# Protocol for Concomitant Temporomandibular Joint Custom-Fitted Total Joint Reconstruction and Orthognathic Surgery Utilizing Computer-Assisted Surgical Simulation

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Clinicians who address temporomandibular joint (TMJ) pathology and dentofacial deformities surgically can perform the surgery in 1 stage or 2 separate stages. The 2-stage approach requires the patient to undergo 2 separate operations and anesthesia, significantly prolonging the overall treatment. However, performing concomitant TMJ and orthognathic surgery (CTOS) in these cases requires careful treatment planning and surgical proficiency in the 2 surgical areas. This article presents a new treatment protocol for the application of computer-assisted surgical simulation in CTOS cases requiring reconstruction with patient-fitted total joint prostheses. The traditional and new CTOS protocols are described and compared. The new CTOS protocol helps decrease the preoperative workup time and increase the accuracy of model surgery. © 2013 American Association of Oral and Maxillofacial Surgeons J Oral Maxillofac Surg 71:2123-2129, 2013

Temporomandibular joint (TMJ) disorders or pathology and dentofacial deformities commonly coexist. The TMJ pathology may be the causative factor of the jaw deformity or develop as a result of the jaw deformity or the 2 entities may develop independently of each other. The most common TMJ pathologies that can adversely affect jaw position, occlusion, and orthognathic surgical outcomes include 1) articular disc dislocation, 2) adolescent internal condylar resorption, 3) reactive arthritis, 4) condylar hyperplasia, 5) ankylosis, 6) congenital deformation or absence of the TMJ, 7) connective tissue and autoimmune diseases, 8) trauma, and 9) other end-stage TMJ pathologies.1 These TMJ conditions are often associated with dentofacial deformities, malocclusion, TMJ pain, headaches, myofascial pain, TMJ and jaw functional impairment, ear symptoms, sleep apnea,

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‡Clinical Professor, Department of Oral and Maxillofacial Surgery, Baylor College of Dentistry, Texas A&M University System Health Science Center, Baylor University Medical Center, Dallas, TX. etc. Patients with these conditions may benefit from corrective surgical intervention, including TMJ and orthognathic surgery. Some of the aforementioned TMJ pathologies may have the best outcome prognosis using custom-fitted total joint prostheses for TMJ reconstruction.

Many clinicians choose to ignore the TMJ pathology and perform only orthognathic surgery for these types of cases. Clinicians who address the TMJ pathology and dentofacial deformities surgically can perform the surgery in 1 stage or 2 separate stages. The 2-stage approach requires the patient to undergo 2 separate operations and anesthesia, significantly prolonging the overall treatment. However, performing concomitant TMJ and orthognathic surgery (CTOS) in these cases requires careful treatment planning and surgical proficiency in the 2 surgical areas.

http://dx.doi.org/10.1016/j.joms.2013.07.024

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Using traditional model surgery and treatment planning techniques exposes the outcome to its own subset of error margin. As a result, CTOS requires experience and expertise.

Over the past decade, computer-assisted surgical simulation (CASS) technology has been integrated to many maxillofacial surgical applications,<sup>2,3</sup> including dentofacial deformities, congenital deformities, defects after tumor ablation, post-traumatic defects, reconstruction of cranial defects,<sup>4</sup> and reconstruction of the TMJ.<sup>5</sup> The authors hypothesized that CASS technology could improve surgical accuracy, provide intermediate and final surgical splints, and decrease the surgeon's time input for presurgical preparation compared with traditional methods of case preparation.

### **Protocol for Traditional CTOS**

Treatment planning for CTOS cases is based on prediction tracing, clinical evaluation, and dental models, which provide the template for movements of the upper and lower jaws to establish optimal treatment outcome in relation to function, facial harmony, occlusion, and oropharyngeal airway dimensions.

For patients who require total joint prostheses, a computed tomographic (CT) scan is acquired of the maxillofacial region that includes the TMJs, maxilla, and mandible with 1-mm overlapping cuts. Using these CT scan data, a stereolithic model is fabricated, with the mandible as a separate piece.

Using the original cephalometric tracing and prediction tracing (Fig 1A), the mandible on the stereolithic model is placed into its future predetermined position using the planned measurements for correction of mandibular anteroposterior and vertical positions, pitch, yaw, and roll (Fig 1B). Many patients with TMJ pathology requiring concomitant orthognathic surgery will benefit from counterclockwise rotation of the maxillomandibular complex, which requires the development of posterior open bites on the model (Fig 1B). Because the mandibular position on the stereolithic models is established using hands-on measurements, the operator's manual dexterity and 3-dimensional perspective play a critical role in setting the mandible in its proper and final position. This step can predispose the planning process to a certain margin of error.

The next step requires the preparation of the lateral aspect of the rami and fossae (Fig 2A, B) for fabrication of the patient-fitted total joint prostheses. The goal of this step is to recontour the lateral ramus to a relatively flat surface in the area where the mandibular component will be set. The fossa requires recontouring only if heterotopic bone or unusual anatomy is present. The recontouring areas are marked in red for duplication of bone removal intraoperatively. Because most patients with TMJ problems requiring CTOS can benefit from counterclockwise rotation of the maxillomandibular complex, the stereolithic model will likely be set with posterior open bites, because the maxilla is maintained in its original position.

Once the stereolithic model is finalized, the model is sent to TMJ Concepts (Ventura, CA) to perform the design, blueprint, and wax-up of the custom-fitted total joint prostheses (Fig 2C), with the design and waxup sent to the surgeon for approval before manufacture of the prostheses. The period from CT acquisition to the manufacturer's completion of the custom-fitted prostheses is approximately 8 weeks.

Then, the surgical procedures are performed on articulator-mounted dental models. The mandible is



**FIGURE 1.** A, Measurement of the cephalometric prediction tracing for the amount of open bite produced at the second molar after counterclockwise rotation of mandible in its new position. B, Duplication of the measurement obtained from the prediction tracing to the new position on the stereolithic model and fixating the mandible to the maxilla with methylmethacrylate.

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**FIGURE 2.** A, Marking the condylectomy osteotomy and the irregularities of the fossa. B, The stereolithic model (*red*) after condylectomy and recontouring of the fossae and rami. C, Stereolithic model with prostheses wax-up for approval by the surgeon. Movahed, Teschke, and Wolford. Computer-Simulated Concomitant Surgery. J Oral Maxillofac Surg 2013.



**FIGURE 3.** Staged computer-aided surgical simulation surgical report. *A*, Simulated preoperative position of the maxilla and mandible. *B*, The maxilla and mandible in the simulated intermediate position, with mandibular surgery performed first for fabrication of the intermediate splint. *C*, The final position of maxilla and mandible, after advancement of mandible and segmental osteotomy of the maxilla, for the production of a palatal splint.

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repositioned on the articulator, duplicating the movements performed on the stereolithic model, and the intermediate splint is constructed. The maxillary model is repositioned, segmented if indicated, and placed into the maximal occlusal fit. Then, the palatal splint is constructed.

### PROTOCOL FOR TRADITIONAL CTOS

- 1. CT scan including the entire mandible, maxilla, and TMJs
- 2. Fabrication of stereolithic model with the mandible separated



**FIGURE 4.** A, Stereolithic model fabricated after simulated maxillary and mandibular advancement to the final position. Condylectomy and recontouring of the lateral rami and fossae was performed (*red*) and sent to TMJ Concepts for construction of the prostheses. *B*, Constructed patient-fitted temporomandibular joint prosthesis using the computer-aided surgical simulation fabricated stereolithic model.

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- 3. Surgeon positions the mandible in its final position and fixates it
- 4. Remove condyles and recontour the lateral aspect of the rami and fossae if indicated
- 5. Model sent to TMJ Concepts for prostheses design, blueprint, and wax-up
- 6. Approval of total joint prostheses blueprint and wax-up by the surgeon
- 7. Manufacture of custom-fitted total joint prostheses
- 8. Prostheses sent to hospital for surgical implantation

Stereolithic Model Preparation	Average Time	Dental Model Surgery	Average Time	Total
Setting mandible	20 min	mounting maxilla and mandible on articulator and preparing bases	90 min	
Condylectomy and preparation of rami	20 min	cutting dental models and fabricating orthognathic splints	60 min	
	40 min		150 min	245 min

### Table 1. TRADITIONAL CONCOMITANT TEMPOROMANDIBULAR JOINT AND ORTHOGNATHIC SURGERY WORKFLOW TIMING

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STEPS IN TRADITION AL ORTHOGNATHIC SURGERY, INTERMEDIATE AND PALATAL SPLINT FABRICATION FOR CTOS

- 1. Acquisition of dental models
- 2. Mounting maxillary and mandibular dental models on an articulator
- 3. Reposition the mandibular dental model, duplicating the positional changes acquired on the stereolithic model
- 4. Fabrication of intermediate splint
- 5. Reposition maxillary dental models with segmentation if indicated
- 6. Construction of palatal splint
- 7. Ready for surgery

### **Protocol for CTOS Using CASS**

For CTOS cases, the orthognathic surgery is planned using Medical Modeling (Golden, CO) CASS technology and moving the maxilla and mandible into their final position in a computer-simulated environment (Fig 3A, B). Using the computer simulation, the anteroposterior and vertical positions, pitch, yaw, and roll are accurately finalized for the maxilla and mandible based on clinical evaluation, dental models, prediction tracing, and computer-simulation analysis. Using Digital Imaging and Communications in Medicine (DICOM) data, the stereolithic model is produced with the maxilla and mandible in the final position and provided to the surgeon for removal of the condyle and recontouring of the lateral rami and fossae if indicated (Fig 4A). The stereolithic model is sent to TMJ Concepts for the design, blueprint, and wax-up of the prostheses. Using the Internet, the design is sent to the surgeon for approval. Then, the custom-fitted total joint prostheses are manufactured (Fig 4B). It takes approximately 8 weeks to manufacture the total joint custom-fitted prostheses.

Approximately 2 weeks before surgery, the final dental models are produced, including 2 maxillary models if the maxilla is to be segmented or dental equilibration is required. One of the maxillary models is segmented if indicated, dental equilibration is performed, and the segments are placed in the best occlusion fit with the mandibular dentition and maxillary segments fixed to each other. The dental models do not require mounting on an articulator. The 3 models (2 maxillary and 1 mandibular) are sent to Medical Modeling for scanning and simulation into the computer model. Because the authors routinely perform the TMJ reconstruction and mandibular advancement with the TMJ Concepts total joint prosthesis first, the unsegmented maxillary model is simulated into the original maxillary position and the mandible is maintained in the final

## Table 2. COMPUTER-AIDED SURGICAL SIMULATION CONCOMITANT TEMPOROMANDIBULAR JOINT AND ORTHOGNATHIC SURGERY WORKFLOW TIMING

Stereolithic Model Preparation	Average Time		Average Time	Total
Condylectomy and preparation of rami/fossa	20 min	Web-meeting time for simulated surgery	15 min	
		segmental maxillary model surgery	20 min	
	20 min		35 min	55 min

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position. The intermediate splint is constructed (Fig 3B). Then, the segmented maxillary model is simulated in the computer model in its final position, with the maxilla and mandible placed in the best occlusal fit, and the palatal splint is fabricated. The dental models, splints, and images of computer-simulated surgery are sent to the surgeon for implementation during surgery.

#### PROTOCOL OF CTOS USING CASS

- 1. CT scan of entire mandible, maxilla, and TMJs (1-mm overlapping cuts)
- 2. Processing of DICOM data to create a computer model in CASS environment
- 3. Correction of dentofacial deformity, including final positioning of the maxilla and mandible, with computer-simulated surgery
- 4. Stereolithic model constructed with jaws in final position and sent to surgeon for condylectomy and rami and fossae recontouring if indicated
- 5. Model sent to TMJ Concepts for prostheses design, blueprint, and wax-up
- 6. Surgeon evaluation and approval using the Internet
- 7. TMJ prostheses manufactured and sent to hospital for surgical implantation
- 8. Two weeks before surgery, acquisition of final dental models (2 maxillary, 1 mandibular) with segmentation of 1 maxillary model if indicated to maximize occlusal fit; models sent to Medical Modeling
- 9. Models incorporated into computer-simulated surgery for construction of intermediate and final palatal splints
- 10. Models, splints, and printouts of computersimulated surgery sent to surgeon

Using CASS technology for CTOS cases eliminates the "traditional" steps requiring the surgeon to manually set the mandible into its new final position on the stereolithic model, thus saving time and improving surgical accuracy. Although model dental surgery is necessary only if the maxilla requires segmentation, the models do not require mounting on an articulator. This saves considerable time by eliminating the time required to mount the models, prepare the model bases for model surgery, reposition the mandible, construct the intermediate occlusal splint, and make the final palatal splint. With CASS technology, the splints are manufactured by Medical Modeling. Tables 1 and 2 present the time commitment comparison between the 2 methods, with CASS technology requiring signifi-

### Discussion

Using CASS technology for CTOS cases, the surgeon superimposes the orthognathic computer-simulated environment on the production of the stereolithic model, hence decreasing the margin of error during hands-on positioning of the jaws before fabrication of the stereolithic model. Furthermore, this technique decreases the time used by the surgeon in the laboratory, by the factory for the fabrication of prostheses, and for setting the stereolithic models and increases the accuracy of the process. According to the authors' general calculation of the prepared cases, the average time spent on traditional CTOS was approximately 190 minutes (Table 1), which was significantly longer than the approximately 55 minutes required for the CASS protocol (Table 2).

The remaining area in which improvement can be made in CASS technology is to perform recontouring of the rami and fossae in the simulated environment in an accurate fashion, which eliminates the requirement for the acquisition of dental models by using laser scanning and performing accurate maxillary segmentation and equilibration using CASS technology. Further research is necessary to achieve this goal and to move the workflow directly from the CASS environment to the fabrication of custom-fitted TMJ Concepts prostheses, without requiring the surgeon to have "hands-on" involvement in the process.

### **Press Release**

This article's Press Release can be found, in the online version, at http://dx.doi.org/10.1016/j.joms. 2013.07.024.

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