 0.001$ for nose and upper lip), two parts: midline and paramedian ($r = 0.54$, $p < 0.01$ and $r = 0.36$, $p < 0.05$, respectively), middle face ($r = 0.71$, $p < 0.001$), and total face ($r = 0.37$, $p < 0.05$) (Table 7).

Discussion

To our knowledge, this is the first study to exclusively evaluate the treatment outcome of facial asymmetry after bimaxillary surgery for adult patients with asymmetric skeletal class II deformity. This study provided outcome details by dividing a face into several regions, which could be affected by OGS. The bimaxillary surgery significantly improved asymmetry in the lower face on the chin, lower contour, and lower incisor. However, 53.3% of the patients still had residual chin asymmetry, which was prominent in the transverse direction.

Table 4 Patients' characteristics before treatment

	Class II ($n = 30$)	Controls ($n = 30$)	p*
Female, n (%)	21 (70)	21 (70)	1.000**
Age at CBCT, years	29.3 ± 5.6	26.2 ± 4.5	0.023
ANB, degrees	7.2 ± 2.0	2.7 ± 1.9	< 0.001
Overjet, mm	4.8 ± 3.0	3.0 ± 1.3	0.003
Overbite, mm	2.6 ± 3.3	2.2 ± 1.8	0.576
Duration of post-operative follow-up, months	20.6 ± 7.2		

Data are means ± SD except where otherwise indicated

*Independent t test

**Chi-square test

Facial asymmetry is a biological variation that commonly occurs in humans; therefore, it is crucial for clinicians to differentiate normal asymmetry from abnormal asymmetry. On the basis of AI measurements from the normal controls, we found that normal asymmetry was more severe in the lower face than the middle face, which is in agreement with previous studies [22–24]. In addition, normal asymmetry was severe in the contour part, moderate in the paramedian part, and mild in the midline part, suggesting a size difference between right and left faces in normal faces.

To identify patients with abnormal asymmetry, we derived a cutoff value, which we defined as the mean plus 2 SD from normal controls. Any asymmetry exceeding this value was considered greater than normal (i.e., abnormal). Similar to

Table 5 Asymmetry index (AI) before and after surgery in class II patients

	Class II ($n = 30$)		p	Controls ($n = 30$)	Cutoff value*	Frequency of initial asymmetry**, %	Frequency of residual asymmetry***, %
	T1	T2					
Area AI							
Nose	2.4 ± 2.6	3.7 ± 2.9	< 0.001	1.9 ± 0.7	3.3	10.0	46.7
Cheek	1.9 ± 1.1	1.9 ± 1.0	0.719	1.5 ± 0.8	3.1	16.7	16.7
Upper lip	3.4 ± 2.7	4.3 ± 3.2	0.067	1.4 ± 1.1	3.6	33.3	46.7
Lower lip	5.8 ± 3.4	4.6 ± 2.9	0.097	2.6 ± 1.1	4.8	50.0	33.3
Chin	23.9 ± 14.3	12.0 ± 7.4	< 0.001	4.7 ± 2.5	9.7	83.3	53.3
Upper contour	7.8 ± 6.4	6.8 ± 5.0	0.408	3.9 ± 2.7	9.3	26.7	26.7
Lower contour	12.1 ± 8.9	8.0 ± 4.8	0.032	4.6 ± 2.9	10.4	53.3	26.7
Upper incisor	1.1 ± 0.8	1.7 ± 1.5	0.054	0.7 ± 0.4	1.5	30.0	50.0
Lower incisor	2.7 ± 1.7	1.8 ± 1.5	0.008	0.6 ± 0.6	1.9	63.3	46.7
Part AI							
Midline	20.9 ± 11.5	15.0 ± 7.1	0.002	5.5 ± 2.3	10.0	83.3	80.0
Paramedian	20.4 ± 9.8	14.8 ± 4.9	0.003	8.0 ± 2.2	12.5	80.0	66.7
Contour	19.9 ± 14.6	14.8 ± 9.3	0.093	8.6 ± 5.1	18.8	36.7	33.3
Zone AI							
Middle face	4.3 ± 2.8	5.5 ± 3.0	0.005	3.4 ± 1.2	5.8	16.7	36.7
Lower face	56.9 ± 30.6	39.1 ± 13.0	0.003	18.7 ± 7.3	33.3	76.7	60.0
Total face AI	61.2 ± 31.7	44.6 ± 13.6	0.005	22.1 ± 7.8	37.6	76.7	66.7

T1 before surgery, *T2* after surgery

Data are means ± SD except where otherwise indicated. For definition of regional or total face AI please refer to Table 3

*Cutoff value is mean plus 2 SD derived from the normal controls

**Preoperative AI is higher than the cutoff value

***Postoperative AI is higher than the cutoff value

Table 6 Landmark asymmetry index (AI) before and after surgery in class II patients

	Class II ($n = 30$)		p	Controls ($n = 30$)	Cutoff value*	Frequency of initial asymmetry**, %	Frequency of residual asymmetry***, %
	T1	T2					
Nose							
Pn AI	0.6 ± 0.8	0.8 ± 1.0	0.055	0.4 ± 0.3	0.9	10.0	30.0
Sn AI	0.3 ± 0.8	0.8 ± 0.9	< 0.001	0.2 ± 0.2	0.5	10.0	50.0
Ala AI	1.4 ± 1.1	2.0 ± 1.2	0.004	1.3 ± 0.6	2.5	6.7	36.7
dAlax	0.7 ± 1.0	1.5 ± 1.3	< 0.001	0.8 ± 0.6	1.9	3.3	40.0
dAlay	0.8 ± 0.7	0.9 ± 0.7	0.647	0.7 ± 0.5	1.8	13.3	6.7
dAlaz	0.6 ± 0.5	0.6 ± 0.6	0.741	0.5 ± 0.4	1.2	10.0	16.7
Cheek							
Chk AI	1.9 ± 1.1	1.9 ± 1.0	0.719	1.5 ± 0.8	3.1	16.7	16.7
dChkx	0.8 ± 0.6	0.8 ± 0.6	0.953	0.8 ± 0.7	2.2	0.0	3.3
dChky	1.4 ± 1.2	1.3 ± 1.1	0.466	0.9 ± 0.8	2.5	20.0	23.3
dChkz	0.6 ± 0.5	0.6 ± 0.5	0.877	0.6 ± 0.4	1.4	6.7	6.7
Upper lip							
Ls AI	0.8 ± 0.7	1.0 ± 0.8	0.071	0.3 ± 0.3	0.8	43.3	53.3
Sto AI	1.0 ± 0.7	1.1 ± 0.8	0.422	0.4 ± 0.4	1.2	33.3	36.7
Cu AI	1.6 ± 1.3	2.2 ± 1.7	0.037	0.8 ± 0.5	1.8	33.3	46.7
dCux	1.4 ± 1.4	2.0 ± 1.7	0.026	0.6 ± 0.6	1.7	33.3	46.7
dCuy	0.4 ± 0.4	0.4 ± 0.3	0.196	0.3 ± 0.3	0.8	10.0	6.7
dCuz	0.4 ± 0.2	0.3 ± 0.4	0.348	0.2 ± 0.2	0.5	30.0	13.3
Lower lip							
Li AI	1.7 ± 1.3	1.3 ± 1.1	0.164	0.6 ± 0.4	1.5	43.3	36.7
Ch AI	4.1 ± 2.2	3.3 ± 1.8	0.083	2.0 ± 0.8	3.5	53.3	33.3
dChx	2.9 ± 2.2	2.1 ± 2.0	0.154	1.2 ± 0.7	2.6	46.7	36.7
dChy	1.6 ± 1.3	1.4 ± 1.2	0.415	1.1 ± 0.9	2.8	10.0	6.7
dChz	1.7 ± 1.2	1.1 ± 0.9	0.013	0.6 ± 0.5	1.7	50.0	20.0
Chin							
B′ AI	3.1 ± 2.1	1.9 ± 1.3	0.002	0.5 ± 0.4	1.3	76.7	60.0
Pg′AI	3.9 ± 2.5	2.0 ± 1.4	< 0.001	0.8 ± 0.5	1.8	80.0	50.0
Me′AI	5.6 ± 3.3	2.6 ± 1.8	< 0.001	1.0 ± 0.6	2.3	86.7	46.7
lC′AI	11.2 ± 6.6	5.5 ± 3.5	< 0.001	2.4 ± 1.1	4.7	86.7	50.0
dlC′x	11.1 ± 6.6	5.3 ± 3.6	< 0.001	2.1 ± 1.2	4.6	86.7	53.3
dlC′y	0.7 ± 0.4	0.7 ± 0.5	0.758	0.6 ± 0.4	1.5	6.7	6.7
dlC′z	1.4 ± 1.1	0.8 ± 0.8	0.002	0.6 ± 0.5	1.5	26.7	23.3
Upper contour							
cSn AI	1.8 ± 1.7	1.9 ± 1.6	0.901	1.3 ± 1.1	3.5	13.3	10.0
cLs AI	2.9 ± 2.4	2.3 ± 1.8	0.237	1.3 ± 0.9	3.2	33.3	26.7
cSto AI	3.1 ± 2.5	2.6 ± 1.9	0.307	1.3 ± 0.9	3.2	36.7	33.3
Lower contour							
cLi AI	3.7 ± 2.9	2.5 ± 1.9	0.076	1.5 ± 1.1	3.7	43.3	23.3
cB′ AI	3.9 ± 3.2	2.6 ± 1.9	0.057	1.4 ± 1.0	3.4	53.3	26.7
cPg′AI	4.5 ± 3.3	2.9 ± 1.9	0.012	1.7 ± 1.2	4.0	43.3	23.3
Upper incisor							
UIE AI	1.1 ± 0.8	1.7 ± 1.5	0.054	0.7 ± 0.4	1.5	30.0	50.0
Lower incisor							
LIE AI	2.7 ± 1.7	1.8 ± 1.5	0.008	0.6 ± 0.6	1.9	63.3	46.7

T1 before surgery, *T2* after surgery, *dx* transverse difference of a landmark, *dy* sagittal difference of a landmark, *dz* vertical difference of a landmark

Data are means ± SD except where otherwise indicated. For definition of landmarks and regional AIs please refer to Tables 2 and 3 respectively

*Cutoff value is mean plus 2 SD derived from the normal controls

**Preoperative AI is higher than the cutoff value

***Postoperative AI is higher than the cutoff value

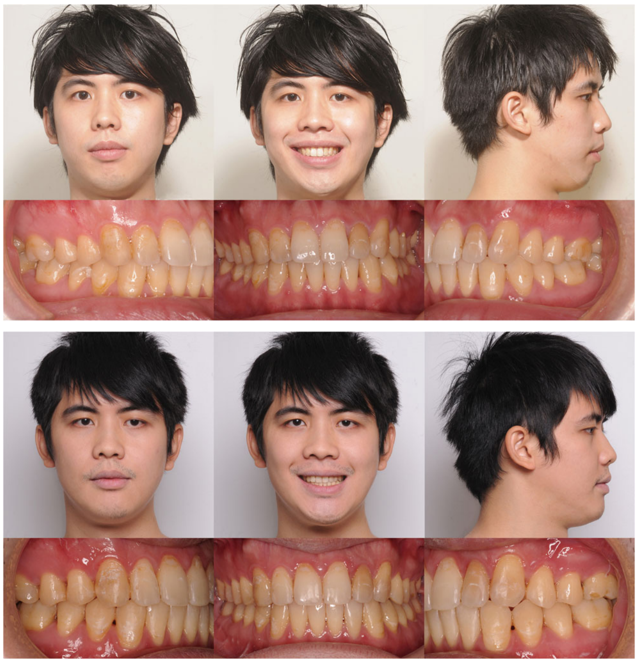


Fig. 3 A patient with skeletal class II deformity and facial asymmetry showing significant improvement of facial profile and asymmetry but residual chin asymmetry after bimaxillary surgery. (Top) Preoperative facial and intraoral photographs. (Bottom) Postoperative facial and intraoral photographs

Table 7 Correlation coefficients between postoperative asymmetric index (AI) and preoperative AI

		Preoperative AI	
		r	*p*
Postoperative AI	Area AI		
	Nose	0.81	< 0.001
	Cheek	0.57	0.001
	Upper lip	0.64	< 0.001
	Lower lip	0.16	0.404
	Chin	0.38	0.039
	Upper contour	0.31	0.100
	Lower contour	0.03	0.864
	Upper incisor	0.22	0.255
	Lower incisor	0.41	0.023
	Part AI		
	Midline	0.54	0.002
	Paramedian	0.36	0.049
	Contour	0.14	0.477
	Zone AI		
	Middle face	0.71	< 0.001
	Lower face	0.30	0.106
	Total face AI	0.37	0.042

For definition of regional AI please refer to Table 3

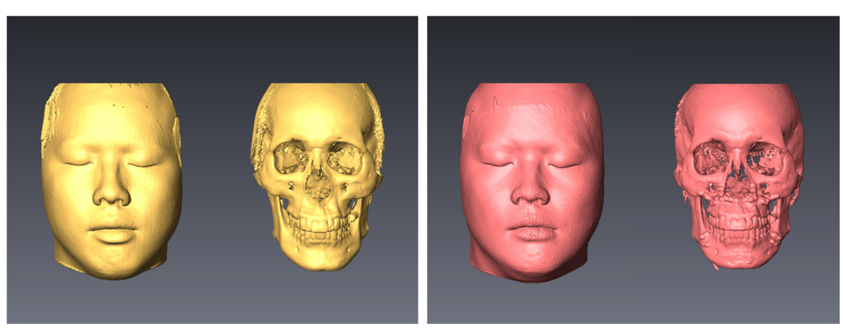
normal controls, the initial asymmetry in patients with class II asymmetry was significant in the lower face, which was major on the lower lip, chin, lower contour, and lower incisor (i.e., preoperative mean AI > threshold AI). After surgery, it is not surprising to find the greatest improvement in the chin area (AI improvement 11.9 mm, 49.8%) since chin asymmetry is often a chief complaint of facial asymmetry, and correction of chin asymmetry is an important treatment goal of OGS [10, 25].

Genioplasty is often the last step of OGS for refining the chin position. In this study, most class II patients (28/30) received genioplasty to further improve the facial profile, proportion, or symmetry, in addition to Le Fort I and BSSO procedures. Although the chin asymmetry was significantly improved after surgery, it still remained asymmetric (i.e., final mean AI > threshold AI). This finding is consistent with previous studies on different types of malocclusion [9, 10, 25], which indicates the difficulty in the recognition of facial midline intra-operatively or relapse post-operatively.

Although previous studies have focused on the correction of facial midline asymmetry with OGS, little is known regarding facial contour asymmetry. However, this problem is relevant in clinical practice as some patients seeking OGS do present significant contour asymmetry, especially in the lower contour. In this study, the second highest improvement of lower face asymmetry was in the lower contour (AI improvement 4.1 mm, 33.9%), confirming the ability of proximal segment displacement after BSSO to improve frontal ramal asymmetry [10, 26].

The nose, upper lip, and upper incisor became asymmetric after surgery (i.e., postoperative mean AI > threshold AI). More specifically, the asymmetry was in the transverse direction of subnasale (Sn), labiale superius (Ls), bilateral Cupid's

Fig. 4 Preoperative and postoperative cone-beam computed tomography of the same patient as shown in Fig. 3. (Left) Before surgery, the total face asymmetric index (AI) and chin AI were 99.2 and 32.7 mm, respectively. (Right) After surgery, the total face AI and chin AI were 50.1 and 11.8 mm, respectively



bow (Cu), and upper incisor embrasure (UIE). This could be explained by the sacrifice of the nasal and maxillary symmetry in order to achieve favorable overall facial symmetry, especially in the mandible. With maxillary osteotomy, nasal asymmetry could be noted due to nasal septal deviation [8, 27]. However, we do not consider this to be a factor, because, at our center, the bony collision during maxillary osteotomy is always avoided by additional resecting the inferior aspect of the septum or superior aspect of ANS or inferior turbinectomy during OGS. This explanation is also supported by the high correlation between the postoperative AI for nose and upper lip ($r = 0.78$, $p < 0.001$). Despite the asymmetry, the mean differences of Sn, Ls, Cu, and UIE from the cutoff value were only 0.3, 0.2, 0.4, and 0.2 mm respectively, which were of no clinical significance. In other words, the mean differences of Sn, Ls, Cu, and UIE from facial midline were too small (0.8, 1.0, 2.0, and 1.7 mm, respectively) to reach clinical significance [28, 29].

This study demonstrates that certain initial AI impact postoperative AI. Postoperative AI for nose, cheek, upper lip, chin, lower incisor, middle face, and total face were positively correlated with their initial AI. Postoperative AI for midline and paramedian parts of faces was positively correlated with their initial AI. These correlations have not been reported previously. The clinical implication of this finding is that it is possible to predict asymmetry outcome based on the initial severity of asymmetry, a consideration relevant to surgical design and consultation of patients for this surgery.

There are some limitations to this study. First, this was a retrospective study. However, this limitation was minimized by selecting consecutive patients. Second, the sample size was small. Increasing the power of the study with more patients might have yielded more robust conclusions. Third, 3D soft tissue asymmetry was evaluated via landmark-dependent method, which has been criticized for the questionable validity and reliability for assessing asymmetry [30]. However, the intra-rater reliability of the landmarks used in this study was excellent. Also, the advantage of the landmark method is the ease of interpreting and applying the results to clinical practice [7] compared to those using computer algorithms for assessing full surface asymmetry [11, 30]. Finally, further study is needed to evaluate the impact of facial asymmetry on the treatment outcome of bimaxillary surgery by using class II patients with no significant facial asymmetry as a control group.

Conclusions

In patients with asymmetric class II deformity after bimaxillary OGS, lower face asymmetry on the chin, lower contour, and lower incisor improved significantly. However, approximately 50% of the patients still had residual chin asymmetry. Middle face asymmetry on the nose deteriorated significantly. However, the deterioration was too small to reach clinical significance. The postoperative asymmetry of total face was moderately related to the initial severity of asymmetry.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study protocol was approved by the Ethics Committee for Human Research, Chang Gung Memorial Hospital, Taoyuan, Taiwan.

Informed consent Informed consent was not needed due to the retrospective design of the study.

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