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ORIGINAL ARTICLE

Outcomes of conventional versus virtual surgical planning of orthognathic surgery using surgery-first approach for class III asymmetry

Yu-Fang Liao [1,2,3,4] · Ying-An Chen [2,3,5] · Yi-Chieh Chen [6] · Yu-Ray Chen [2,3,4,5]

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Abstract

Objectives To determine if patient outcome variables differ between conventional and virtual surgical planning of orthognathic surgery for class III asymmetry.

Material and methods This retrospective case-control study examined 95 patients with class III asymmetry who had been consecutively treated with at least a Le Fort I osteotomy and a bilateral sagittal split osteotomy with a surgery-first approach. Two groups were examined: 51 patients treated with conventional surgical planning and 44 with virtual surgical planning. After treatment, quantitative assessment was determined with measurements of midline symmetry, contour symmetry, and overall facial symmetry using standardized frontal photographs. Subject assessments were analyzed with questionnaires regarding self-perception of overall appearance, satisfaction with appearance, and quality of life.

Results Conventional and virtual surgical planning resulted in significant improvements in outcomes for all patients. However, facial midline and overall facial symmetry were significantly greater for the virtual compared with the conventional group. There were no significant differences in subjective measures of appearance, satisfaction with appearance, and quality of life for patients treated with conventional or virtual surgical planning; measures were high for both groups.

Conclusions Conventional and virtual surgical planning of surgery-first bimaxillary orthognathic surgery resulted in quantitative and qualitative improvements in facial symmetry. Although patient satisfaction was similar for both approaches, virtual surgical planning was superior to conventional surgical planning for the improvement of midline and overall asymmetry.

Clinical relevance Improvements with virtual surgical planning in facial midline, facial contour, and overall facial symmetry are as good as or better than conventional surgical planning.

Keywords Orthognathic surgery · Facial asymmetry · Class III malocclusion · Outcome · Satisfaction · Virtual surgical planning

✉ Yu-Fang Liao
yufang@cgmh.org.tw

1 Department of Craniofacial Orthodontics, Chang Gung Memorial Hospital, No. 123, Dinghu Road, Gueishan Township, Taoyuan 333, Taiwan

2 Craniofacial Center, Chang Gung Memorial Hospital, Taoyuan, Taiwan

3 Craniofacial Research Center, Chang Gung Memorial Hospital, Linkou, Taiwan

4 Graduate Institute of Dental and Craniofacial Science, Chang Gung University, Taoyuan, Taiwan

5 Department of Plastic and Reconstructive Surgery, Chang Gung Memorial Hospital, Linkou, Taiwan

6 Chicing Plastic Surgery, Taipei, Taiwan

Introduction

Patients with skeletal class III deformity often include facial asymmetry, which can have multiple forms: skeletal asymmetry, soft tissue asymmetry, functional asymmetry, or a combination. The most prevalent asymmetry involves deviations of the jaw and face. In instances of jaw asymmetry, the only procedure for centering jaws in adult patients is orthognathic surgery.

Recently, virtual (3D) planning of orthognathic surgery has been proposed to shorten the planning time [1–3], improve the surgical planning [4–6], and enhance the surgical accuracy [7–9] as compared to conventional (2D) planning. Therefore, our center has been using virtual orthognathic planning for every patient since the year 2015 despite increased costs for the cone beam computer tomography (CBCT)

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machine, 3D scanner, virtual 3D software packages, and trained technicians for carrying out planning preparation.

Many studies on the outcomes of orthognathic surgery and virtual surgical planning to correct facial asymmetry have been conducted for patients with skeletal class III deformity [6, 9–13]. The focus of most of these studies was on surgical accuracy [9, 10, 12, 13]. Although surgical accuracy is a critical component of virtual surgical planning, assessment of both objective and subjective outcome variables, as well as time of assessment, is also important. Despite superior improvement of occlusal cant, frontal ramal symmetry, lower incisor deviation, and menton deviation with virtual surgical planning compared to conventional surgical planning in a cephalometric study by Wu et al. [11], their investigation of the outcome of asymmetry was limited to skeletal structures. Therefore, the purpose of this study was to compare surgical outcomes between patients treated for orthognathic correction of class III asymmetry with conventional and virtual surgical planning with regard to soft tissue symmetry and patient satisfaction.

Materials and methods

Patients

We selected 95 consecutive patients (58 females, mean age 23.3 ± 5.1 years) treated with orthognathic surgery for skeletal class III asymmetry from our database who met the selection criteria: (1) adults at least 18 years of age who had stable body height; (2) ANB angle ≤ 0 degree and menton deviation ≥ 4 mm or significant contour asymmetry; (3) minimum of a combined Le Fort I and a bilateral sagittal split osteotomy using a surgery-first approach for early improvement of facial esthetics and efficient orthodontic tooth movement [14] from year 2012 to 2016 by the same team of surgeons; (4) conventional surgical planning (years 2012 to 2014) or virtual surgical planning (year 2015 to 2016) and post-surgical orthodontic treatment performed by a single orthodontist; (5) absence of genetic syndromes or congenital malformations; (6) availability of digital photographs taken before treatment and after orthodontic debonding; and (7) availability of self-report questionnaires completed following orthodontic debonding.

Surgical planning

Before the year 2015, conventional orthognathic planning was used based on 2D (lateral and posteroanterior) cephalograms, photographs, and dental casts, which consists of four laboratory procedures: mounting of dental casts onto an articulator using the standard face-bow transfer and bite registration; setup of surgical occlusion using preoperative dental casts; a manual paper surgery for moving the maxillary and mandibular osteotomized segments as a unified complex according to the planning principles [15] while maintaining the surgical occlusion; and fabrication of the surgical splint (i.e., final splint) using the final setup models. Corrective surgery using a prefabricated surgical splint is performed according to the 2D surgical plan.

After the year 2015, virtual orthognathic planning using Dolphin 3D software (Peterson Company, USA) was performed based on CBCT, photographs, and dental casts, which consists of eight laboratory procedures: scanning of preoperative maxillary and mandibular dental casts; replacement of the dental arches of CBCT by scanned dental cast images; defining of maxillary or mandibular osteotomy planes on CBCT; using of clinical measures for virtual head orientation; setup of surgical occlusion using preoperative dental casts; scanning of the surgical occlusion setup; virtual moving of the maxillary and mandibular osteotomy segments as a unified complex according to the same planning principles [15] while preserving the surgical occlusion; and fabrication of the surgical splint (i.e., final splint) using the final setup models. Corrective surgery using a prefabricated surgical splint is performed according to the 3D surgical plan.

Surgical technique

Surgery was similar to that described previously [14], which uses a modification of the Hunsuck bilateral sagittal split osteotomy [16, 17] in combination with the Le Fort I osteotomy, comparable to the technique popularized by Bell [18, 19]. Following the complete mobilization of the maxillomandibular complex, intermaxillary fixation of the complex is achieved with a prefabricated surgical splint (i.e., single splint). Preoperative planning determines repositioning of the maxillomandibular complex (Figs. 1 and 2), and metal wires on the nasomaxillary and zygomaticomaxillary buttress are used to temporarily fix the maxilla [20]. The repositioning of the complex is then confirmed with seven checkpoints, described by Yu et al. [20]: midline coordination, upper incisor show, intercommissural plane, cheek symmetry, paranasal fullness, Ricketts E line, lower face proportions, and contour symmetry. After repositioning is confirmed, titanium bone plates and screws are used for rigid fixation of the maxillomandibular complex, and if needed, a genioplasty or mandibular contouring is performed at the same time [15, 20].

Photographic analysis

Quantitation of facial symmetry was analyzed with anthropomorphic measurements of digital photographs. Frontal photographs taken pretreatment were compared with those taken at least 1 year following surgery and after orthodontic debonding. One skilled professional photographer photographed all patients. Image acquisition met the standards of the European Association for Cranio Maxillo Facial

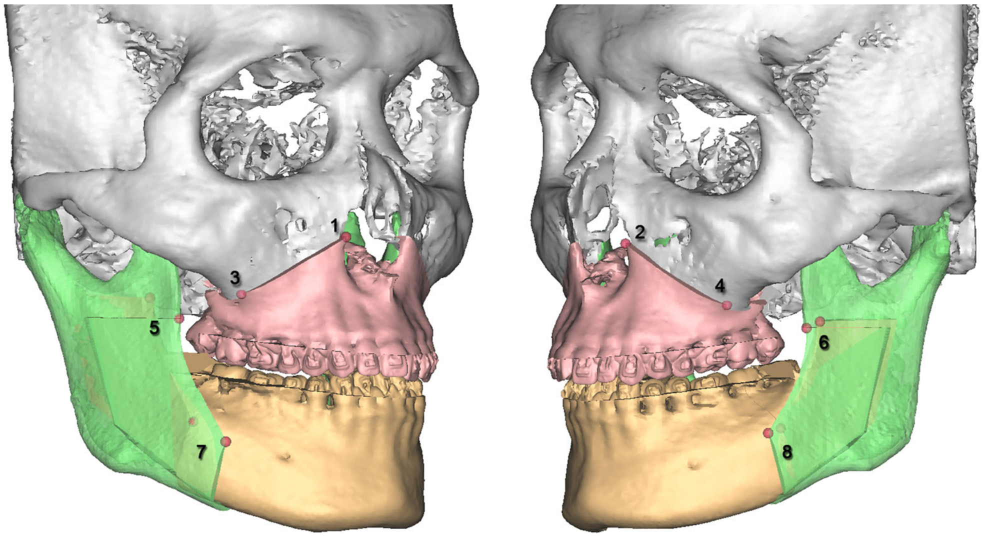
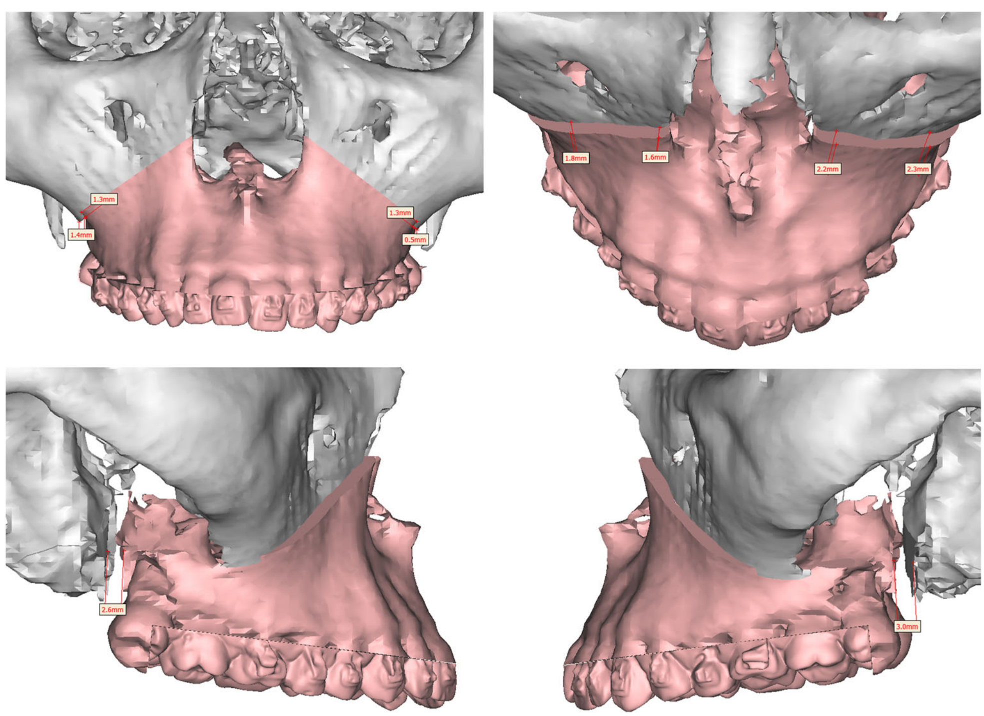


Fig. 1 Example of a surgical plan from virtual planning with graphic presentation and the amount and direction of surgical movement. 1 (right pyriform): advance 2.9 mm, impact 1.9 mm; 2 (left pyriform): advance 3.1 mm, impact 1.9 mm; 3 (right zygomatic buttress): advance 2.8 mm, impact 1.7 mm, to left 0.2 mm; 4 (left zygomatic buttress): advance 3.4 mm, impact 1.8 mm, to left 0.2 mm; 5 (right ramus): setback 8.5 mm, upward 1.7 mm; 6 (left ramus): setback 3 mm, upward 1.8 mm; 7 (right body): setback 11 mm; 8 (left body): setback 5 mm

Surgery [21, 22] using a Canon EOS 350D digital camera (Canon, Inc., Tokyo, Japan), with the resolution set at 2496 × 1664 pixels. Quantification of facial symmetry from anonymized digital images was performed by an experienced researcher with Photoshop 9.0 (Adobe Systems, Inc., San Jose, CA, USA). Photographs, instruments, software, and quantification of symmetry using a symmetry indexes based on seven angular measurements have been described previously [14]. Analysis included four midline facial measurements, which included midface and chin deviations (Fig. 3) and three facial contour deviations (Fig. 4). Perfect symmetry was defined as zero; values greater than zero indicate a greater degree of asymmetry. The same researcher measured 10 photographs randomly selected from a collection of presurgery images ($n = 5$) and postsurgery images ($n = 5$) to assess intra-observer reliability. The intraclass correlations coefficient suggested excellent reliability ($p < .05$; range = 0.985 to 0.996).

Fig. 2 (Continued) Alternate view of surgical plan from virtual planning shown in Fig. 1



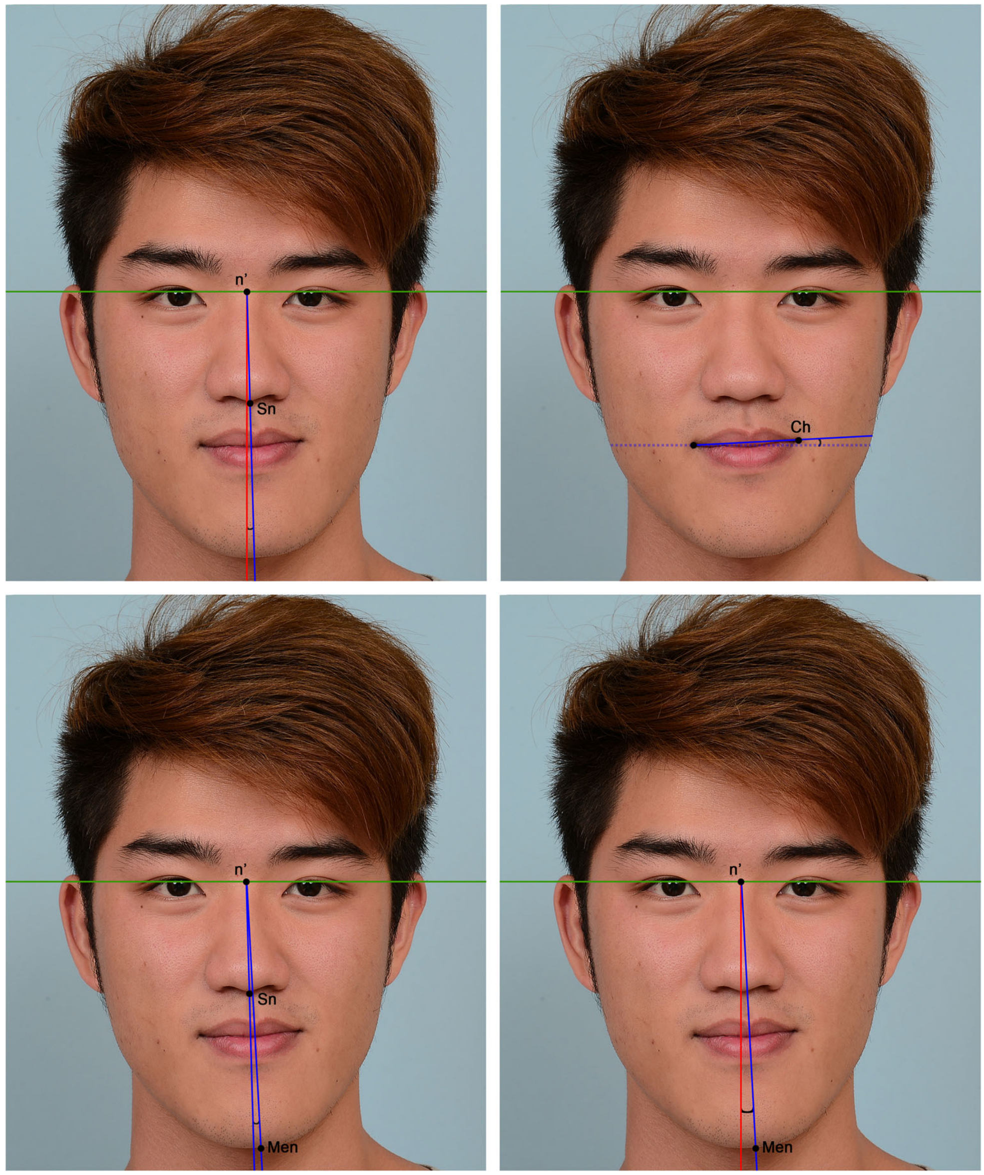


Fig. 3 Representative images demonstrating measurement areas for midline symmetry. (Top, left) Midface deviation, determined by the angle formed between midface deviation line (blue line, n'-Sn) and facial midline (red) passing through n'; (Top, right) Intercommissural line deviation, determined by the angle formed between the intercommissural line (blue, Ch-Ch) and interpupillary line (green); (Bottom, left) Chin from midface deviation, determined by the angle between the midface deviation (blue lines, n'-Sn and Sn-Me); (Bottom, right) Chin deviation determined by the angle between n'-Me (blue line) and facial midline (red line). n', nasion projection on the interpupillary line; Sn, subnasale; Ch, cheilion; Me, menton. References: interpupillary line (green) and facial midline, (red line perpendicular to the interpupillary line

Satisfaction questionnaires

All patients completed four self-report questionnaires regarding satisfaction with the appearance and quality of life postsurgery. These questionnaires have been previously demonstrated to be valid instruments for patients following orthognathic surgery [23]. Perception of appearance [23] was determined with two measures, the Overall Appearance Rating (OAR) and Satisfaction with Facial Appearance (SFA). OAR assesses an ideal face and one's own face: perceptions are scored from 0 to 100. Appearance is rated as 0 = extremely unattractive, 50 = ordinary, and 100 = extremely attractive. Satisfaction with facial appearance evaluates patient satisfaction with specific facial areas: face, nose, cheek, lip, teeth, upper gum, chin, and facial contour from 1 = very dissatisfied to 5 = very satisfied. Quality of life was evaluated with the Body Image Quality of Life Inventory (BIQLI) developed by Pruzinsky and Cash [24]. The scale measures effects of body image on experiences that influence an individual's quality of life. We used a Chinese version of the BIQLI validated for orthognathic surgery patients, which contains five items relative to the problems of dentofacial deformity: chewing, speech, smile, self-confidence, and social life [23]. Items are rated from 1 = very dissatisfied to 10 = very satisfied.

Statistical analysis

Demographic data and objective measures were analyzed with descriptive statistics (mean, standard deviation (SD), and frequency). Differences in demographics and measurements between groups were compared with independent t-tests and chi-

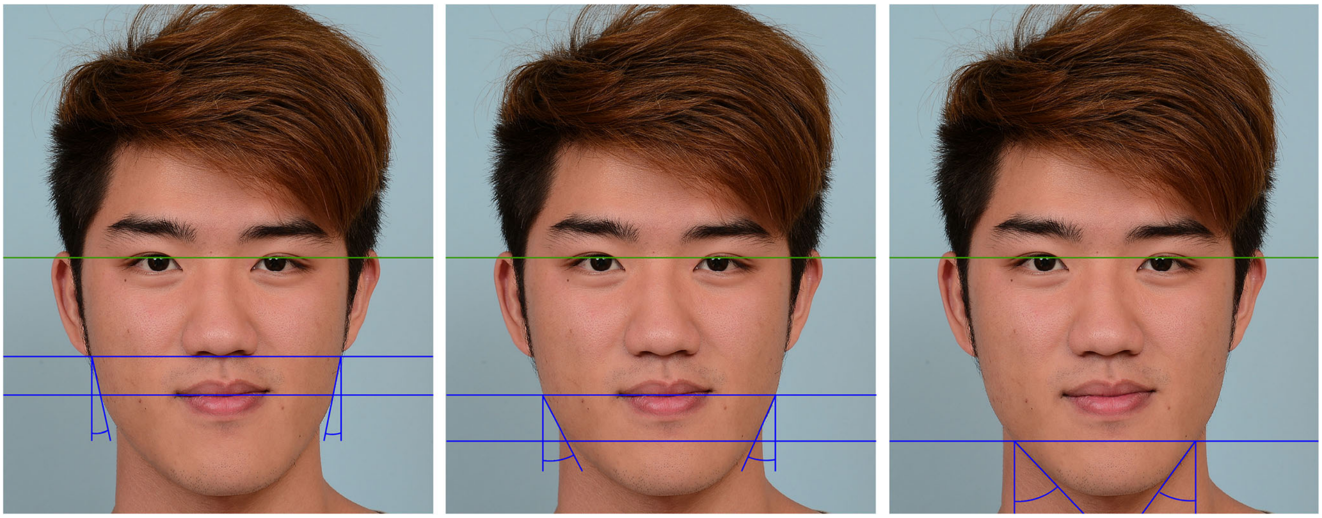


Fig. 4 Representative images demonstrating measurement areas for facial contour symmetry. (Left) Upper contour deviation determined by the absolute difference between the right and left upper contour angle, which is the angle between the tangent line from the upper contour to the facial midline (blue lines); (Center) Middle contour deviation determined by the absolute difference between the right and left middle contour angle, which is the angle between the tangent line from the middle contour to the facial midline (blue lines); (Right) Lower contour deviation, determined by the angle between the tangent line from the lower contour to the facial midline (blue line). The interpupillary line is shown in green

square tests when indicated. Differences in measures before and after treatment were compared with paired t-tests. All tests were two-tailed; statistical significance was set at $p < 0.05$. Data were analyzed using the statistical package SPSS (Version 21.0; SPSS Inc., Chicago, Ill.,USA).

Results

Ninety-five patients met the inclusion criteria; 51 patients had been treated with conventional surgical planning (years 2012 to 2014); and 44 had been treated with virtual surgical planning (years 2015 to 2016). In pre-treatment, there were no differences in demographics (Table 1) or preoperative facial asymmetry (Table 2) between the two groups.

After 1 year following treatment, there were significant improvements in most outcome measures for both groups; only the midface deviation and middle contour deviation. (Table 2). However, significant differences were seen between groups for chin from midface deviation, chin deviation, facial midline symmetry, and overall facial symmetry index. These were all more favorable for the virtual group (Table 2).

Table 3 shows the mean scores on the self-assessment questionnaires. There was no significant difference in scores for perception of overall appearance of the participants' own face, which was 83.9 ± 9.2 for patients in the conventional group

Table 1 Clinical characteristics of conventional and virtual surgical planning groups before surgery

Characteristics	Conventional (n = 51)	Virtual (n = 44)	P
Female, n (%)	34 (67)	24 (55)	0.29
Age at surgery, years (Mean ± SD)	24 ± 5	22 ± 5	0.07
Bimaxillary surgery			
With maxilla segmentation, n (%)	5 (10)	6 (13)	0.75
With mandible segmentation[a], n (%)	0 (0)	1 (21)	0.46
With genioplasty, n (%)	37 (73)	26 (59)	0.20
With mandible contouring, n (%)	3 (6)	9 (21)	0.06
Treatment duration, days (Mean ± SD)	531 ± 214	538 ± 191	0.90
Postoperative follow-up, years (Mean ± SD)	1.5 ± 0.7	1.6 ± 0.6	0.88

SD, standard deviation.

[a] Kole procedure

Table 2 Facial symmetry[a] of conventional surgical planning and virtual surgical planning groups before and after surgery

Measurement	Conventional (n = 51)			Virtual (n = 44)			Conventional vs virtual	
	Before Mean ± SD	After Mean ± SD	*P*	Before Mean ± SD	After Mean ± SD	*P*	Before *P*	After *P*
Midface deviation, degrees	0.6 ± 1.1	0.4 ± 0.9	0.054	0.4 ± 0.7	0.3 ± 0.6	0.088	0.404	0.490
Intercommissural line deviation, degrees	2.8 ± 2.4	1.4 ± 1.2	< 0.001	2.2 ± 1.6	1.1 ± 0.9	< 0.001	0.160	0.082
Chin from midface deviation, degrees	4.8 ± 3.1	3.4 ± 3.0	0.002	6.0 ± 2.9	1.7 ± 1.5	< 0.001	0.062	0.001
Chin deviation, degrees	3.6 ± 2.1	2.1 ± 1.8	< 0.001	3.9 ± 1.8	1.1 ± 0.9	< 0.001	0.499	0.001
Facial midline symmetry index	9.0 ± 5.2	5.8 ± 4.6	< 0.001	10.3 ± 4.7	3.0 ± 2.4	< 0.001	0.218	< 0.001
Upper contour deviation, degrees	4.4 ± 3.2	3.4 ± 2.6	0.020	3.9 ± 3.2	3.1 ± 2.4	0.035	0.272	0.544
Middle contour deviation, degrees	4.3 ± 3.2	3.5 ± 2.4	0.092	3.6 ± 2.4	2.7 ± 3.8	0.216	0.188	0.190
Lower contour deviation, degrees	4.5 ± 3.1	3.5 ± 2.5	0.044	4.8 ± 4.1	2.8 ± 2.5	< 0.001	0.648	0.227
Facial contour symmetry index	13.3 ± 6.7	10.4 ± 5.1	0.003	12.1 ± 7.5	8.5 ± 5.8	0.015	0.424	0.104
Overall facial symmetry index	26.8 ± 13.0	17.6 ± 7.7	< 0.001	24.6 ± 12.4	12.6 ± 6.9	< 0.001	0.409	0.001

SD, standard deviation.

[a] Indirect anthropometric measurements quantified from patients' digital photographs

compared with 82.6 ± 7.6 in the virtual group. There was also no significant difference between groups for specific facial areas. In both the conventional and virtual groups, the lowest scores were for the nose (6.7 ± 2.0 and 6.5 ± 2.0, respectively). The highest satisfaction was for the teeth; scores were 8.4 ± 1.4 for the conventional group and 8.9 ± 1.2 for the virtual group. Satisfaction ratings for quality of life following surgery were also not significantly different between groups (Table 4). Scores were lowest for chewing and speech; highest satisfaction was with smile, self-confidence, and social life. Gender had no influence on the satisfaction with appearance and quality of life postsurgery (all $p > 0.05$).

Discussion

Previous studies that have compared skeletal symmetry after treatment with conventional and virtual surgical planning have favored virtual surgical planning [4, 7, 9, 11]. However, frontal appearance is more likely to be the perspective patients' use for subjective assessments of surgical outcomes. Similar to the study by Liao et al. [14], this study analyzed the difference in outcomes for the conventional and virtual groups using frontal midline and frontal contour outcomes. Self-report questionnaires were also employed to obtain patients' subjective measures of the results.

Table 3 Patient satisfaction ratings[a] for overall appearance and facial areas following conventional and virtual surgery planning

Satisfaction questionnaire	Conventional (n = 51) Mean ± SD	Virtual (*n* = 44) Mean ± SD	*P*
Overall facial appearance (range = 0 to 100)			
Ideal appearance	87.6 ± 11.5	90.5 ± 6.7	0.181
Personal appearance	83.9 ± 9.2	82.6 ± 7.6	0.516
Facial area satisfaction (range = 0 to 10)			
Nose	6.7 ± 2.0	6.5 ± 2.0	0.588
Cheek	7.4 ± 1.6	7.2 ± 2.1	0.586
Lips	7.6 ± 1.7	7.5 ± 1.9	0.969
Teeth	8.4 ± 1.4	8.9 ± 1.2	0.093
Upper gum	7.9 ± 1.7	8.0 ± 1.8	0.792
Chin	8.0 ± 2.1	8.6 ± 1.3	0.156
Facial contour	8.1 ± 1.2	8.5 ± 1.2	0.240

SD, standard deviation.

[a] Higher rating indicates higher satisfaction

Table 4 Patient satisfaction ratings[a] for quality of life following conventional and virtual surgery planning

Quality of life	Conventional ($n = 51$) Mean ± SD	Virtual ($n = 44$) Mean ± SD	P
Psychosocial domains (range = 0 to 10)			
Chewing	7.6 ± 2.1	7.9 ± 1.9	0.529
Speech	7.5 ± 1.9	8.0 ± 1.8	0.295
Smile	8.2 ± 1.7	8.7 ± 1.3	0.092
Self-confidence	8.3 ± 1.5	8.7 ± 1.1	0.166
Social life	8.1 ± 1.5	8.3 ± 1.7	0.714

SD, standard deviation.

[a] Higher rating indicates higher satisfaction

Both conventional and virtual surgical planning resulted in significant improvements in outcome measures of facial symmetry. In addition, mean scores for specific facial areas were high for the lip and chin, demonstrating a subjective satisfaction with treatment. Lip cant and chin deviation have been reported to be one of the primary sources of dissatisfaction resulting from facial asymmetry, which is one reason for surgical correction of lip and chin asymmetry. In addition, we found that virtual surgical planning was superior to conventional planning for improving facial midline symmetry determined by measures of chin from midface deviation and chin deviation, which indicates recognition of facial midline intraoperatively is more difficult with conventional surgical planning.

We found that neither method of surgical planning resulted in a favorable improvement of midface deviation. This is consistent with previous studies on class II asymmetry [25, 26]. This could be explained by sacrificing nasal symmetry at the expense of achieving satisfactory overall facial symmetry, especially in the mandible. Participants' scores for specific facial areas were lowest for the nose. Nasal morphology following Le Fort I advancement results in increased nasal width or nostril show [27–30]. Previous studies have reported Asian patients are more likely to subjectively rate satisfaction with the nose as worse following maxillary advancement [27–29]. Our findings, in concert with those of previous studies, suggest achieving satisfactory nasal morphology, and paranasal fullness is a challenge when treating Asian patients.

In this study we demonstrated both conventional and virtual surgical planning were associated with improvements in upper and lower contour deviations, and neither planning proved superior, which is in agreement with previous studies [11, 31]. However, improvement in middle contour deviation was not evident with either approach. This could be explained by a size asymmetry between right and left mandibular angles from the preoperative size difference [32, 33] or postoperative size difference following bone remodeling. Another explanation is the limitation or instability of outward roll rotation of the opposite proximal segment for the improvement of angle symmetry.

This study found that improvements with virtual surgical planning in facial midline, facial contour, and overall facial symmetry were as good as or better than conventional planning. However, the patient's perception of appearance demonstrated a comparable improvement between the two surgical planning methods. Several elements can influence subjective assessments of patient satisfaction, including the relationships that are established between the surgical-orthodontic team and patient over the lengthy course of treatment [14]. Improvements in facial profile and smile following improvements in facial symmetry can also increase a patient's self-confidence as well as social life, resulting in a subjective assessment of outcomes that are greater than the quantitative assessment.

In this study, the function of temporomandibular joints (TMJ) and nasal breathing was not measured. The method of transferring the conventional or virtual surgical planning to the actual surgery was graphics-simulated movement in amount and direction. Further studies are needed to evaluate if the outcomes including TMJ and nasal breathing function are different with the additional use of computer-aided design and computer-aided manufacturing of intermediate splints or cutting guides.

Conclusions

These findings demonstrate that surgery-first bimaxillary surgery with both conventional and virtual surgical planning can successfully maintain or improve facial symmetry. However, the virtual surgical planning was superior in the improvement of facial midline asymmetry than the conventional approach. Satisfaction outcomes were similarly high with both methods of surgical planning.

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Compliance with ethical standards

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

Ethical approval All procedures performed in the study were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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

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