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# A Look Back: A Single Surgeon's Experience Using Virtual Surgical Planning in Adult Orthognathic Surgery

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**Abstract:** The evolution of virtual surgical planning (VSP) in the last 2 decades has led to improved precision and efficiency for orthognathic surgery, both pre- and intraoperatively. This study evaluates a single surgeon's experience with this technology over the past 6 years. Patients undergoing orthognathic surgery using VSP with the senior author between 2015 and 2021 were retrospectively reviewed. Virtual surgical planning –specific data including incidence of midline/cant correction, occlusal equilibration, serial splints, segmental osteotomies, and custom plates were recorded and analyzed. Sixty patients undergoing orthognathic surgery using simulated VSP in the study period were retrospectively reviewed. Mean age at time of surgery was 23.5 ± 7.9 years. Forty-nine patients (81.7%) underwent LeFort I osteotomy combined with at least 1 additional procedure (eg, unilateral or bilateral sagittal split osteotomy, condylectomy, genioplasty, etc.). Twenty-six (43.3%) of patients in the studied cohort underwent maxillary midline correction, 30.0% required occlusal equilibration, 36.7% underwent maxillary molar cant correction, 30.0% underwent mandibular cant correction, and 21.7% required both maxillary and mandibular cant correction. Three patients required serial splinting, and 15 patients (25.0%) required modification of splint design. Custom plates were utilized in 15 patients (25.0%). This study demonstrates the utility of VSP in accurately detecting occlusal cants, asymmetry, and occlusal interferences. Virtual surgical planning also allows for a dynamic preoperative planning process, offering the surgeon a high degree of versatility in splint design, and the ability to fabricate multiple customized splints for each case. This is particularly useful in patients with limited or unpredictable soft tissue elasticity.

**Key Words:** Craniofacial surgery; jaw surgery; maxillomandibular surgery; orthognathic surgery; virtual surgical planning

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Historically, orthognathic surgeons have faced the challenge of manipulating the complex 3-dimensional anatomy of the jaw and the face based on 2-dimensional images and plaster dental casts.[1] Over the last 2 decades, virtual surgical planning (VSP) has revolutionized the evaluation and treatment planning for patients undergoing orthognathic surgery.[2] Virtual surgical planning refers to the use of computer-aided design and computer-aided manufacturing technology for preoperative planning, production of models and cutting guides, and surgical navigation.[3,4] The senior author integrated VSP into his practice in 2008 and has adjusted to both the learning curve and evolution associated with the use of this technology over the last decade. This study describes the developments the senior author has observed and the evolution of treatment planning and surgical execution he has made in his 13-year experience of using VSP for orthognathic surgery, with a specific focus on surgeries performed between 2015 and 2021.

Before the integration of VSP into clinical practice, orthognathic surgery required a dental laboratory, articulator-mounted plaster dental casts, and significant time commitment to perform model surgery for the fabrication of surgical splints.[5] Despite this labor intensive process aimed to optimize accuracy of surgical splints, the process was ridden with multiple potential sources of error. From mandible-first cases to segmental maxillary surgery when a splint within a splint is required, nearly every form of traditional model surgery was tedious and labor-intensive.[1] Before the introduction of VSP, it was technically challenging and financially unfavorable for a surgeon to perform orthognathic surgery without well-trained assistants, residents, or fellows aiding in the fabrication of surgical splints.[5]

Virtual surgical planning has enhanced the efficiency and accuracy of treatment planning and splint fabrication in orthognathic surgery.[6,7] Ever since the first introduction of computer-aided design and the realization of the utility of stereolithographic models, the capabilities of VSP have evolved. The purpose of this article is to describe the senior author's

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experience with VSP as its introduction to his practice and to explore how the author's use of VSP evolved over the course of his 13-year experience using this technology.

## MATERIALS AND METHODS

The senior author began using VSP in orthognathic treatment planning in 2008. All patients undergoing orthognathic surgery in whom VSP was used for treatment planning between June 2015 to February 2021 were retrospectively reviewed. Inclusion criteria included index (ie, first) orthognathic procedures in patients of any age. Revision procedures were excluded from analysis. All plans were created by 3D Systems (Littleton, CO). Each plan recorded the presurgical and postsurgical position of cephalometric landmarks and tooth position to the 100th of a millimeter. The plans also included splint design, use of custom plates, use of clear aligner therapy, and the sequence of the maxillary and mandibular osteotomies. Data were collected regarding the specific utilization of VSP including incidence of midline correction, cant correction, occlusal equilibration, serial splints, and custom plates. Midline correction was defined as lateral change ($\geq 1$ mm) in position of the midline of the maxillary incisor. Cant correction was defined as vertical change ($\geq 1$ mm) in position of the maxillary canines, maxillary molars, and mandibular molars. Data points were analyzed for trends over time by comparing the first and last 3 years of study data using $\chi^2$ testing. Statistical analysis was performed using STATA v.16 (StataCorp, College Station, TX) with significance defined as $P < 0.05$.

## RESULTS

A total of 60 patients undergoing orthognathic surgery using simulated virtual surgical plans during the study period were included. Mean patient age at time of surgery was $23.5 \pm 7.9$ years. Thirty-three patients (55.0%) were female (Supplemental Table 1, Supplemental Digital Content, < bold > http://links.lww.com/SCS/E333 < /bold > ).

### Surgical Procedures

Forty-nine patients (81.7%) in the studied cohort underwent LeFort I osteotomy (41 single-piece, 8 multi-piece) combined with 1 or more procedures (ie, unilateral or bilateral sagittal split osteotomy, genioplasty, condylectomy, mandibular body osteotomy, and inverted L osteotomy). Overall, the most common combined procedure was a LeFort I with BSSO (n = 46;76.7%). Eight patients (13.3%) underwent LeFort I osteotomies alone (7 single-piece, 1 multi-piece) and 1 (1.7%) underwent only BSSO. A total of 19 genioplasties (31.7%) were performed, with the vast majority of these patients undergoing Le Fort I with BSSO and genioplasty (n = 14/19, 73.7%). Two patients (n = 2/19,10.5%) underwent BSSO alone with genioplasty and 1 patient (n = 1/19,5.3%) underwent Le Fort I alone with genioplasty. Most patients (n = 47,78.3%) underwent bimaxillary surgery (36 maxilla-first, 11 mandible-first).

### Orthognathic Corrections Guided by Virtual Surgical Planning

Twenty-six patients (43.3%) had maxillary midline correction. A total of 22 patients (36.7%) underwent maxillary molar cant correction. All patients who required occlusal plane adjustment at the maxillary canines also required adjustment at the maxillary molars. Eighteen patients (30.0%) underwent mandibular cant correction with 13 (21.7%) requiring maxillary molar and mandibular correction. Occlusal equilibration was performed in 18 patients (30.0%). Three patients required serial splints; however, 15 patients (25.0%) required modification of the splint design. Custom plates were implemented in 15 patients (25.0%) and were used exclusively during the latter 3 years of the study period.

### Complications

Infection was the most common complication in the studied cohort, occurring in 4 patients (6.7%). Three of these patients required incision and drainage or hardware removal in the operating room. There were no hematomas in the studied population. Two patients (3.3%) experienced wound dehiscence, and nonunion occurred in 1 patient (1.7%). Five patients (8.3%) required revision surgery. Ten patients (16.7%) required unexpected return to the operating room for other reasons such as incision and drainage or removal of hardware. Median follow-up in the studied cohort was 6.95 months (interquartile range 2.9,14.8). Patient reported outcomes were not able to be collected from available data but are will be an important area of future study with regards to VSP outcomes.

### The Evolution of Virtual Surgical Planning in Practice

Surgeries were split evenly between the first and second halves of the study period. Custom plates were used more frequently in the latter 3 years of the study period. The incidence of genioplasty was not significantly different between the first half and second half of the study period (10/30,33.3% versus 9/30,30.0%;$P = 0.781$). The incidence of bimaxillary surgery was also not significantly different between the first and second halves of the study (22/30,73.3% versus 25/30,83.3%;$P = 0.347$). The incidence of midline correction and cant correction did not change over time but occlusal equilibration occurred more frequently in the second half of the study (4/30,13.3% versus 14/30,46.7%;$P = 0.005$). In no case was the VSP splint found to be unusable.

## DISCUSSION

Orthognathic surgery has traditionally been associated with complex presurgical laboratory work that was succeptible to error and could subsequently complicate intraoperative care and compromise outcomes.[8] In their 2005 paper, Zins et al[9] reported that orthognathic surgery is a poorly reimbursed procedure, making these cases financially less practical for the plastic surgeon. In fact, it has been argued that when the additional time for laboratory work is considered, jaw surgery is one of the most poorly reimbursed procedures in plastic surgery.[9]

In 2008, VSP became widely available to maxillofacial surgeons for orthognathic surgery. At that time, correctly positioning the patient's computed tomography (CT) scan with respect to head position required patients to use a bite jig on a gyroscope that was connected to a computer to record the pitch, roil, and yaw of the head. These *x*-, *y*-, and *z*-axis coordinates were then emailed to the bioengineers to dictate the orientation of the CT scan to reflect a natural head position. A CT scan disc, dental casts, and a written description of the proposed surgery were also sent to bioengineers by physical mail. The evolution of VSP obviated the need for this dimensional recording of head position. The CT or cone beam CT could instead be mailed or uploaded directly to the VSP website, eliminating the need for physical transfer of patient records. The CT images are now obtained using a specific protocol that requires the condyles to be seated in the fossa with the teeth in maximal intercuspal position. If a minor condylar malposition is noted, the bioengineers may have the ability to digitally seat


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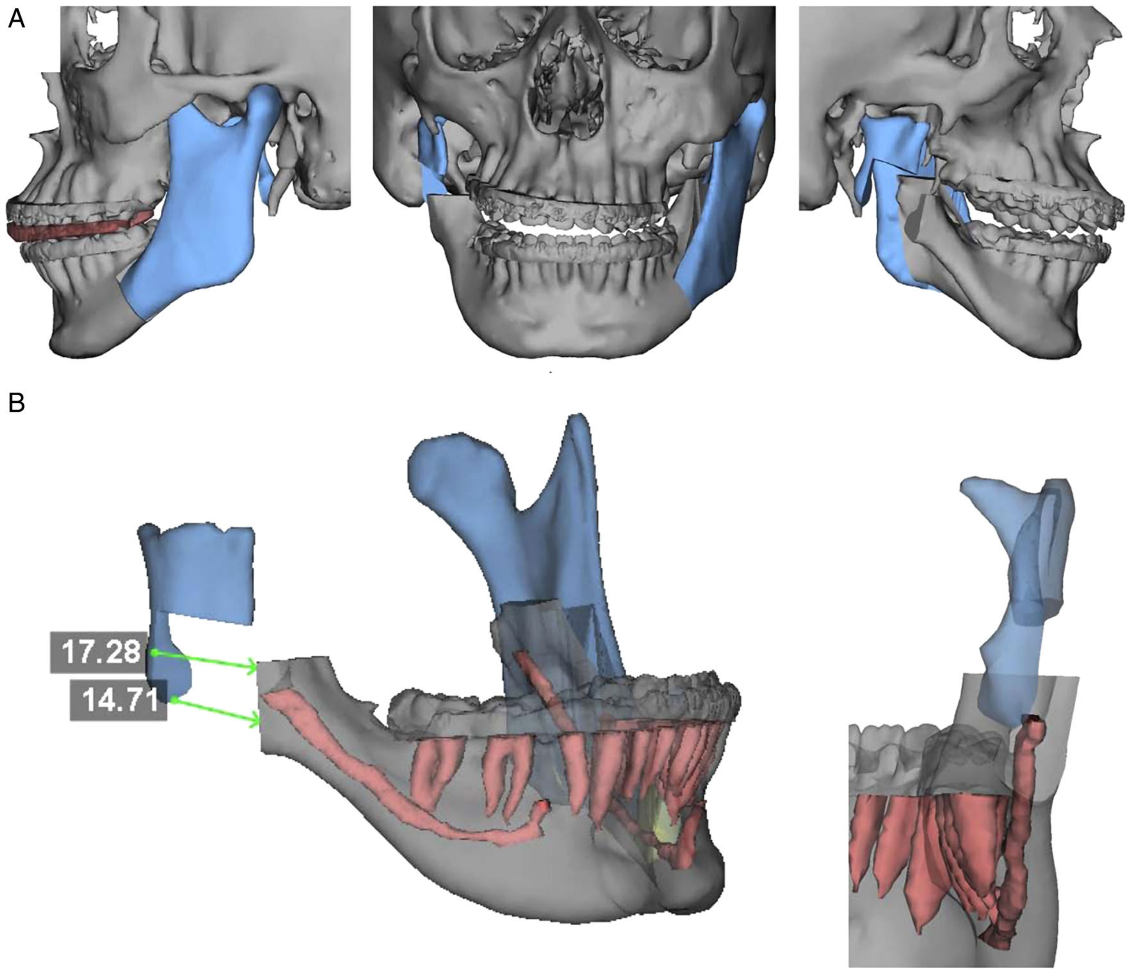


**FIGURE 1.** (A and B) This hemifacial microsomia patient had undergone mandibular distraction of her right ramus previously and now required definitive maxillomandibular osteotomies to correct her facial asymmetry (A). An inverted L osteotomy was performed on the right mandible and VSP allowed accurate assessment of nerve location, allowed the osteotomy to be planned posterior to the mandibular foramen, and rendered accurate measurements of the bone graft that was placed between the osteotomy segments (B). VSP indicates virtual surgical planning.

the condyle without impairing the accuracy of splint fabrication. Cone beam CT scans meet the VSP requirements while exposing patients to only a fraction of the radiation exposure of a conventional CT scan.[10] Once the data are received, the treatment planning session is scheduled through any device with audio/video capability.

Traditionally, dental casts were obtained from alginate impressions into which plaster would be poured. If the impression is not taken with even contact pressure, distortion can occur leading to inaccuracy. The plaster casts require trimming and inaccuracies can also arise from variation in water temperature, slurry viscosity, and cure time. Digital scans have supplanted plaster casts in many orthodontic practices. These digital scans are more accurate and can be used to print plastic models that are lightweight and more resistant to fracture or cusp damage with handling. The data from the scans can also be uploaded directly to the VSP site from the orthodontist's office or by the surgeon. If maxillary segmentation is necessary, the VSP biomedical engineers can perform digital segmentation at the treatment planning session.

The subsequent treatment plan is primarily based on the physical exam and is beyond the scope of this article. One important point relevant to VSP is the maxillary dental midline. When the bioengineers set the midline, they consider skeletal midline structures; it is, however, the senior author's preference to set the maxillary midline at the soft tissue vermillion midline of the upper lip. These midlines may be incongruous, and it is important to be aware of any discrepancies when positioning the maxillary dental midline. During the VSP session the bones that are to be osteotomized (maxilla, mandible, and chin) are placed in their desired positions. At this time the surgeon and the bioengineer can assess and adjust several aspects of the proposed surgery. From a basilar view, for example, the yaw can be adjusted to optimize the overlap of the proximal and distal mandibular sgements to minimize postoperative asymmetry of the gonial angles.

Occlusal plane rotation is a valuable tool that can be used to address a patient with either a shallow or steep mandibular plane. A counterclockwise rotation will increase posterior ramus height and increase anterior mandibular projection. In contrast, a clockwise rotation will deproject the anterior chin point in a class 3 patient with excessive mandibular projection. The effects of occlusal plane rotation on facial form can be viewed during the treatment planning session as the bioengineer rotates the bimaxillary complex.



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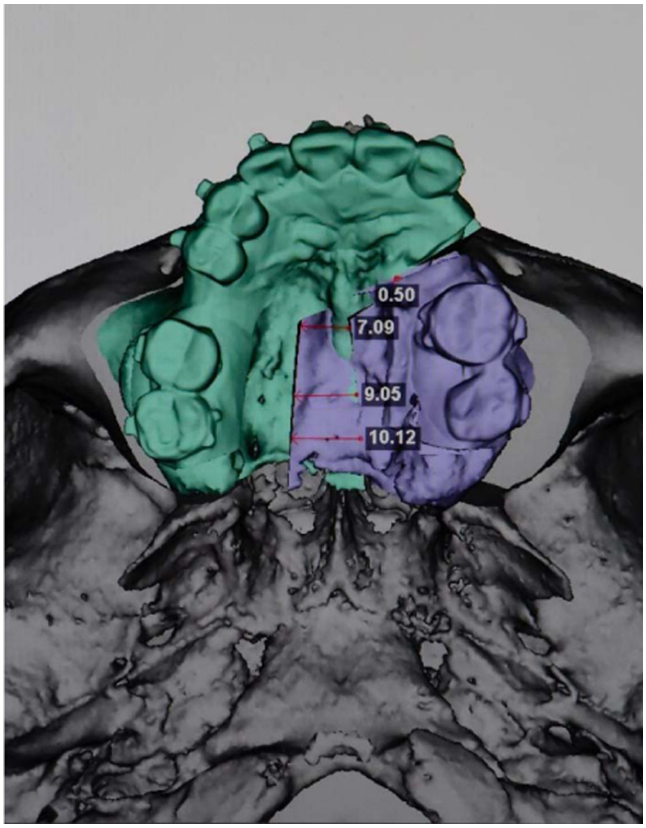


**FIGURE 2.** Maxillary movements are also quantified, allowing the surgeon to know the exact degree of maxillary expansion or contraction required in segmental osteotomies. In this patient, medialization of the posterior maxillary segment was indicated and the degree of medialization at each point along with the sagittal plane is indicated in the plan.

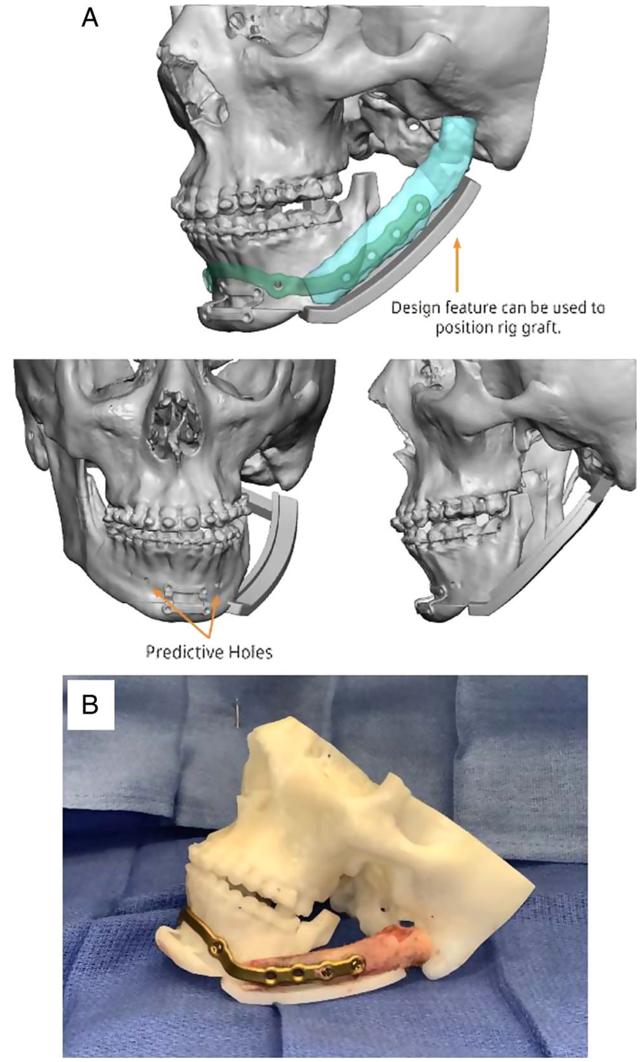


**FIGURE 3.** (A and B) This patient presented for bimaxillary surgery, left mandibular reconstruction with a rib graft, a genioplasty, and fat grafting. A custom tray was used to position the rib to the native left mandible for contouring (A). A custom cutting guide was used to index the proper position of the custom plate, and the crib and plate were used in tandem to secure the rib graft to the plate in the desired position (B).

During the treatment planning session, anatomical aspects of the surgery are also reviewed, including bone thickness around the nerves, distance of proposed osteotomies to nerves (Fig. 1A-B), mandibular osteotomy segment overlap, and quantified distance of proposed movements (Fig. 2). Interdental distances for proposed segmental maxillary osteotomies are visualized and custom cutting guides can be fabricated to minimize the risk of inadvertent tooth root injury. If a segmental osteotomy is planned, the surgeon can physically cut and glue a plaster cast to simulate the segmental movement and have this scanned and digitally incorporated into the CT scan. In segmental maxillary surgery, the senior author initially perfomed physical segmentation on the casts in addition to digital segmentation in the event that the latter was inaccurate. However, the senior author has since found digital segmentation to be accurate and has converted to utilizing only digital segmentation for all of his segmental maxillary osteotomies. The incorporation of digital segmentation eliminates the need to physically send any materials to the bioengineers since all of the necessary pre-VSP material exists as digital data that can be uploaded remotely before treatment planning.

Once the position of the maxillary and mandibular segments is determined, splint design is addressed. The ease and versatility of splint fabrication is one of the biggest advantages of VSP. Two-jaw surgery requires intraoperative maxillomandibular fixation (MMF) for intermediate splinting. The ease of securing MMF with an intermediate splint varies depending on whether the maxilla or the mandible is plated first. In a counterclockwise occlusal plane rotation, the intermediate splint is very wide and MMF is difficult if the maxillary osteotomy is perfomed first. In these cases, a mandible-first surgical approach narrows the distance between the jaws making MMF with the intermediate splint much easier. Virtual surgical planning allows simulation of each approach, enabling the surgeon to compare the splint design of each technique to determine the optimal approach for each individual patient. In maxillary segmental 2-jaw surgery, a sandwich splint (also known as a splint within a splint) is utilized, which can be accurately and efficiently fabricated using VSP. These splints are easily designed for either a maxillary-first or mandible-first surgical approach.

Serial splint design is a different approach that can be particularly useful for patients in whom scarring or other etiologies may cause the patient's tissue to be inelastic and difficult to manipulate intraoperatively. In these patients, decreased tissue


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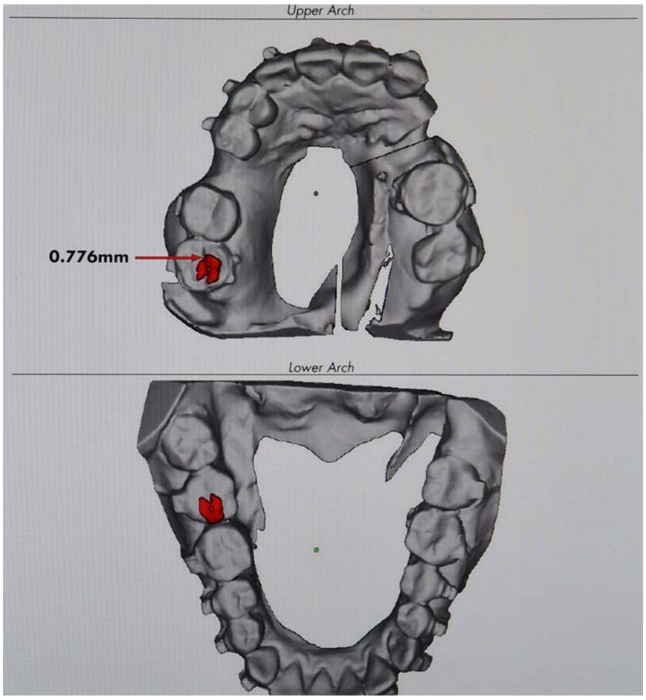


**FIGURE 4.** Occlusal interferences are not uncommon in orthognathic surgery patients and surgeons usually reduce major interferences intraoperatively. Historically, this required dyed articulating paper placed between the jaws while the mouth was closed. The cusps and fossa that showed heavy dyed marks were reduced until the occlusion was equilibrated. Virtual surgical planning identifies and quantifies the degree of occlusal interference using a color map that corresponds to the amount of occlusal equilibration in millimeters. This equilibration guide saves time and allows for more precise equilibration.

elasticity can be accounted for by designing several splints that reflect a progressive array of proposed movements. The senior author has found this approach especially useful for maxillary expansion and advancement in patients with scar tissue from prior cleft surgery who decline or are not ideal candidattes for maxillary distraction osetogenesis. For example, in a cleft patient for whom a 10 mm advancement is indicated but in whom the surgeon discovers that the maxilla can only be advanced 6 mm, a series of maxillary splints can be made preemptively at sizes of 6, 8, and 10 mm. If the movement is easily accomplished, the intended splint is used, but if the advancement is found to be difficult intraoperatively, the surgeon is prepared with alternate splints to successfully complete the case. The same principle can be applied to maxillary segment lateralization in the presence of scarred palatal tissue. Virtual surgical planning facilitates planning for this approach by enabling accurate dimensional analysis of every movement to assist the surgeon in making otherwise challenging decisions.

Virtual surgical planning is also particularly helpful for cases in which a rib graft is required for mandibular reconstruction in hemifacial micromsia (Fig. 3A-B). Virtual surgical planning allows for the design of a custom reconstruction plate that can provide accurate rigid fixation upon which the rib graft can be secured. A custom guide is also used to accurately position the rib graft so that it is in the fossa and has the intended contour of mandibular form before it is secured to the custom plate. A template is also provided to denote the proper dimensions of rib to harvest. After the template iis used to harvest the graft, it is positioned in its desired position in the rib crib as the custom rigid fixation is applied to the mandible and the graft.

Custom plate fabrication is increasingly being adopted by orthognathic surgeons as the planning and design of these plates can also take place during the VSP surgical planning session. Proposed osteotomies are marked on the CT scan and a heatmap showing the variable thickness of bone is generated to ensure that the holes on the custom plates are placed over adequately thick bone. The surgeon aids in the design and can customize the plate as he or she wishes. The use of a custom plate eliminates the need for a splint to position the maxillary or mandibular segment before the application of fixation. The desired position of the jaw is determined preoperatively on the CT scan during the VSP treatment planning session, and a custom plate is made to secure this jaw in its desired position. Before the osteotomy an occlusal-based cutting guide is used to drill holes that will correspond to the plate after the osteotomy has been completed. The guide also indicates where the osteotomy should be located. After the osteotomy is complete, the custom plate is aligned to the osteotomy segments so the predrilled holes from the cutting guide are superimposed to those of the custom plate. This superimposition ensures that the custom plate is securing the jaw into the proper position. Because the design of the custom plate positions the jaw, no MMF is necessary for osteotomy positioning. The use of custom plates can facilitate the efficiency of the surgical process and even eliminate the need for MMF during the surgery.

In every case, the desired occlusion is verified at the end of surgery. There are frequently minor cuspal interferences that preclude optimal intercuspal position. Virtual surgical planning provides a detailed occlusal image showing the surgeon each tooth that requires occlusal reduction. This image also quantifies the distance, in millimeters, that each area is to be reduced (Fig. 4). Occlusal equilibration is performed easily with a round diamond bur and helps optimize the immediate postsurgical occlusion. Before VSP, the senior author used dental occlusal dyed paper or did not perform equilibration at all. Virtual surgical planning provides the surgeon with an easy-to-follow map to complete this process without the need for any extra materials.

Surgery-first is an approach to orthognathic surgery that has been suggested to save time and expenses for the patient. It requires a digital occlusal analysis that decompensates the occlusion, allowing the surgeon and the orthodontist to determine where the jaws should be positioned to accommodate the desired final occlusion before surgical orthodontic therapy begins. Virtual surgical planning is then used to create splints to position the jaws in their planned position. After surgery, the orthodontist moves the teeth to the optimal occlusion as permitted by the new position of the jaw. Before VSP the surgery-first approach was very difficult and time consuming but the digitization of orthodontic therapy has allowed this approach to grow in popularity.

The senior author was one of the first to adopt VSP for orthognathic surgery and has previously reported on both the increased accuracy and efficiency of VSP.[1,11] Many advances have since made the surgical treatment planning of these cases more sophisticated and accurate. Rogers et al[12] have shown that when the surgeon accounts for the increased efficiency of VSP, orthognathic surgery compares very favorably to almost all other reconstructive procedures in plastic surgery when evaluated on the basis of relative value units per hour.

The next goal of VSP is to enable surgeons to accurately predict 3-dimensional responses of the facial soft tissue to skeletal movements. This technology would pave the way for treatment planning that allows the desired soft tissue outcome to dictate jaw position and subsequently occlusion: nearly a complete reversal from the traditional approach to orthognathic surgery wherein the occlusion has dictated facial form.



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## CONCLUSION

The advent of VSP in orthognathic surgery has led to an enhanced accuracy and efficiency in preoperative planning and postoperative outcomes. The findings of this study highlight the experience of the senior author using this technology and demonstrate the ability of VSP to detect occlusal cants, asymmetry, and occlusal interferences with superior accuracy and efficiency relative to other traditional preoperative planning tools. Furthermore, VSP offers the unique advantage of flexibility and adaptability during preoperative planning, which can ultimately lead to a smoother operation.

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