Orthognathic Positioning System: Intraoperative System to Transfer Virtual Surgical Plan to Operating Field During Orthognathic Surgery

John W. Polley, MD,* and Alvaro A. Figueroa, DDS, MS

Purpose: To introduce the concept and use of an occlusal-based “orthognathic positioning system” (OPS) to be used during orthognathic surgery.

Materials and Methods: The OPS consists of intraoperative occlusal-based devices that transfer virtual surgical planning to the operating field for repositioning of the osteotomized dentoskeletal segments. The system uses detachable guides connected to an occlusal splint. An initial drilling guide is used to establish stable references or landmarks. These are drilled on the bone that will not be repositioned adjacent to the osteotomy line. After mobilization of the skeletal segment, a final positioning guide, referenced to the drilled landmarks, is used to transfer the skeletal segment according to the virtual surgical planning. The OPS is digitally designed using 3-dimensional computer-aided design/computer-aided manufacturing technology and manufactured with stereolithographic techniques.

Conclusions: Virtual surgical planning has improved the preoperative assessment and, in conjunction with the OPS, the execution of orthognathic surgery. The OPS has the possibility to eliminate the inaccuracies commonly associated with traditional orthognathic surgery planning and to simplify the execution by eliminating surgical steps such as intraoperative measuring, determining the condylar position, the use of bulky intermediate splints, and the use of intermaxillary wire fixation. The OPS attempts precise translation of the virtual plan to the operating field, bridging the gap between virtual and actual surgery.

© 2012 American Association of Oral and Maxillofacial Surgeons
J Oral Maxillofac Surg ■ 1-10, 2012

Treatment planning for orthognathic surgery (OS) has been greatly enhanced by the use of computer-aided design/computer-aided manufacturing (CAD/CAM) technology. The new CAD/CAM approach to OS has proved efficient and highly accurate. It is rapidly replacing the use of traditional 2-dimensional cephalometric analysis and mock surgery using mounted dental models. CAD/CAM virtual surgical planning (VSP) has improved preoperative planning and our understanding of the surgical anatomy and has facilitated the digital preparation of traditional surgical splints. However, an equal innovation of this planning technology to assist the surgeon in the operative field is still lacking.

The purpose of the present report is to introduce the concept and use of an occlusal-based “orthognathic positioning system” (OPS) for OS. The OPS consists of intraoperative devices that transfer the VSP to the operating field for repositioning of the osteotomized dentoskeletal segments. The OPS is digitally designed with surgeon input using 3-dimensional (3D) CAD/CAM technology and manufactured using stereolithographic techniques. This new system could eliminate the errors inherent to the traditional indirect treatment planning techniques that can lead to suboptimal outcomes. It decreases the time required for surgical planning, it does not require mock surgery on mounted dental models, and it does not...
require preparation of a "guiding intermediate" splint. The use of the OPS also prevents exposure to dust and toxic laboratory chemicals. Familiarization with the OPS could simplify surgery, it might reduce the operating time, and, most importantly, it could translate the accuracy of CAD/CAM technology to the operating field.

**Materials and Methods**

The material included in the present report was a part of a larger project that was reviewed and approved by the institutional review board at Rush University Medical Center (Chicago, IL). Patients for whom the OPS system will be used require a complete preoperative physical examination and all traditional facial, intraoral, and functional evaluations. Two sets of maxillary and mandibular dental impressions are obtained to produce the dental stone models. The mandibular centric relation (CR) and centric occlusion (CO) are recorded. If a significant discrepancy is found, the CR is used for the VSP. A high-resolution helical computed tomography (CT) scan of the maxillofacial and mandible region is obtained. All scans should be performed with 1-mm collimation, a 25.0-cm field of view, and 0° gantry tilt. The CT scan of the maxillofacial and mandibular region is obtained with the patient wearing a patient-specific bite registration connected to a fiducial facebow to guide the patient’s mandibular position into either CR or CO (depending on the case). To determine the natural head position, a published technique using a patient-specific bite registration mounted on an external fiducial facebow attached to a digital orientation sensor is used. The pitch, roll, and yaw for the patient’s head are determined through the orientation sensor and recorded digitally in a computer with proprietary software. The preoperative records, CT scan, bite jig, digital clinical photographs, stone models (with indication of final occlusion), and orientation sensor readings are sent to the modeling company (Medical Modeling, Golden, CO) for case preparation. The CT scan is converted into 3D digital models. The scan coordinates and digital head position are adjusted according to the recorded natural head position (pitch, yaw, and roll) from the orientation sensor recordings. The bite registration is also used to integrate the laser surface scanned maxillary and mandibular dental casts into the CT scan for accurate skeletal and dental 3D reconstruction of the skull. It should be stressed that obtaining the CT scan with an accurate condylar registration, according to the recorded CR and/or CO, as dictated by the individual case, is critical. Just as in traditional surgery, a faulty CR and/or CO registration will invariably result in a compromised outcome.

Virtual OS is then performed with assistance from experienced engineers familiar with the proprietary software to manipulate the scan in 3 dimensions. This is done through an online Web meeting. The surgical treatment plan is based primarily on the clinical examination findings and dental cast assessment. It can be supplemented by photographic and cephalometric analysis. The desired skeletal repositioning of the maxilla (single or multiple segments), mandibular autorotation or repositioning of mandibular proximal and distal segments after sagittal split osteotomies, inverted osteotomies, subapical osteotomies, and genioplasty are completed virtually. This process allows accurate and detailed assessment of all desired skeletal and dental movements and changes in condylar position. The surgeon is able to visualize, from multiple angles, simulated postoperative skeletal contacts, identifying interferences, condylar position, position of the mandibular nerve, bone graft requirements (including specific graft dimensions), and so forth, allowing adjustments to the final surgical treatment plan. The visualization of the condyles further assists the surgeon in selecting the appropriate fixation type and location to minimize condylar position changes and prevent unexpected treatment outcomes.

Once the virtual planning is complete, occlusal splints and orthognathic positioning guides are digitally designed as follows. Before moving any skeletal segments, bony landmarks (or stable anatomic reference points) located on the zygomatic/maxillary buttress, mandibular proximal segment, and chin are identified bilaterally. These landmarks are placed on stable bone that will not be repositioned during the surgical procedure. The bone thickness at each landmark site is surveyed in the CT scan data. The landmarks serve as reference points that will be used to transfer the osteotomized preoperative position of the skeletal segment to its final postoperative position. In the maxilla, the reference landmarks are located above the osteotomy line, over stable, thick bone. If mandibular surgery is planned, the landmarks can be placed on either the lateral and anterior surface of the ramus through a percutaneous approach or the medial aspect of the coronoid process between the anterior and medial ridges at a level above the entrance of the mandibular nerve and the intended horizontal sagittal split ramus osteotomy. This is determined during the VSP and OPS design sessions. If genioplasty is planned, the reference points are located lateral to the midline and below the osteotomy. All reference landmarks should be positioned to not interfere with the fixation process (Figs 1 and 2 [online only]).

Patients requiring multiple maxillary segments or simultaneous mandibular subapical osteotomies with dental extractions require an initial (before any movement) and final (after skeletal movements and
recording the desired final occlusion) occlusal splint. In these cases, the surgeon must determine the desired intra-arch relations and postoperative occlusion by segmenting the dental casts. The final dental models should also be scanned and incorporated into the VSP. After VSP, using 3D CAD/CAM technology, the necessary occlusal splints and drilling or positioning guides to correlate the pre- and postoperative skeletal and dental relationships are designed.

An occlusal splint is designed with the occlusal relationship in the final position and with lateral attachment sites on the left and right sides of the splint (Fig 3). For the maxillary drilling guides (which will demarcate the zygomatic/maxillary buttress bony landmarks in the preoperative position), bone-borne footplates are designed with anatomically contoured struts that connect to the occlusal splint footplates. The splint footplates attach precisely to the lateral attachments on the splint. The bone-borne drilling footplates have 2 large diameter openings. These openings are designed to fit a metal drill guide for precise delineation (drilling) of the bony registration landmarks (Figs 4A,B [online only] and Fig 5). The left and right drill guides are designed separately, and each is able to manually and firmly attach and detach from the occlusal splint independently. The attachment system is such that it does not permit rotation of the guide relative to the occlusal splint.

Maxillary positioning guides are also designed, with the maxilla in its simulated final position. A bone-borne positioning footplate with small diameter holes that fit over the previously determined reference landmarks is similarly designed. The maxillary positioning guides will be attached to the occlusal splint and also secured to the stable maxillary bone using screws (Figs 6, 7A,B [online only]). This will temporarily secure the mobilized Le Fort I segment in its final position before rigid skeletal fixation (Fig 7C [online only]). Similarly, mandibular proximal segment (Figs 7C [online only], 8, 9) and genioplasty (Figs 10 and 11) drilling and positioning guides are
designed, if needed. After they have been designed, the occlusal splints and drilling and positioning guides for the OPS, which can be sterilized with autoclave, are manufactured using stereolithographic techniques.4

During surgery, the occlusal splint is either permanently (1-piece Le Fort I osteotomy only) or temporarily (multiple-segment maxillary Le Fort osteotomies, double jaw cases, maxillary and mandibular subapical osteotomies) secured to the maxillary dentition. The maxilla is exposed, and the maxillary drilling guide is attached to the occlusal splint through the male/female attachment sites on the guides and occlusal splint. The Le Fort bone-borne drilling footplate delineates the stable bony landmarks above the osteotomy and along the lateral zygomatic/maxillary buttress,
as previously identified during VSP. A metal drill guide with a 1.1 or 1.5-mm center opening is fitted to the bone-borne footplates to allow for precise drilling of the bony landmarks. Two reference landmarks are drilled on both the left and right zygomatic/maxillary buttresses (Figs 1, 5, 6, 12, 13, 14).

If mandibular surgery is planned, drilling and positioning proximal segment guides are used with a similar concept to that of the maxilla. The occlusal splint is transferred to the lower arch and secured. Access is obtained to the rami for the sagittal split osteotomies. Reference landmarks can be drilled on the lateral surface of the ramus through a percutaneous approach (Figs 1 and 15 [online only]) or on the medial aspect of each coronoid process (Fig 2 [online only]). The latter are drilled above the intended horizontal medial cut of the sagittal split osteotomy using the proximal segment drilling guide with the metal drill guide inserted into it. The landmarks are drilled at approximately 30° to 45° from the opposite side mandibular canine area to the medial surface of the anterior third of the mandibular coronoid processes (Fig 1 and Figs 2, 16, 17, 18 [online only]).

After drilling all the reference landmarks, the Le Fort I osteotomy is down fractured, with transverse and vertical adjustments to the maxillary bone, nasal septum, and turbinates completed as required by the preoperative VSP. With the occlusal splint wired to the maxillary dentition, the positioning guides are attached to the splint using the same male/female attachment sites used for the drilling guides. The bone-borne footplates are aligned over the previously drilled maxillary bony landmarks. This point, virtually planned final alignment of the mobile maxilla in all orientations of space, is achieved. Screws are used to secure the bone-borne footplates of the positioning guide to the previously drilled maxillary stable bony landmarks. With the left and right maxillary positioning guides fixed securely to the midface skeleton and occlusal splint, rigid fixation of the maxilla is performed bilaterally along the medial naso/maxillary buttress (Figs 7, Fig 19A–C [online only]). Once fixed, the guide-splint complex is extremely stable. Fixation is performed without the need for intermaxillary wire fixation, intraoperative measuring, rotating, and holding the maxillary/mandibular complex, and guessing the condylar position. The maxillary positioning guides lie along the lateral zygomatic/maxillary buttress; therefore, the medial naso/maxillary buttresses are initially fixed (Fig 19C [online only]). Both maxillary positioning guides are sequentially removed, and fixation of the lateral zygomatic/maxillary buttresses is performed. If only a Le Fort I osteotomy is planned, after the mandibular movements are checked, closure is performed.

For mandibular surgery, the sagittal split osteotomies are completed with care to preserve the
landmark perforations if the coronoid landmarks are selected. (Figs 1, 2 [online only]). The proximal segment positioning guides are connected to the attachment sites of the splint on the right and left sides. The bone-borne footplates of the proximal segment positioning guides rest on the lateral wall of the ramus or over the coronoid processes and delineate the previously drilled landmarks to maintain the preoperative condylar position. The right and left proximal segment positioning guides are temporarily secured with screws to either the coronoid process (Fig 20 [online only]) or the lateral aspect of the proximal segment through a percutaneous approach (Figs 7C [online only], 9, 21 [online only]). Final fixation of the segments is completed with screws and/or plates.

If genioplasty is planned, the guides are used after the maxilla and mandible are rigidly fixed. The menton is exposed, the drilling guides for the chin are attached to the occlusal splint, and the bone-borne drilling footplates are used to demarcate the bony landmarks below the planned horizontal osteotomy (Figs 1, 10 and 22 [online only]). The drill guides are removed,
the osteotomy is completed, the chin positioning guide is attached to the splint, and the osteotomized genioplasty segment is manipulated until exact alignment with the previously drilled landmarks or references is obtained. Surgical screws are placed to temporarily secure the chin positioning guide (Figs 11 and 23 [online only]) and rigid fixation of the osteotomized chin segment is performed. After final fixation, all guides and the occlusal splint are removed.

### Case Report

The case of a 17-year, 5-month-old woman with maxillary hypoplasia, mandibular prognathism, and facial asymmetry is presented. At 14 years old, she initiated orthodontic treatment. After arch alignment and coordination, she was scheduled to undergo Le Fort I osteotomy with advancement and mandibular setback with correction of asymmetry. All necessary preoperative records and a CT scan were obtained. The CT scan and patient-specific bite jig attached to an orientation sensor to record the natural head position was done, as previously described.

During the VSP, it was determined that the maxilla required a 6- to 7-mm advancement at the incisor level with a 1-mm midline correction to the left and 1-mm inferior repositioning. The mandible required a setback of 4 mm at the incisor level, with a 2-mm midline correction to the right.

Drilling and positioning guides for the maxilla and mandible and an occlusal splint (recording ideal maxillary and mandibular occlusal relations) were designed and manufactured. At surgery, the splint was secured to the maxillary dentition and exposure of the maxilla completed. The maxillary drilling guides were secured, and the maxillary skeletal references landmarks were drilled on each lateral zygomatic/maxillary buttress. The splint was removed from the maxillary arch, and it was secured to the mandibular arch. Access was obtained to the sagittal split osteotomies, and the reference landmarks on the lateral aspect of the ramus were drilled through a percutaneous approach (Fig 1).

The Le Fort I osteotomy and down fracture were completed. The splint was wired to the maxillary teeth, and the maxillary positioning guides were attached to the splint through the attachment sites. The bone-borne footplates were fitted precisely over the previously drilled zygomatic/maxillary buttress reference landmarks. The guides were temporarily secured with 1.5-mm screws, and the maxilla was rigidly fixed (Fig 7C [online only]). The sagittal split osteotomies were completed, and the distal segment was wired into the splint. The required amount of bone, determined during VSP, was removed from the proximal segments to allow for the setback, asymmetry correction, and close contact between the proximal and distal segments. The proximal segment positioning guides were attached bilaterally to the attachment sites on the splint, and the proximal segments were manipulated until the previously drilled rami landmarks were in close contact to the bone footplates, temporarily screwed through a percutaneous approach and ensuring the preoperatively recorded proximal segment and condylar position (Figs 7C, 15, 21 [online only]). Subsequently, bilateral fixation of the segments was completed with screws. The planned occlusion was obtained in the operating room. All incisions were closed. The final splint with the attachment sites was removed from the mandible, a methyl methacrylate occlusal splint was wired to the maxillary dentition, and the patient was placed in elastic fixation. The patient’s postoperative surgical course was uneventful, and the desired functional, occlusal, and aesthetic outcomes were achieved (Figs 24, 25, 26 [online only]).

### Results

The present case underwent successful OS with no intra- and postoperative complications. The follow-up for the patient was longer than 15 months. Since 2010, the OPS has been used in 24 patients with various diagnoses, including dentofacial deformities in 11,
facial asymmetry in 2, cleft lip/palate in 4, hemifacial microsomia in 2, craniosynostosis syndromes in 3, micrognathia in 1, and tumor reconstruction in 1. The performed osteotomies in that cohort include 1-piece Le Fort I in 13, 2 pieces in 9, and 3 pieces in 2; sagittal splits in 29; inverted in 1, mandibular subapical in 2, and genioplasty in 13.

Discussion

A paradigm shift has recently revolutionized preoperative planning in OS. This new reference standard in treatment planning uses CAD/CAM technology, orientation sensor documentation of the natural head position, and 3D VSP. Virtual OS planning has eliminated the traditional indirect planning techniques, including 2-dimensional cephalometry, face bow transfer, articulated dental models, and mock model surgery. In addition, exposure to laboratory dust and chemicals by the surgeon and laboratory personnel has been eliminated. These preoperative diagnostic advances have enhanced the accuracy of preoperative planning and the surgeon’s understanding of the maxillofacial deformity and the intricacies of the skeletal relations and contacts after the various maxillo/mandibular surgical procedures.

Despite the significant diagnostic and treatment planning advances through virtual imaging, the practical transfer of this information to the operating room has been lacking. Even with the use of this new technology, surgeons must still rely on the traditional “intermediate splint” and intraoperative measurements to guide them during surgery, defeating the main advantages of 3D technology. With the introduction of the occlusal-based intraoperative OPS, we address this deficiency. The OPS consists of CAD/CAM-designed intraoperative devices or guides that first establish the reference points or bony landmarks in the stable nonosteotomized maxillofacial skeleton (through the drilling guides) and then relate and secure the repositioned osteotomized skeletal segments of the maxillofacial skeleton to the drilled bony landmarks (through the positioning guides) into the desired final position. This technique provides 3D guidance and placement of the segments in accordance with the virtual preoperative plan. The OPS is designed with surgeon input following VSP and is manufactured using stereolithography.

The OPS transfers the VSP to the operating room. The OPS eliminates the need for intraoperative placement of peripheral reference markers to measure the desired skeletal movements. When the OPS is used, intraoperative intermaxillary wire fixation can be eliminated for 1- and/or 2-jaw surgery cases. Maxillary surgery can be performed without intermaxillary wire fixation and without rotating a wired maxillary/mandibular complex, many times with an oversized intermediate splint, while trying to preserve the condylar position. The OPS can translate the 3D repositioning of the maxilla and distal mandibular and chin segments as established by the VSP. The OPS assists in maintaining the condylar position intraoperatively, eliminating the guessing of condylar position during traditional OS.

Surgeons in the past have tried to accomplish predictable condylar control through various techniques with varying degrees of success. However, owing to difficulties in design, ease of fabrication, and their cumbersome use in the operating room, the techniques have not been popular. In addition, some of the previously designed devices did not control rotational movement of the proximal segment.

During mandibular surgery, the OPS assists in maintaining the proximal mandibular segments and preoperative condylar relations during fixation to the distal segments without the need for a second experienced assistant. The mandibular OPS stabilizes the proximal segment in an anteroposterior plane and prevents lateral torqueing of the condyles during fixation. The OPS is designed with high accuracy from a digital representation of the patient’s maxillofacial skeleton, ensuring adherence to the surgical plan and preservation of the preoperative condylar position. It appears that the current VSP and CAD/CAM technology is close to answering the 1994 question of Ellis.

“With all of the new technology being developed, one can only wonder how we will be positioning condyles in the future.”

The OPS has eliminated the need for the traditional intermediate splint during bimaxillary surgery. A single splint is usually required, unless segmental osteotomies of the dental arches are to be performed. In such cases, a final splint will be required to maintain new arch configuration and relate the desired occlusal relations. Complex genioplasties such as those required in patients with severe distal mandibular asymmetries or those who require large advancements can be precisely repositioned with the aid of the OPS.

In addition to the benefit of assisting with the 3D repositioning of dental/skeletal segments during OS, the OPS provides stability of the mobilized segments while applying skeletal fixation. This intraoperative advantage eliminates the need for intermaxillary fixation, the use of traditional intermediate splints, manual seating of the condyles, the need for an experienced surgical assistant during the fixation phase of the procedure, and intraoperative reference measurements. In addition, it permits the surgeon to modify the surgical sequence according to the patient’s needs, performing either maxillary or mandibular surgery first.
The concept of using guiding systems for OS is not new. Surgeons have used indirect methods, such as the use of an intermediate splint to assist in maxillary positioning during double jaw surgery. As indicated, attempts have been made to assist the surgeon with proximal segment position using various devices. The introduction of VSP and CAD/CAM technology has permitted preparation of digital traditional surgical splints for orthognathic surgery and guides for head and neck reconstruction to custom design and osteotomize bone grafts for replacement of large maxillary and mandibular bone defects.

Zinser et al. reported on a system to reposition skeletal segments during OS using 3 occlusal wafers. Gateno et al. and Xia et al. reported on a device to assist in accurate fixation of the distal segment after a chin osteotomy. However, their devices were cumbersome designed and were apparently of 1 piece. The OPS we have described takes full advantage of VSP and CAD/CAM technology, the individual devices are removable and easily interchanged and have been streamlined, and the OPS bridges the gap from the virtual environment to the operating room.

As we gained experience using the OPS, we noted that it has decreased our treatment planning time and operative time, especially in cases requiring just a Le Fort I osteotomy. We have subjectively noted quite favorable clinical results for cases that otherwise would have been extremely challenging and unpredictable. As this approach becomes widely used, clinical trials will be able to analyze the long-term accuracy and stability, morbidity, operative times, and overall cost implications.

In conclusion, we have introduced a new occlusal-based OPS for performing OS using VSP and CAD/CAM digital technology. The OPS introduced in the present report bridges the gap between the virtual, computer-aided surgical evaluation and actual OS.

Acknowledgment

The authors recognize the expert support of the Virtual Surgical Planning Department of Medical Modeling (Golden, CO), specifically Mr Chris Beaudreau and Mrs Katie Weimer.

Supplementary Material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.joms.2012.11.004.

References

27. Arnett GW, Gunson MJ: Drs. G. William Arnett and Michael J. Gunson on esthetic treatment planning for orthognathic