INTRODUCTION

Orthognathic surgery (OS) is a powerful tool in the treatment of dentofacial deformities and creation of a balanced maxillomandibular relationship. Furthermore, OS is an effective tool in the aesthetic armamentarium for facial surgery that can result in a more attractive facial appearance, hence improving self-perception of beauty.\(^1\)\(^-\)\(^4\)

Computer-aided surgical planning has become popular for planning orthognathic surgery (OS) as it saves surgeons’ time and effort. A recent advancement has been the utilization of patient-specific cutting guides and osteosynthesis. The purpose of this study is to report the postoperative bimaxillary position utilizing custom plates for both jaws versus custom plates used in the maxilla only in 23 consecutive patients.

Methods: All patients who underwent bimaxillary OS in 2017–2018 with preoperative computed tomography (CT) scan, postoperative day 1 CT scan, and at least 6 months follow-up were included in the study. Group 1 utilized maxillary preprinted plates (maxilla only). Group 2 utilized bimaxillary preprinted plates (maxillomandibular). Eight cephalometric landmarks to evaluate the movements were chosen. The ranges of the angle between the sella/nasion plane and the nasion/A plane (SNA), the angle between the sella/nasion plane and the nasion/B plane (SNB), and the angle created by the A point, nasion, and B point, which measures the relative position of maxilla to mandible, were analyzed to assess the angular change. Mean-squared displacement and the SD of the distances were used to assess movement in space.

Results: Twenty-three patients (nine in group 1 and 14 in group 2) met the inclusion criteria. Results showed interarch relationships using custom plates for both jaws with ANB 0.4 compared to ANB 1.4 for maxillary custom plates only. Mandibular landmarks showed greater variation, and the t test study revealed the right mandibular first molar landmark showing the greatest variation (\(P = 0.03\)).

Conclusions: Custom osteosynthesis plates for OS show good accuracy for the maxilla and higher variation in the mandible. Further studies will determine the margin of error that cannot be corrected with postoperative orthodontics. (Plast Reconstr Surg Glob Open 2022;10:e4609; doi: 10.1097/GOX.0000000000004609; Published online 18 November 2022.)

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movements\textsuperscript{5} due to the compounded inevitable errors in every step. Arguably, the advent of computer-aided design (CAD) and computer-assisted manufacturing (CAM) has ushered orthognathic surgery into a new technological era. Utilization of computer-aided surgical simulation and creation of three-dimensional (3-D) rendering of the craniofacial skeleton for the treatment planning and fabrication of reliable intraoperative occlusal splints have significantly changed the paradigm for craniofacial surgeons, allowing them to visualize different movements in all three Cartesian coordinates.\textsuperscript{6–15}

The computer-guided treatment planning theoretically may minimize the human error during the process of presurgical planning as well as significantly reduce the time and manpower needed to accurately depict the occlusal–skeletal relationship.\textsuperscript{14,15} Recent surveys show that computer-aided surgical simulation planning and CAD/CAM fabrication of occlusal splints is becoming the technique of choice due to the more efficient nature of the process for the management of dentofacial deformities requiring orthognathic surgery,\textsuperscript{16–18} whereas the principles of planning utilized by the surgeons remain the same, whether traditional or computer-guided.

The next logical advancement in orthognathic surgery is the incorporation of preplanned, patient-specific cutting guides and osteosynthesis plates for bimaxillary procedures. In early studies, this method has shown an accuracy in osteotomies and fixation when applied to isolated maxillary or mandibular surgery.\textsuperscript{19} However, preprinted cutting guides and fixation devices may also magnify some of the disadvantages of CAD/CAM, including inaccurate bone positioning intraoperatively if occlusion is not exact. In this study, we present the results of 14 consecutive patients undergoing bimaxillary OS utilizing patient-specific drills, cutting guides, and fixation hardware. This is the first part of an ongoing investigation comparing splintless bimaxillary surgery with patient-specific fixation plates to traditional splint-based procedures.

\textbf{PATIENTS AND METHODS}

\textbf{Patients}

This study was approved by The Children’s Hospital of Philadelphia Institutional Review Board. All patients who underwent bimaxillary orthognathic surgery in 2017–2018 at The Children’s Hospital of Philadelphia with at least 6 months of follow-up were reviewed in this retrospective study. Those without sufficient follow-up or postoperative CT scans were excluded. Demographics and pre- and postoperative 3-D cephalometric measurements were reviewed. Identified patients were retrospectively placed into two groups varying on the type of mandibular fixation techniques. All patients underwent one-piece LeFort I surgery. Eight cephalometric landmarks were used to evaluate the movements of the osteotomy segments including rotational movements of the mandible. The landmarks in the mandible included skeletal B-point, left mandibular first molar, right mandibular first molar, mandibular midline incisor, and the maxillary landmarks included skeletal A-point, left maxillary first molar, right maxillary first molar, and maxillary midline incisor. The ranges of SNA, SNB, and ANB angles were analyzed to assess the angular change among the study subjects.

\textbf{Initial Two-dimensional Analysis}

For preoperative planning, craniofacial CT scans, dental casts, and clinical photographs were obtained when orthodontic treatment was completed just before surgical planning. A multidisciplinary team including the senior surgeon and orthodontist determines the final positioning

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
\textbf{Takeaways} & \textbf{Question} & \textbf{Findings} \\
\hline
\textbf{Question:} Is custom-printed plates for orthognathic surgery inferior to traditional model surgery splint-guided orthognathic surgery? & & \textbf{Findings:} Custom plates for orthognathic surgery show good accuracy for maxillary movements. Mandibular plates demonstrate higher variation compared to maxillary plates \\
\hline
\textbf{Findings:} Custom osteosynthesis plates for orthognathic surgery may provide faster and efficient means of planning and executing bimaxillary orthognathic surgery. This three-dimensionally designed planning may eliminate the use of surgical splints and save time and effort for a surgeon.
\hline
\end{tabular}
\caption{Takeaways}
\end{table}
methods established in the literature. All patients underwent sur-
gical corrective procedures and followed the standard orthognathic tech-
iques. The head position is further adjusted to the neutral position. This 3-D complex as a unit is then analyzed.

Final 3-D Surgical Planning

Once the 2-D cephalometric analysis is completed, a virtual 3-D planning session is scheduled with a computer engineer. All clinical information is sent for virtual planning (Materialize, Plymouth, Mich.) approximately 2–3 weeks before the surgery. Using the CT scan, and occlusal casts, a 3-D model of the skull is built where the mandible is in centric relation, and the occlusal details are visualized free of artifacts caused by restorations or attached appliances. The head position is further adjusted to the neutral head position. This 3-D complex as a unit is then analyzed to detect pitch, roll, and yaw discrepancies. With the correction of these skeletal discrepancies, the occlusal plane is repositioned to maximize intercuspidation, occlusal cants are corrected, and both skeletal and dental midlines are re-established in a fashion where a balanced and harmonious skeletal relationship is created. Furthermore, these 3-D movements take into consideration the soft-tissue overlay and the affected soft-tissue components such as lip position, incisal shown in repose and smile, and nasal tip projection. Once all movements are finalized, predesigned maxillary and mandibular cutting guides and fixation plates are then fabricated (Depuy Synthes, West Chester, Pa.).

Surgical Technique

All surgical procedures were performed by the senior surgeons and followed the standard orthognathic techniques established in the literature. All patients underwent a one-piece LeFort I osteotomy; the procedures were performed with maxillary osteotomy first, followed by mandibular sagittal split osteotomy. As all patients had a tendency of the measurements. Last, an unpaired Student t test was used for quantitative accuracy analysis with statistical significance set at a P value less than 0.05. Of note, for SNA and SNB angles, considering the variation in inclination of the SN line in the population, the ranges of the values calculated and the resultant ANB discrepancies were calculated. For statistical analysis, Microsoft Excel 2019 and for graphic representation of the results MATLAB were used to create graphs.

RESULTS

A total of 23 patients met the inclusion criteria. Group 1 had nine patients (four clefts, nine class III). Group 2 had 14 patients (six clefts, 2CFM, three previous

| Parameters             | MO Group 1     | MM Group 2     | P   |
|------------------------|----------------|----------------|-----|
| A-Point                | 1.00 ± 0.64    | 0.87 ± 0.41    | 0.40|
| B-Point                | 2.70 ± 1.75    | 2.84 ± 1.39    | 0.87|
| R Max 1st Molar        | 2.60 ± 2.69    | 1.05 ± 0.64    | 0.06|
| L Max 1st Molar        | 2.25 ± 2.10    | 1.01 ± 0.67    | 0.35|
| R Man 1st Molar        | 4.82 ± 4.21    | 2.34 ± 1.34    | 0.03|
| L Man 1st Molar        | 3.09 ± 1.48    | 2.54 ± 1.65    | 0.06|
| Max midline incisor    | 1.02 ± 1.56    | 1.03 ± 0.74    | 0.30|
| Man midline incisor    | 2.53 ± 2.26    | 2.64 ± 1.66    | 0.99|

P < 0.05,
mandibular distractions, seven class II, seven class III). The results showed the greatest variation to be among the mandibular landmarks in terms of 3-D movements of the fragments. Table 1 shows the mean distance (mm) and standard deviation between the planned and post-op landmarks in 3-D Cartesian system in group 1 and group 2, t test (one-tailed) study compared the average discrepancy of planned and actual movements in groups 1 and 2 with the right mandibular first molar being the only landmark showing statistically significant variation with $P = 0.03$ (significance $P$ value <0.05). Table 2 shows SNA, SNB, ANB variation and range in groups 1 and 2. Despite the wider range of SNA and SNB in group 2, this group had a narrower ANB range. Box and whiskers plots, shown in Figure 1, were used to show the error distribution in groups 1 and 2 and to identify the outliers among the study subjects. Figure 2 shows a postoperative analysis of the planned versus postoperative position where the postoperative position (green) overlaid on the final position (orange).

**DISCUSSION**

In many surgical units throughout the developed world, CAD with the use of computer-generated intermediate and final splints has been replacing the more traditional facebow transfer, articulator, plaster models, and model surgery for orthognathic surgery. The high level of accuracy of splintless, maxillary orthognathic surgery in terms of minute deviations in 3-D space using customized cutting guides, and osteosynthesis was previously shown and attributed to the fact that the maxilla is positioned using only the upper face rather than involving the splint and mandible which are in no direct contact with the rest of the face.\(^2\) As an early adapter of this technology in North America, we were similarly interested in exploring the benefits of utilization of splint-free surgery with custom plates in bimaxillary surgery. In this study, we looked at 14 consecutive procedures done by the senior author (S.P.B.) using both maxillary and mandibular plates and compared the results to those of one of the co-authors (J.A.T.) who utilized the custom maxillary plates but continued to use traditional lag screws and splint technique when setting the final position of the mandible.

The freedom of modifying structures in 3-D space limits the utilization of traditional 2-D quantitative measures to assess the accuracy of this new technique. Previous studies have shown that there can be significant errors associated with traditional presurgical evaluation, facebow record and transfer, model surgery, and the final outcomes of bimaxillary orthognathic surgery.\(^8,21–24\) since the traditional methods utilize a 2-D cephalometric analysis and use multiple steps which result in compounding the error.\(^28–30\) It is therefore expected that the involvement of the mandible and the TMJ apparatus will introduce some degree of error for bimaxillary orthognathic surgery. Furthermore, this inaccuracy is further amplified, as the position of condyles in the supine

| Landmark | Error Range | MO Group 1 | MM Group 2 |
|----------|-------------|------------|------------|
| SNA      | 0 - 2.1     | 0.1 - 3.8  | 0, 3.8     |
| SNB      | 0.1 - 2.8   | 0.2 - 4.3  | 0.1 - 4.1  |
| ANB      | 0.2 - 1.6   | 0.1 - 0.5  | 0.4        |

Fig. 1. Boxplot graphic representation of cephalometric landmark error in millimeters in post-operative analysis relative to the planned positions where landmarks with plus sign contained an outlier. Patient-specific prefabricated maxillary (A) and mandibular (B) fixation plates. A, Group 1: cephalometric landmark error, postoperative vs planned. B, Group 2: cephalometric landmark error, postoperative vs planned.
position can vary, especially if neuromuscular paralysis is used, which tends to mask functional shifts caused by the musculature, which presents itself as apertognathia once maxillomandibular fixation is released or in the immediate postoperative period in the absence of paralytics. As a result, traditional orthognathic surgery has the potential to result in inadequate translation from the laboratory-generated movements of the dentofacial apparatus in the intraoperative setting.\(^8\) However, studies lack a clear understanding of intraoperative factors contributing to the inaccuracy of orthognathic surgery, since other factors such as postoperative edema can cause postoperative malocclusion which will make identification of etiology rather challenging.

Although skeletal landmarks were mainly utilized to plan and analyze the movements, one must consider the effects of dentition on the results as well. Having the largest occlusal tables in dentition, even minute orthodontic movements of maxillary first and mandibular first molar teeth will result in inaccuracy of the movements. Considering that there is a 2- to 4-week gap between treatment planning and surgery, this may contribute to the observed level of inaccuracy in the maxillary first molar. Since the "maxilla first" approach was utilized in all procedures, the changed maxillary first molar position will contribute to the inaccurate position of the mandibular first molar. The error in the maxillary first molar position will result in an exaggerated anterior translation of the mandible as a unit. The results of group 2 show a narrower range of error for ANB (0.1–0.5), compared to group 1 which showed an ANB error range that is wider (0.2–1.6).

Additionally, in group 1, the maximum translation of mandible was 6.6, whereas the maxilla had an 8.3 mm maximum translation. In group 2, the maximum translation of mandible was 8.9 mm, whereas the maxilla translated 6.2 mm at most. The degree of movements in other planes, generally in 3-D, was variable. Considering the maximum intercuspsation is only one position, 3-D changes can easily affect cusp–fossa relationships and cause deviation from the planned position which is demonstrated by the variation in first molar planned versus the postoperative position. Considering the results of this study, it is essential to address the level of occlusal discrepancy. In patients with significant mandibular asymmetry, steep curve of Spee, or absent canine guided occlusion due to suboptimal canine position or angulations, since first molar occlusion is heavily relied upon, the benefits of this technique will require further investigations.

A major limitation of this study is the small sample size, as this technology was just recently offered to our institution. Furthermore, the study utilizes cephalometric landmarks which are known to have limited clinical relevance. Moreover, we utilized the 2-D landmarks to compare the outcomes of 3-D planned procedures which will not capture the difference between the two techniques. Utilization of heat-maps and topographic analysis using computer software in future may further allow us to provide a better technique for comparison. Another limitation of this study is the comparison of two surgeons and their differing techniques. One senior surgeon does not incorporate prefabricated mandibular plates in his current practice.

As discussed previously, we utilized the variation in mean-squared distance between the two points in 3-D space (planned and postoperative landmark coordinates) to assess the variation of custom-fabricated fixations in relation to planned movements which may not fully represent the error involved in this technique. Additionally, it is possible that due to prior orthodontics, arch deficiencies, specifically transverse deficiencies were masked, and such patients would have benefited from a segmental maxillary surgery which potentially could have improved the stability of the treatments. Of note, in both groups, first molar orthodontic adjustments played a major role in postoperative orthodontic adjustments with anterior discrepancies addressed using elastic bands. All patients had maximal intercuspation 6 months after surgery; however, the ease of correction between the two groups was not quantified.

**CONCLUSIONS**

In this study, we looked at 14 consecutive procedures performed by the senior author using both custom maxillary
and mandibular plates and compared the results to those of the co-author who adapted to using custom maxillary plates and continued to use traditional lag screws and split technique (nine patients). In the setting of the final position of the mandible, we have shown that utilization of custom mandibular hardware in the mandible shows a higher variability in comparison to the maxilla. The utilization of CAD has significantly improved the accuracy and outcomes of the procedures digitally planned and it is hoped that the utilization of custom plates will continue to advance this agenda and may eliminate the use of surgical splints which may reduce intraoperative time. The authors would like to emphasize the small sample size in this study which prevents any generalizable conclusions to be drawn; with further utilization of this technique and longer follow-ups, we are hoping to identify the appropriate indications for this type of planning and treatment and further improve the accuracy. In addition, we hope to learn how this method relates to the overall impact on dentition, occlusion, and postoperative orthodontic adjustments required in these patients.

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