Custom Plates in Orthognathic Surgery: A Single Surgeon's Experience and Learning Curve

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Background: Virtual surgical planning (VSP) now allows for the fabrication of custom plates in orthognathic surgery. The senior author was an early adopter, using VSP and stereolithographic splints for over a decade, before transitioning to custom plates in 2019. The authors present our experience and learning curve with this new technology and compare results to a prior cohort of orthognathic patients.

Methods: A retrospective chart review identified patients undergoing orthognathic surgery with the senior author between 2016 and 2021. All underwent VSP and stereolithographic splint formation, and then either traditional or custom-plate fixation. Demographics, perioperative variables, and postoperative outcomes were analyzed. Traditional fixation consisted of craniomaxillofacial plates, bent intraoperatively by the surgeon to adapt to the facial skeleton. Custom plates were prefabricated and prebent to fit drill holes outlined by customized cutting guides.

Results: Forty-three patients underwent surgery in the study period, 25 (58.1%) with traditional fixation hardware and 18 (41.9%) with custom plates. The surgical technique evolved throughout the custom-plate cohort, with the most recent technique involving custom maxillary plate fixation and traditional mandibular plate fixation. When comparing this group of patients to the prior cohort of traditional fixation patients, operative time significantly decreased (mean 233 minutes versus 283 minutes, $P = 0.044$), without significant difference in complications.

Conclusions: Patient-specific cutting guides and custom plates allow for precise spatial positioning of the osteotomized jaw in the orthognathic surgery. Unsurprisingly, obstacles must be overcome in adopting this new technology; here, we outline our experience and technical modifications that have resulted in increased surgical efficiency with comparable outcomes.

Key Words: Custom plates, orthognathic surgery, virtual surgical planning

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Orthognathic surgery is a powerful tool used for the correction of maxillary and mandibular deformities resulting from malocclusion, injury, or disease. The success of orthognathic surgery largely depends on 3 main factors: (1) precise evaluation and diagnosis of complex dentofacial deformities; (2) creation of an appropriate and effective surgical plan predicting the final three-dimensional spatial positioning of the jaws and their relationship to the rest of the craniofacial skeleton; and (3) the ability to accurately and precisely execute the presurgical plan in the operating theater.

Over the past 2 decades, the advent and implementation of virtual surgical planning (VSP), along with computer-aided design and computer-aided manufacturing, have changed the landscape of traditional orthognathic surgical planning and execution, improving upon each of these 3 factors.[1,2] Traditional evaluation consisted of physical examination, two-dimensional photographs, cephalometry, and dental molds. This has been augmented with cone-beam computed tomography and laser-scanning of the dental arches, allowing for precise three-dimensional analysis in VSP. Traditional presurgical planning involved the creation of dental molds and casts, facebow transfer of these dental casts onto articulators, and model surgery to move the dental casts into their final positions and allow for occlusal splint creation (both intermediate and final splints in the case of double jaw surgery). This traditional model-surgery process not only required a significant time contribution but also was susceptible to compounding errors throughout the process, potentially resulting in suboptimal final jaw position.[3] VSP subsequently allowed for a more efficient, and possibly more accurate, alternative to this traditional workflow: digital CT scans and dental impressions are uploaded into a software platform, and during a planning session, the surgeon and engineer work together to plan the osteotomies and simulate movements of the osteotomized segments virtually. Once these plans are finalized, custom fabrication of stereolithographic splints follows, and these splints can be used in the operating room. The senior author was an early adopter of VSP and stereolithographic splint creation over 10 years ago, and reported on both its time-saving and accurate nature; since then, multiple authors have shown improvements in both time spent planning as well as overall surgical accuracy when using VSP (and the associated stereolithographic splints) compared to the traditional articulator-based model surgery.[4–9]

More recently, developments in VSP have focused on accurately translating the presurgical plan in the operating room. Chief among these developments has been the creation of custom patient-specific implants and cutting guides. This technology allows the surgeon and engineer to design customized cutting guides around proposed

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osteotomies; these guides also contain templates for screw holes based on bone thickness and tooth root position. Custom plates are then designed and fabricated to fit the predrilled holes and hold the osteotomized segments in their desired final position. Although this is new technology, several authors have already reported improved final surgical accuracy when using VSP and patient-specific custom plates compared to VSP and stereolithographic splints.[10,11,12] The purpose of this paper is to report the senior author's experience over the past 3 years using VSP and custom patient-specific implants in orthognathic surgery cases and compare these cases to a prior cohort of orthognathic surgical patients who underwent VSP without custom plates. Most importantly, we seek to specifically describe the learning curve and technical adaptations that we have implemented both in the planning and execution phases to improve intraoperative efficiency with this new technology.

MATERIALS AND METHODS

Institutional Review Board approval was obtained for this retrospective study. A retrospective chart review was performed on all patients undergoing orthognathic surgery between April 2016 and November 2021. All patients in this series, whether treated with standard craniofacial plates or custom plates, underwent VSP and stereolithographic splint fabrication. Patient demographics, perioperative variables, and postoperative outcomes were analyzed. Perioperative variables included length of surgery, use of custom or standard plates, planned maxillary and/or mandibular osteotomies and specific movements, and concomitant genioplasty. Postoperative complications including hematoma, seroma, infection, unplanned return to surgery, need for hardware removal, and need for revision were recorded within the available follow-up period. Univariate analyses were carried out to compare patient demographics, operative times, and postoperative complications between patients undergoing orthognathic surgery with traditional hardware fixation and those in whom patient-specific custom plates were used. Traditional hardware fixation consisted of craniomaxillofacial plates (Stryker Corporation, Kalamazoo, MI) which were bent intraoperatively by the surgeon to adapt to the facial skeleton. Custom plates, on the other hand, were prefabricated and prebent to fit the drill holes outlined by the customized cutting guides. Descriptive statistics are reported as a mean +/- standard deviation or percentage within groups where appropriate.

RESULTS

There were 43 patients included in this study. Twenty-five patients (58.1%) had traditional orthognathic plating, and 18 patients (41.9%) had surgery with patient-specific cutting guides and custom plates. Supplementary Digital Content, Table 1, http://links.lww.com/SCS/D883 displays the demographic data and perioperative data. Of note, there were no statistically significant differences in any of the demographic categories examined. Importantly, in the custom plate cohort, custom plates were used for the maxilla in all cases; however, custom plates were only used on the mandible for the first 12 patients, after which the mandible was fixated with traditional hardware for the remaining 6 patients (for reasons which are detailed in the discussion below). When comparing the overall custom plate group to the traditional group in terms of operative time, there was no significant difference (271 minutes versus 283 minutes). However, when the custom plate group was subdivided into the custom versus traditional mandibular plates, the subgroup of patients who had custom maxillary plates with traditional mandibular plates had significantly shorter operative times than both the overall traditional plate group (226 minutes versus 283 minutes, $P = 0.036$) and the subgroup with custom plates on both the maxilla and mandible (226 minutes versus 295 minutes, $P = 0.044$).

Supplementary Digital Content, Table 1, http://links.lww.com/SCS/D883 also displays the types of movements utilized in each cohort. Of note, midline correction was defined as a change >1 mm. Likewise, cant and plane correction was defined as a change >1 mm. There was no significant difference in the movements between cohorts.

Supplementary Digital Content, Table 2, http://links.lww.com/SCS/D884 displays the postoperative outcome and complication data stratified by cohort. The average follow-up for all patients was 9.8 months; 13 months in the traditional plate group, and 5.4 months in the custom plate group ($P = 0.012$). Of note, there was no significant difference in either overall complications or individual complications. In the traditional plate cohort, there were 2 postoperative infections, of which one required removal of hardware and the other required only incision and drainage. There was one case of persistent hardware exposure requiring removal. There was one case of partial maxillary necrosis requiring debridement of a small area of nonviable bone. There were 2 cases of occlusal relapse which required revision; one of these revisions was complicated by an early postoperative peri-hardware fracture in the setting of blunt trauma 2 weeks after surgery.

In the custom plate cohort, there were 3 postoperative infections, all of which occurred within the custom mandibular plate subgroup. One of these infections resolved with oral antibiotics, whereas the remaining 2 infections required plate removal 9 months after surgery. There was also a palatal fistula created during a 2-part Lefort I osteotomy, which required repair in the operating room 3 months after the index surgery. No patients in the custom plate cohort required revision surgery.

DISCUSSION

Virtual surgical planning has changed the landscape of orthognathic surgery over the past 2 decades. Early implementation of the technology allowed for the creation of stereolithographic models to improve both patient and surgeon understanding and visualization of complex three-dimensional structures, deformities, and movements.[13,14] Subsequent improvements allowed for the creation of stereolithographic splints to be used intraoperatively. Literature over the past decade has repeatedly demonstrated at least equal (and in many cases, superior) accuracy of the stereolithographic splints compared to splints which were fabricated in the traditional articular-model-surgery fashion.[4–9] We began using these stereolithographic splints exclusively in 2010. The resultant accuracy and time saved in the preoperative planning phase have been significant, and have been published upon by our team and others.[4–9]

The most recent advances in the VSP arena are focused on improving accuracy and efficiency in translating and executing the presurgical plan in the operating theater. To this end, the use of patient-specific cutting guides and custom plates has been shown to result in improved accuracy (compared to VSP with stereolithographic splints) by several authors.[10,11,12] One obvious theoretical advantage is in reliably establishing the position of the maxilla with respect to the skull base. Custom plating obviates the need for the creation of a vertical reference point for maxillary positioning. However, this technology is new, and as with many new technologies, there are obstacles that must be overcome in its implementation. We have used custom plates in our orthognathic cases since December 2019 and have performed 18 such cases. Below, we outline our learning curve and the changes that we have made in both preoperative planning and technical execution to improve efficiency and accuracy.

Our preoperative process consists of close communication with the orthodontic provider, ensuring that the patient's preoperative occlusion is optimized before surgery. Patients undergo cone-beam computed tomography of the maxillofacial skeleton, as well as intraoral laser scanning to create virtual dental casts. These data are combined and manipulated with the help of 3D Systems (Littleton, CO). A virtual meeting follows, during which the surgeon and engineer together outline the proposed jaw movements and final positions. At this point, if using custom plates, occlusal-based cutting guides are designed to coapt to the facial skeleton and outline both the osteotomy sites and drill holes for proposed screw locations. These hole locations are planned based on bone thickness, locations of tooth roots, and locations of any other vital structures. Intermediate and final splints are always designed. After the plan is finalized, the components (splints, cutting guides, and custom titanium plates) are fabricated and mailed to our facility. Figures 1–3 demonstrate the typical VSP for double-jaw surgery.

Our initial approach to the utilization of custom plates was as follows: on the day of surgery, the splints and cutting guides are sterilized. In the operating room, lower buccal sulcus incisions are used to exposed the mandible. Cutting guides are placed and the osteotomies are started, as well as holes drilled in the indexed locations. Before completing the sagittal split, an upper buccal sulcus incision spanning the midline provides access to the nasomaxillary and zygomaticomaxillary buttresses, which are exposed subperiosteally and widely. The occlusal-based cutting guides are then placed, the proposed drill holes are drilled, and the osteotomy is initiated through the indicated portion of the guide (Fig. 4). The guide is removed, the osteotomies are completed, the maxilla is mobilized, and the custom plates (one for each side) are then affixed to the predrilled holes both above and below the osteotomy, positioning the maxilla in the desired position (Fig. 5). The intermediate splint is then used to confirm the accurate placement of the maxilla after fixation. Attention is then re-directed to the mandible, which is split and fully mobilized. Custom plates are then placed, using the predrilled holes again to position the mandible in the desired location. At this point, the final splint is then used to confirm the movements and the final occlusion.

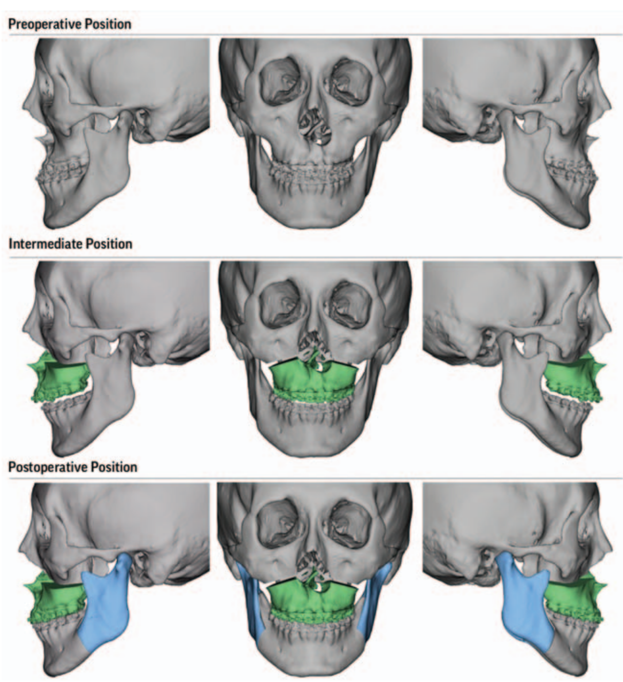

FIGURE 1. Virtual surgical planning for Lefort I and bilateral sagittal split osteotomy. Typical virtual surgical plan for Lefort I and bilateral sagittal split osteotomies, outlining the proposed osteotomies and final jaw positions.

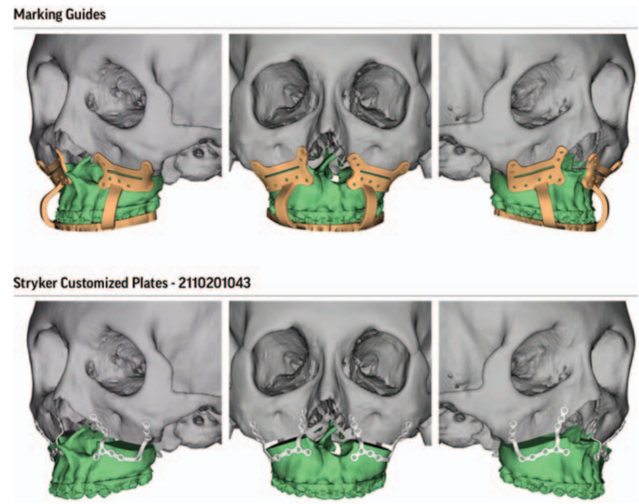

FIGURE 2. Virtual surgical planning for maxillary cutting guides and custom plates. Virtual surgical plan demonstrating the occlusal-based custom maxillary cutting guides, as well as the custom maxillary plates. Note the slot demonstrating positioning of the anterior osteotomy, as well as the index locations for drill holes.

Over the past 2 years, we have modified the above process to account for several difficulties that we encountered along the way. It cannot be overemphasized that stereolithographic splints should always be designed and manufactured. The first technical change that we implemented was to adjust our maxillary osteotomy technique for cases with custom plates. Before custom plates, we performed transverse osteotomies of the anterior maxillary sinus with a standard reciprocating saw. However, in the thin bone overlying the sinus, we observed unpredictable shattering of small areas around the osteotomy, which could potentially compromise a fixation point of the custom plate, rendering it unusable. Therefore, for the transverse osteotomy of the anterior maxilla, we have transitioned to using an ultrasonic scalpel (Sonopet; Stryker; Kalamazoo, MI), which in our experience has reliably allowed for precise osteotomies without damage to the surrounding thin bone.

After the first 10 cases, we noted that the mandibular occlusal-based cutting guide designs posed several difficulties. Overall, the mandibular guides were too bulky to fit into the subperiosteal

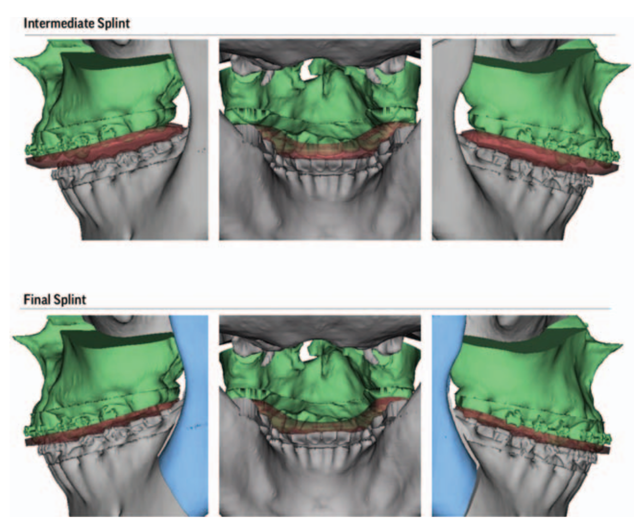

FIGURE 3. Virtual surgical planning for stereolithographic splints. Virtual surgical plan for creation of intermediate and final stereolithographic splints.

FIGURE 4. Custom maxillary cutting guide in place. Right-sided custom occlusal-based maxillary cutting guide in place, demonstrating slot for anterior osteotomy, as well as index drill holes.

FIGURE 5. Maxillary custom plates in place. Custom prefabricated and prebent maxillary plates holding the osteotomized maxilla in precise predetermined spatial positioning.

pocket. Additionally, the proposed drill holes were difficult to reach with our traditional in-line drill. We designed lower-profile guides to fit more easily into the surgical pocket. In the operating room, we also began to score the periosteum of the mandibular pocket to allow for expansion and increased exposure to accommodate the guides. To address the difficulty with drilling the holes, we transitioned to a right-angle drill (Stryker; Kalamazoo, MI) to reach the difficult holes. Although the above changes did make it possible to reliably use custom plates for the mandible, our overall approach to the mandible has largely reverted to the use of traditional plates, forgoing the mandibular guides and custom plates. We do this because once the maxillary position is spatially fixed with the custom plate and verified with the intermediate splint, the mandibular osteotomies and plating proceed quickly and easily with the final splint and traditional plates. We now plate the maxilla with custom plates as described above, complete the bilateral sagittal split osteotomies on the mandible, and place the mobilized mandibular segment into the final splint in maxillomandibular fixation. Plating then proceeds with traditional mandibular plates, maxillomandibular fixation is removed, and the occlusion is verified.

We have found that the use of the custom maxillary plates reduces the error in applying maxillary fixation in the traditional approach. Traditional maxillary fixation requires rotating the post-osteotomy maxillomandibular complex to the desired vertical maxillary position and maintaining proper condylar seating while applying fixation. This sequence requires a surgeon and 2 quality assistants to accurately retract, apply hardware, and maintain desired maxillary position. The predetermination of maxillary position with a custom plate reduces the number of variables in accurate maxillary position. This, in turn, increases surgical efficiency and decreases operative time. Once the maxilla has been positioned accurately (and verified in the intermediate splint), a standard bilateral sagittal split osteotomy is completed and traditional plating follows.

The increased efficiency of the above sequence is borne out in our data regarding operative times, which showed several interesting trends. First, upon initially transitioning to custom plate use (for both the maxilla and mandible), operative times increased slightly. This was largely due to difficulty placing the mandibular cutting guides due to pocket size constraints, and in difficulty drilling the holes with the guides in place. In several cases, this difficulty translated into decreased precision in drilling the mandibular holes, which manifested in malocclusion after the custom plates were in place, requiring removal of the distal screws, repositioning into the final splint, and then re-drilling and fixating the distal aspects of the plates in the proper location to allow for satisfactory occlusion. Of course, this increased operative times. Since transitioning to the use of custom maxillary plates and traditional mandibular plates, our operative times have decreased significantly, compared to both the traditional plate cohort overall as well as the early all-custom plate subgroup. We view our current technique as a "best of both worlds" compromise, utilizing the custom plating to rapidly and efficiently position the maxilla.

Of note, the VSP process reliably identifies and localizes all areas of bony interference that need to be resected in order for the desired movements to be performed. We have found this to be extremely helpful in the plating of the maxilla using custom plates. Further, the VSP process allows us to locate and quantify occlusal

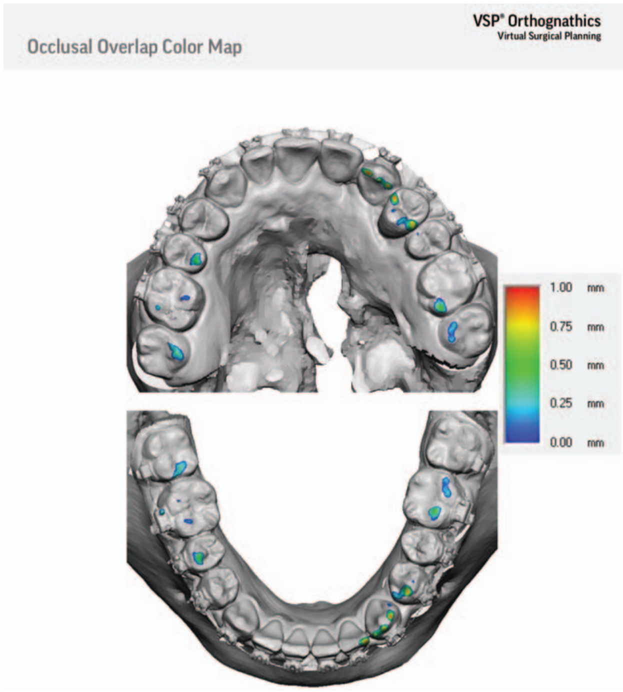

FIGURE 6. Virtual surgical planning for identification of occlusal interferences. Virtual surgical plan demonstrating final occlusal interferences. This allows for easy identification of interferences, which can be subsequently reduced intraoperatively to allow for optimal occlusion and intercuspation.

interferences, which likewise can be burred to ensure optimal occlusion and maximal intercuspation without interference (Fig. 6).

From a complication standpoint, we did experience expected complications in both groups. Particularly, noteworthy is the fact that in the custom plate cohort, all 3 infections occurred in patients who had custom mandibular plates. When using the custom guides, the mandibular plates are positioned relatively more superiorly and are therefore closer to the incision. We believe that this may contribute to the risk of infection.

Our study has several inherent flaws. The first is its retrospective nature, which introduces bias. Second, there is a lack of homogenization in our 2 cohorts. Such heterogeneity makes it difficult to compare operative times both between and within groups. Third, the operative technique throughout the custom plate period evolved, and therefore was not standardized. Finally, our follow-up time is significantly less in the custom plate cohort. This is easily explained by the fact that the cohort represents our most recent surgical cases, but this shorter follow-up likely does not capture all of the complications that will be observed in the group. Further areas of study include longer-term follow-up, as well as postoperative imaging and accuracy analysis to compare desired and actual postsurgical jaw positioning.

Overall, our surgical technique has evolved over the past 2 decades from traditional model-surgery planning, to VSP with stereolithographic splint fabrication, and most recently to the use of patient-specific cutting guides and plates. At present, we prefer to use custom guides and custom plates for the maxillary osteotomies and have largely reverted to traditional hardware and fixation for the mandibular osteotomies. Our learning points and technical modifications have been outlined above. Our data suggest shorter operative times with our current technique, with a similar complication profile, supporting the continued use of custom plates in our population.

CONCLUSION

VSP continues to change the landscape of orthognathic surgery. Most recently, the implementation of customized patient-specific cutting guides and plates allows precise osteotomies and spatial positioning of the osteotomized jaw. Unsurprisingly, obstacles must be overcome in adopting this new technology; we have outlined our learning curve and technical modifications in our series of patients treated with custom plates for orthognathic surgery, and shown the technique to result in shorter operative times and similar complication profile compared with stereolithographic splint-based surgery with traditional fixation.

REFERENCES

1. Hammoudeh JA, Howell LK, Boutros S, et al. Current status of surgical planning for orthognathic surgery: traditional methods versus 3D surgical planning. *Plast Reconstr Surg Glob Open* 2015;3:e307–316
2. Efanov JI, Roy AA, Huang KN, et al. Virtual surgical planning: the pearls and pitfalls. *Plast Reconstr Surg Glob Open* 2018;6:e1443–1452
3. Ritto FG, Schmitt ARM, Pimentel T, et al. Comparison of the accuracy of maxillary position between conventional model surgery and virtual surgical planning. *Int J Oral Maxillofac Surg* 2018;47:160–166
4. Iorio ML, Masden D, Blake CA, et al. Presurgical planning and time efficiency in orthognathic surgery: the use of computer-assisted surgical simulation. *Plast Reconstr Surg* 2011;128:179e–181e
5. Baker SB, Goldstein JA, Seruya M. Outcomes in computer-assisted surgical simulation for orthognathic surgery. *J Craniofac Surg* 2012;23:509–513
6. Kwon TG, Choi JW, Kyung HM, et al. Accuracy of maxillary repositioning in two-jaw surgery with conventional articular model surgery versus virtual model surgery. *Int J Oral Maxillofac Surg* 2014;43:732–738
7. Park S, Hwang D, Song J, et al. Comparison of time and cost between conventional surgical planning and virtual surgical planning in orthognathic surgery in Korea. *Maxillofac Plast Reconstr Surg* 2021;43:18–24
8. Steinhuber T, Brunold S, Gärtner C, et al. Is virtual surgical planning in orthognathic surgery faster than conventional planning? A time and workflow analysis of an office-based workflow for single-and double-jaw surgery. *J Oral Maxillofac Surg;* 2018;76:397–407
9. Wrzosek MK, Peacock ZS, Laviv A, et al. Comparison of time required for traditional versus virtual orthognathic surgery treatment planning. *Int J Oral Maxillofac Surg* 2016;45:1065–1069
10. Karanxha L, Rossi D, Hamanaka R, et al. Accuracy of splint vs splintless technique for virtually planned orthognathic surgery: a voxel-based three-dimensional analysis. *J Craniomaxillofac Surg* 2021;49:1–8
11. Rückschlo T, Ristow O, Müller M, et al. Accuracy of patient-specific implants and additive-manufactured surgical splints in orthognathic surgery: a three-dimensional retrospective study. *J Craniomaxillofac Surg* 2019;47:847–853
12. Wong A, Goonewardene MS, Allan BP, et al. Accuracy of maxillary repositioning surgery using CAD/CAM customized surgical guides and fixation plates. *Int J Oral Maxillofac Surg* 2021;50:494–500
13. Hirsch DL, Garfein ES, Christensen AM, et al. Use of computer-aided design and computer-aided manufacturing to produce orthognathically ideal surgical outcomes: a paradigm shift in head and neck reconstruction. *J Oral Maxillofac Surg* 2009;67:2115–2122
14. Lee Z, Alfonso AR, Ramly EP, et al. The latest evolution in virtual surgical planning: customized reconstruction plates in free fibula flap mandibular reconstruction. *Plast Reconstr Surg* 2020;146:872–879