Conformity of the Actual to the Planned Result in Orthognathic Surgery

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Background: Virtual surgical planning has facilitated preoperative planning, splint accuracy, and intraoperative efficiency in orthognathic surgery. The translation of the virtual surgical plan to the actual result has not been adequately examined. The authors examined the conformity of the virtual surgical plan to the postoperative result. They hypothesize that the greatest conformity exists in the anteroposterior dimensions.

Methods: The authors examined patients who underwent Le Fort I maxillary advancement, bilateral sagittal split osteotomy, and genioplasty. The preoperative virtual surgical planning file and postoperative cone beam computed tomographic scan were registered in Mimics using unchanged landmarks. The conformity to the virtual surgical plan was quantified using linear and angular measurements between bone surface landmarks. Results were compared using t tests, with $p < 0.05$ considered statistically significant

Results: One hundred patients who underwent Le Fort I maxillary advancement, bilateral sagittal split osteotomy, and genioplasty were included. Three-dimensional analysis showed significant differences between the plan and outcome for the following landmarks: A point (y, $p = 0.04$; z, $p = 0.04$), B point (y, $p = 0.02$; z, $p = 0.02$), pogonion (y, $p = 0.04$), menton (x, $p = 0.02$; y, $p = 0.01$; z, $p = 0.03$), and anterior nasal spine (x, $p = 0.04$; y, $p = 0.04$; z, $p = 0.01$). Angular measurements sella-nasion-A point, sella-nasion-B point, and A point-nasion-B point were not statistically different.

Conclusions: There is a high degree of conformity comparing the orthognathic virtual surgical plan to the actual postoperative result. However, some incongruency is seen vertically (maxilla) and sagittally (mandible, chin). Departures of the actual position compared with the plan could be the result of condylar position changes, osteotomy locations, aesthetic intraoperative decisions, and/or play in the system. (*Plast. Reconstr. Surg.* 144: 89e, 2019.)

Orthognathic surgery involves manipulation of facial bony architecture to restore form and function by correcting for malocclusion, dysmorphology, and defect.[1] Innovations in technique, preoperative planning, and surgical technology have advanced the field to enable low complications and high patient satisfaction.[2,3]

Advancements in computer-aided design and manufacturing and high-resolution cone-beam computed tomography have enabled virtual surgical planning to create a paradigm shift in orthognathic surgery. Previously, surgeons performed radiocephalometric analysis of the malocclusion followed by model surgery before creating custom molded intermediate and final surgical splints to translate manipulations of the maxillomandibular complex to the patient in the operating room. Virtual planning allows a more precise analysis of

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bony anatomy and malocclusion, and more precise three-dimensional printing of intermediate and final splints to translate the plan intraoperatively.[4,5] Virtual surgical planning has been shown to significantly reduce the time and cost associated with traditional orthognathic planning[6,7] when performing primary mandibular bilateral sagittal split osteotomies, Le Fort I osteotomy, and osseous genioplasty (triple-jaw surgery).[8] Furthermore, when compared to the traditional method, virtual planning is associated with a more accurate translation of the surgical plan intraoperatively.[8–13]

Van Hemelen et al. published results of a multicenter, prospective trial demonstrating precision of 1.42 mm in the horizontal plane and 1.44 mm in the vertical plane, which are superior compared with the 2.29-mm deviations observed in the horizontal plane and 2.07-mm deviations in the vertical plane when using two-dimensional cephalometric planning. However, this study is limited by the small sample size and variations in surgical technique among numerous surgeons.[9] In addition, Hsu et al. demonstrated the precision of surgical simulation in orthognathic surgery, ranging from 0.6- to 3.5-mm deviations from the virtual plan.[7] This study was again limited by the small sample size and varying number of osteotomies in each orthognathic procedure.

Despite these advances in the surgical literature, there have been few studies examining the precision of the postoperative result to the virtual surgical plan with a single surgeon and matching sequence and number of osteotomies. The purpose of this study was to determine the conformity and precision of the postoperative result to the virtual surgical plan following triple-jaw surgery performed by a single surgeon.

PATIENTS AND METHODS

Medical records were reviewed retrospectively at Yale-New Haven Hospital from 2015 to 2016 with human investigations committee approval. Included patients underwent primary mandibular bilateral sagittal split osteotomy, Le Fort I osteotomy, and osseous genioplasty (triple-jaw surgery) performed by a single surgeon with virtual surgical planning preoperatively. All patients underwent virtual surgical planning and triple-jaw surgery in a mandible-first sequence, with guiding elastics placed postoperatively. Preoperative computed tomography was performed approximately 7 to 10 days before surgery, virtual surgical planning was performed approximately 4 to 7 days before surgery, and postoperative cone-beam computed tomography was performed on postoperative day 1. No osteotomy cutting guides were used in this study. All osteotomies were planned to achieve the optimal facial harmonization for the individual patient's maxillomandibular dysmorphology and malocclusion. All patients included in the study underwent the same postoperative care regimen, in the same institution, and were cared for by the same group of residents. Patients were discharged in guiding elastics to aid in acclimation of the new occlusion postoperatively. Patients with a cleft lip/palate deformity, syndromic craniofacial conditions, and repeated triple-jaw surgery were excluded. Data collected included demographic information, surgical indications/malocclusion, preoperative cone-beam computed tomographic virtual surgical planning session data, and postoperative cone beam computed tomographic data. Cone-beam computed tomography was performed both preoperatively and postoperatively in identical orientations with matching dentofacial imaging protocols.

Virtual surgical planning sessions were performed using Mimics software (Materialise, Leuven, Belgium) by the senior surgeon and engineers. Intermediate and final splints were printed three-dimensionally according to the virtual surgical plan from the same operation. The conformity of the postoperative cone-beam computed tomographic scan to the three-dimensional virtual surgical plan was measured using Mimics with both files in the stereolithography format.[14] Images were registered using the Frankfurt horizontal plane, parallel to the "floor." Registration and superimposition between the preoperative and postoperative imaging was performed using unaltered landmarks (mastoid, styloid, and the orbitozygomatic region) and stereolithography global registration in accordance with protocols similarly reported in the orthognathic literature.[7,15]

Measurements between the virtual surgical plan and postoperative cone-beam computed tomographic scans were made between standard anthropometric landmarks described in the craniofacial literature: A point, B point, pogonion, mention, anterior nasal spine, sella-nasion-A point, sella-nasion-B point, and A point-nasion-B point.[16] These landmark assignments were repeated on 10 separate occasions with two separate researchers to ensure intrarater and interrater reliability. Linear distances between preoperative and postoperative landmarks were measured in the x, y, and z axes, which correlate with transverse, sagittal, and vertical planes, respectively (Table 1). Subgroup analysis was performed between classes

Table 1. Description of Dimensions

Dimension	Direction
x	Left/right (transverse)
y	Anterior/posterior (sagittal)
z	Superior/inferior (vertical)

of malocclusion. All data were analyzed using R (R Foundation for Statistical Computing, Vienna, Austria). Differences between the preoperative and postoperative three-dimensional models were compared using paired *t* tests, with vales of $p < 0.05$ being statistically significant.

RESULTS

One hundred patients who underwent triple-jaw surgery performed by a single surgeon were included. Forty-three percent of patients were female and 57 percent of patients were male, with a mean age of 21.7 years (range, 15 to 47 years). Dysmorphologies included class III malocclusion (67 percent), class II malocclusion (24 percent), class I occlusion (6 percent), and facial asymmetry (3 percent). Images were measured by two independent researchers, with an interclass correlation coefficient of 0.804 (95 percent CI, 0.418 to 0.947) (Table 2).

The translation of the maxilla and mandible is represented by comparing the anthropometric landmarks in the preoperative and postoperative images. Mean differences were calculated in the *x* plane (transverse), *y* plane (sagittal), and *z*

Table 2. Interrater Reliability

Landmark and Dimension	Average Difference (mm)	*p*
A point		
x	1.37 ± 1.23	<0.001
y	1.12 ± 1.27	<0.001
z	1.58 ± 1.77	<0.001
B point		
x	1.24 ± 1.19	<0.001
y	1.40 ± 1.18	<0.001
z	1.93 ± 1.72	<0.001
Pg		
x	1.77 ± 1.53	<0.001
y	3.55 ± 2.42	<0.001
z	3.26 ± 2.80	<0.001
Me		
x	1.98 ± 1.62	<0.001
y	3.40 ± 2.17	<0.001
z	2.85 ± 2.56	<0.001
ANS		
x	1.61 ± 1.39	<0.001
y	2.21 ± 2.71	<0.001
z	1.50 ± 1.52	<0.001

PG, pogonion; Me, menton; ANS, anterior nasal spine.
*Interrater reliability: intraclass correlation coefficient = 0.804 (95% CI, 0.418–0.947).

Table 3. Conformity of Linear Measurements

Landmark and Dimension	Average Difference (mm)	*p*
A point		
x	1.23 ± 1.3	0.09
y	1.34 ± 0.9	0.04*
z	1.74 ± 1.0	0.04*
B point		
x	1.32 ± 1.3	0.07
y	2.15 ± 1.2	0.02*
z	1.67 ± 0.9	0.02*
Pg		
x	1.24 ± 1.1	0.07
y	3.71 ± 2.1	0.04*
z	2.12 ± 2.0	0.06
Me		
x	2.62 ± 1.2	0.02*
y	3.95 ± 1.9	0.01*
z	2.4 ± 0.8	0.03*
ANS		
x	1.12 ± 0.5	0.04*
y	1.2 ± 0.4	0.04*
z	1.71 ± 0.8	0.01*

Pg, pogonion; Me, menton; ANS, anterior nasal spine.
*Statistically significant ($p < 0.05$).

Table 4. Conformity of Angular Measurements

	Planed (deg)	Actual (deg)	Difference (deg)	*p*
SNA	84.26 ± 5.46	84.22 ± 5.27	0.04	0.95
SNB	81.02 ± 4.95	81.37 ± 5.27	0.65	0.63
ANB	3.51 ± 1.59	3.52 ± 1.76	0.01	0.98

SNA, sella-nasion-A point angle; SNB, sella-nasion-B point angle; ANB, A-point-nasion B-point angle.

Table 5. Conformity of Planned to Actual Result for Occlusion Subgroup Analysis

	Class 3	Class 2	Difference	*p*
A point, mm				
x	1.49 ± 1.41	1.16 ± 0.67	0.33	0.14
y	1.37 ± 1.37	1.27 ± 1.07	0.10	0.73
z	1.82 ± 1.54	2.15 ± 2.47	0.33	0.54
B point, mm				
x	1.34 ± 1.27	1.30 ± 0.88	0.04	0.87
y	1.50 ± 1.03	1.84 ± 1.40	0.34	0.28
z	1.99 ± 1.70	2.32 ± 2.09	0.33	0.49
Pg, mm				
x	1.78 ± 1.46	2.08 ± 1.74	0.30	0.46
y	2.91 ± 1.96	3.67 ± 2.97	0.76	0.25
z	3.12 ± 2.57	3.14 ± 3.53	0.02	0.98
Me, mm				
x	1.85 ± 1.56	2.44 ± 1.83	0.59	0.17
y	3.04 ± 2.14	3.33 ± 2.43	0.29	0.62
z	2.81 ± 2.55	3.33 ± 2.71	0.52	0.41
ANS, mm				
x	1.54 ± 1.61	1.30 ± 0.80	0.24	0.36
y	2.49 ± 3.15	1.90 ± 1.55	0.59	0.24
z	1.88 ± 1.59	1.82 ± 1.48	0.06	0.86
SNA, deg	1.55 ± 1.47	1.15 ± 1.07	0.40	0.16
SNB, deg	0.90 ± 0.62	0.99 ± 0.88	0.09	0.67
ANB, deg	1.15 ± 0.98	1.03 ± 0.85	0.12	0.59

A, A point; B, B point; Pg, pogonion; Me, menton; ANS, anterior nasal spine; SNA, sella-nasion-A point angle; SNB, sella-nasion B-point angle; ANB, A-point-nasion-B-point angle.

plane (vertical) (Table 1). The study did not have patients with greater than 6 mm of movement in any direction. The mean differences between preoperative and postoperative linear measurements are as follows: A point (x = 1.23 mm, p = 0.09; y = 1.34 mm, p = 0.04; z = 1.74 mm, p = 0.04), B point (x = 1.32 mm, p = 0.07; y = 2.15 mm, p = 0.02; z = 1.67 mm, p = 0.02), pogonion (x = 1.24 mm, p = 0.07; y = 3.71 mm, p = 0.04; z = 2.12 mm, p = 0.06), menton (x = 2.62 mm, p = 0.02; y = 3.95 mm, p = 0.01; z = 2.40 mm, p = 0.03), and anterior nasal spine (x = 1.12 mm, p = 0.04; y = 1.20 mm p = 0.04; z = 1.71 mm, p = 0.01) (Table 3).

The greatest nonconformity of the actual result when compared to the virtual surgical plan was found in the vertical plane (A point and B point) and the sagittal plane (pogonion, menton, and anterior nasal spine). High fidelity between planned and actual angular measurements [sella-nasion-A point angle, 0.04 degree (p = 0.95); sella-nasion-B point angle, 0.65 degree (p = 0.63); and A-point-nasion B-point angle, 0.01 degree (p = 0.98)] was observed, with no statistically significant differences detected (Table 4). Subgroup analysis of patients stratified by occlusal dysmorphology failed to reach significance in linear and angular measurements (Table 5).

DISCUSSION

The advent of virtual surgical planning has caused a paradigm shift in orthognathic surgery, offering improvements in intraoperative efficiency and possibly surgical outcomes.[17–20] The purpose of this study was to evaluate the conformity of the three-dimensional plan (virtual surgical plan) to the actual result following 100 triple-jaw operations performed by a single surgeon (Figs. 1 and 2). Precision within the range of 2 mm is usually considered an acceptable margin of error in orthognathic surgery, placing the postoperative maxillomandibular position within the

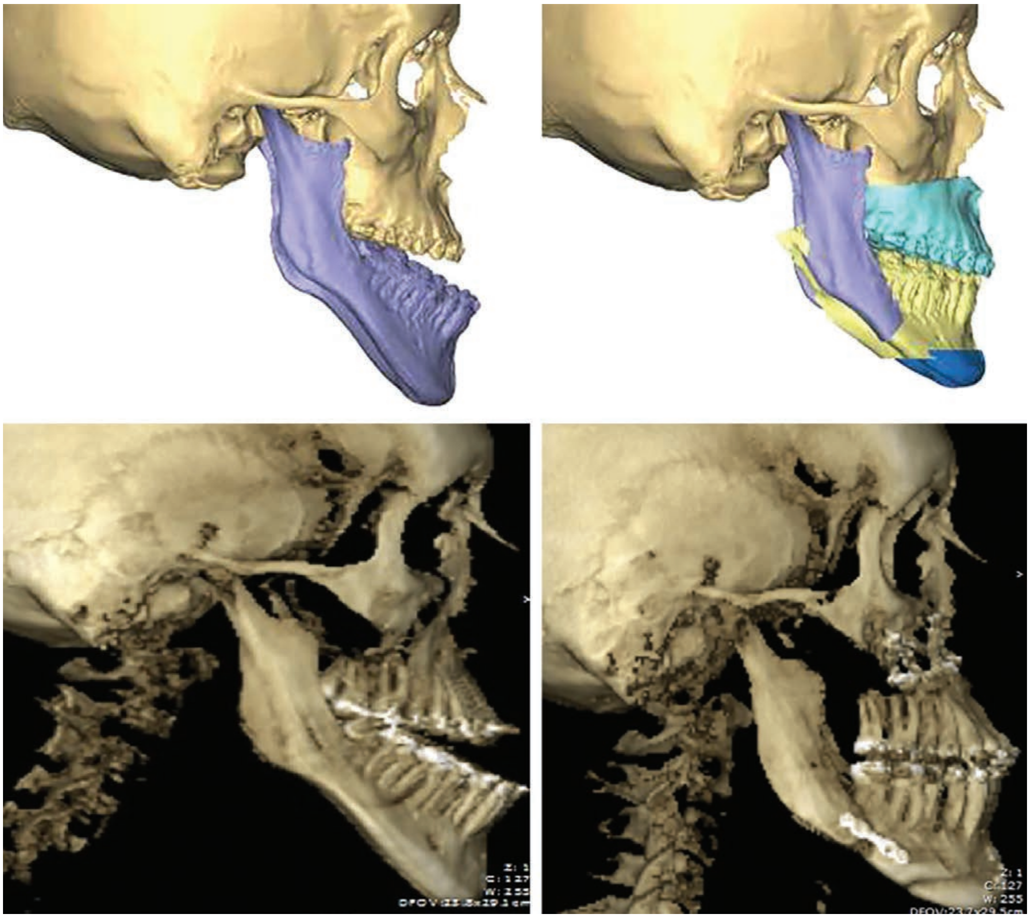

Fig. 1. Virtual surgical planning session for a patient with class 2 malocclusion. (*Left*) Preoperative three-dimensional scan (*above*, *left*) and cone beam computed tomographic scan (*below*, *left*). (*Right*) Virtual surgical plan (*above*, *right*) and corresponding postoperative (*below*, *right*) cone beam computed tomographic scan.

range of orthodontic compensation to achieve an occlusal relationship well under the margin of less than 1 mm.[7,21–26] As we hypothesized, the precision of the virtual surgical plan is well translated intraoperatively, with the majority of results within margins of clinical significance (<2 mm).[7,21–26] We observed a clinically significant deviation in the sagittal positioning of the mandible and chin. In addition, clinically insignificant deviation in the vertical height of the maxilla was observed.

Our results show the highest degree of conformity to the virtual surgical plan in the positioning of the maxilla. Correct positioning of the maxilla is the keystone to the successful result in orthognathic surgery. Clinically significant deviations will affect occlusion, aesthetic proportions of the midface, location of the central incisors, and lower face position. Our data represent an accurate translation of the virtual surgical plan to the actual result in maxillary positioning. The greatest deviation from the virtual surgical plan existed in the vertical plane of the A point (1.74 mm; $p = 0.04$) and the anterior nasal spine (1.71 mm; $p = 0.01$).

In our cohort, intraoperative vertical positioning of the maxilla was determined in part based on measurements from an external reference point using the medial canthus to fixed dental landmarks, following sagittal repositioning and rigid fixation of the bilateral split sagittal osteotomy. A planned vertical change was borne in mind during maxillary plating, but the aesthetic relationship of upper lip to central incisal show took precedence, and, at times the planned or measured expected vertical change could have been ignored (Fig. 3). The vertical measurements were used more to correct a frontal cant (or to ensure one was not created), rather than strict reliance on the absolute value (with impaction or disimpaction). The vertical height discrepancies reported in our data are similar to other reports in the literature.[27–29] These vertical height alterations did not appreciably impact the sagittal or transverse relationship of the maxilla as described by Polido et al.[27] In our analysis, deviations in the vertical position did not affect maxillomandibular sagittal placement [seen by sella-nasion-A point angle, sella-nasion B-point angle, and A-point-nasion-B-point angle (0.04, 0.65, and 0.01 degree), respectively]. None of the angular deviations were statistically different.

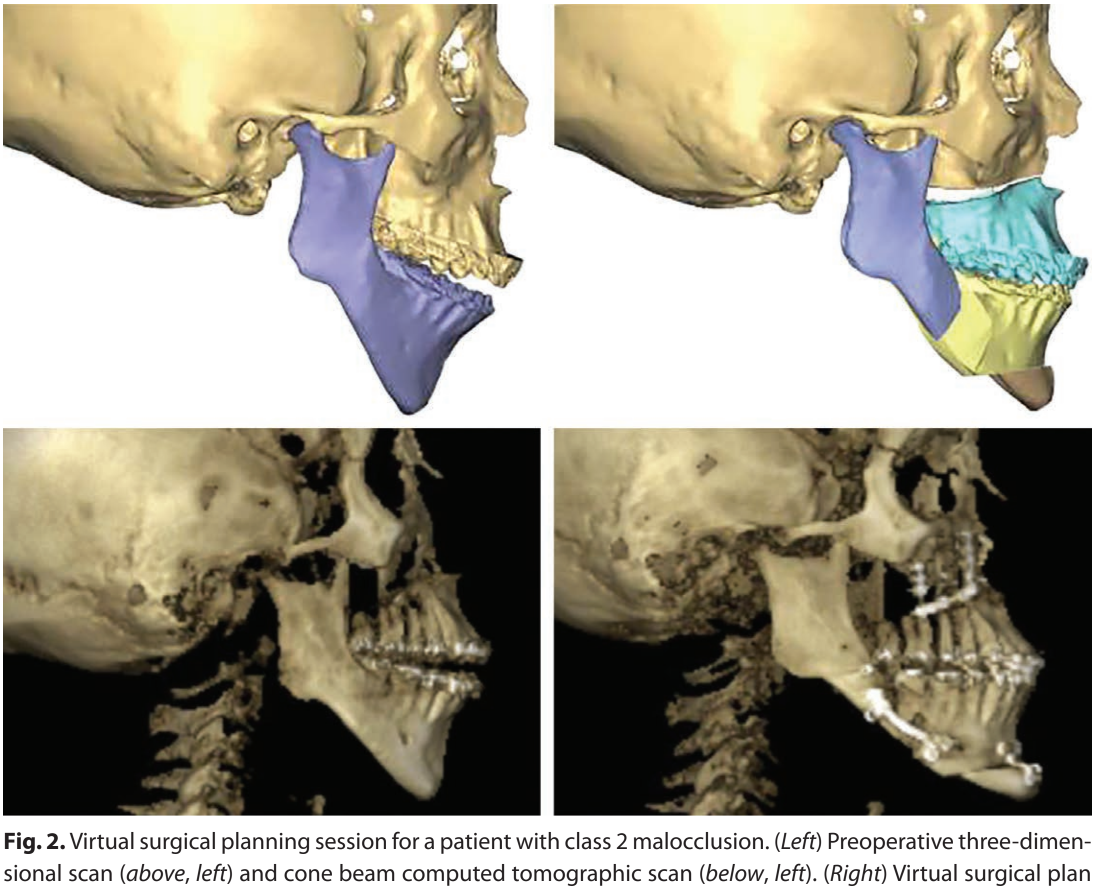

Fig. 2. Virtual surgical planning session for a patient with class 2 malocclusion. (*Left*) Preoperative three-dimensional scan (*above*, *left*) and cone beam computed tomographic scan (*below*, *left*). (*Right*) Virtual surgical plan (*above*, *right*) and corresponding postoperative (*below*, *right*) cone beam computed tomographic scan.

Fig. 3. Photographs of a patient with class 3 malocclusion who underwent triple-jaw orthognathic surgery, obtained preoperatively (*above*) and postoperatively (*below*).

We postulate that maxillary vertical height deviations can also be partially attributed to "play" in the system, with variable upward pressure on the maxillomandibular complex, and the subjective/aesthetic decisions of the upper incisor, and vertical measurements, all taken into consideration before maxillary plating. The three-dimensional plan is translated as a splint only, without a direct bone-to-bone guide, and though the splint will achieve a reproducible occlusal relationship, there are differences that occur in the osseous location, especially vertically. The next generation of three-dimensional planning, with osseous cutting guides and three-dimensionally printed plates, should correspond nearly identically on the bone level, in all planes of space. However, this technique will lock in the planned bone position, determined from computed tomography, without all soft-tissue information. Once the three-dimensionally printed plate strategy is more common, the pros, cons, reproducibility, and aesthetic results should all be studied/gauged. Despite using splints only, we observed a high degree of fidelity between the virtual surgical plan and maxillary positioning; however, some interesting deviations in the final mandibular location were observed (Fig. 4).

In particular, the mandible demonstrated less congruency in the sagittal (2.15 mm; $p = 0.02$) and vertical (1.67 mm; $p = 0.02$) planes. The transverse

Fig. 4. Photographs of a patient with class 2 malocclusion who underwent triple-jaw orthognathic surgery, obtained preoperatively (*above*) and postoperatively (*below*).

dimension, however, showed better conformity (1.32; $p = 0.07$). These deviations may be secondary to the clockwise and counterclockwise pitch alterations of the maxillomandibular complex, which translate to greater or less sagittal projection at pogonion (depending on clockwise or counterclockwise movement). Furthermore, virtual surgical planning is a static platform, enabling the distal mandible to be moved anywhere in space, but not taking into account several biological variables. For instance, virtual surgical planning does not accurately predict changes about the temporomandibular joint in the glenoid fossa. It can be difficult to predict the natural condylar position, and opening patterns (hinge and translator) and intraoperative manipulation of proximal segment and plating can alter this response (which translated to altered sagittal and vertical dimensions). Greater upward and backward force to the proximal segment during plating can result in a larger bone gap, with a greater body/pogonion sagittal projection. The effect of muscle tension (or lack thereof intraoperatively) and supine patient positioning can also contribute to temporomandibular joint position alterations, resulting in sagittal projection different from that planned.[30–35]

To further evaluate the impact of sagittal plane deviations in mandibular positioning, a subgroup analysis was performed between class 2 and class 3 malocclusion. No significant differences existed between planned and actual results between these subgroups. There has been scant investigation in the surgical literature regarding the precision of virtual surgical planning translation between class 2 and class 3 malocclusion. The deviations in the sagittal positioning of the mandible are incorporated initially in a mandible-first approach. Then, the maxilla is repositioned to the neomandible, and our findings showed still a very close sagittal maxillary conformity, with leeway in the vertical position.

The least virtual surgical planning conformity was observed in the positioning of the chin following osseous genioplasty. The deviation from the plan was most evident in the sagittal plane of menton (3.95 mm; $p = 0.01$) with more subtle deviations observed in the transverse (2.62 mm; $p = 0.02$) and vertical (2.4 mm; $p = 0.03$) planes. Following occlusal surgery, the bony position of the chin greatly impacts the contour of the lower third of the face and jawline. Currently, the senior author (D.S.) does not use an orthognathic positioning system for this third and final portion of the triple-jaw surgery. The positioning of the chin is purely an aesthetic decision. The lack of genioplasty closeness to the virtual surgical plan is likely attributable to the following: (1) the underemphasized magnitude and spatial repositioning in the plan; and (2) a greater emphasis on the on-table aesthetic position (ignoring the virtual surgical plan).

Figure, Supplemental Digital Content 1, shows photographs of a patient with class 2 malocclusion who underwent triple-jaw orthognathic surgery, obtained preoperatively (*above*) and postoperatively (*below*), ***http://links.lww.com/PRS/D536***.

This study is limited by its retrospective nature. In addition, the operations analyzed were performed by a single surgeon and may not be applicable to most craniofacial surgeons. Furthermore, every effort was made to ensure interrater and intrarater reliability; however, slight variations in measurement techniques may still be evident. Also, we are unsure that the conformity is impacted by the magnitude of maxillary, mandibular, and chin movements. This is a future direction of research, to quantify the conformity for patients who have had three-dimensionally custom-printed maxillary plates based on virtual surgical planning.

CONCLUSIONS

There is a high degree of conformity comparing the orthognathic virtual surgical plan to the actual postoperative result. However, some incongruency is seen, vertically (maxilla) and sagittally (mandible, chin). Departures of the actual position compared to the plan outline weaknesses of the virtual surgical planning platform, namely, predicting condylar changes, optimizing aesthetic proportions, and predicting play inherent in orthognathic splints.

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