

Original Article

Application of computer-assisted surgical simulation for temporomandibular joint reconstruction with costochondral graft

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Abstract: Objective: To introduce the application of computer-assisted surgical simulation (CASS) for temporomandibular joint (TMJ) reconstruction with costochondral graft (CCG). Materials and methods: Consecutive patients who underwent TMJ reconstruction with CCG from November 2013 to March 2015 were included in this study. Before surgery, the cranial-maxillofacial and chest computed tomography (CT) scans were preformed and imported into the Mimics software for virtual positioning and osteotomy planning to guide the selection and placement of the rib and bone trimming of the condyle and ramus. Clinical and radiographic parameters were used to assess the efficacy of CASS guided CCG. Results: 7 consecutive patients (9 joints) who underwent CCG utilizing CASS were included. There were 5 female and 2 male patients with a mean age of 30.2 years (range, 21 to 45 years). There were 5 patients with unilateral joints and 2 patients with bilateral joints. In 7 joint reconstructions, the 6th rib was selected, while the 7th rib was selected in 2 joints. All the grafted ribs were not trimmed or contoured intraoperatively. There were significant improvements of the MIO and VAS at 6 months after surgery ($P < 0.001$). Proper positions of the grafts were documented by postoperative CT. Conclusions: CASS is an accurate method to select a suitable rib (usually the 6th and 7th) matching with the TMJ anatomy and avoid the blindness of CCG.

Keywords: Temporomandibular joint, costochondral graft, computer-assisted surgical simulation

Introduction

The temporomandibular joint (TMJ) is the only movable joint that connects the skull. Diseases of the TMJ such as osteoarthritis, ankylosis, injury, and tumor would severely affect the functions of mastication and speech, as well as the patient's psychological well-being [1]. Two main techniques of reconstruction have been described including autogenous (fibula, metatarsal, clavicle, iliac, and costochondral) and alloplastic (acrylic, synthetic fibers, ulnar head prosthesis, compressible silicone rubber, and total joint systems) [2-4].

The widely accepted autogenous technique involves the costochondral graft (CCG) because of its biologic compatibility, workability, functional adaptability, and minimal additional detriment to the patient [5]. Costochondral grafts

(CCG) for reconstruction of the ramus/condyle unit were first documented by Gillies in 1920; however, their use and outcomes remained a focus of discussion [4, 6]. Since 1966 many authors have established a physiological rationale for their use, in particular as replacements for a non-functioning condylar head [7]. Recently, the CCG is favored by many maxillofacial surgeons worldwide as the treatment of choice [4, 8, 9].

Nevertheless, the previously mentioned studies have focused on the modifications of the surgical procedure, and no study reported the influence of the rib condition on the reconstruction procedure [5, 8]. Actually, the rib condition, including the curvature degree, thickness, and width, has a close relationship with the rib grafts for TMJ reconstruction and postoperative joint function. Therefore, it is necessary to

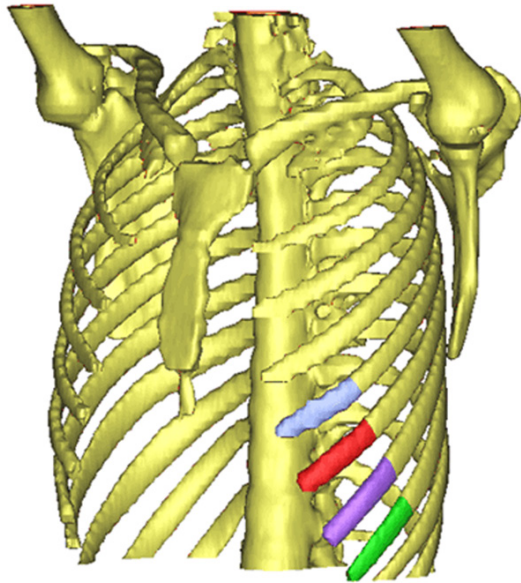


Figure 1. Preoperative chest 3D reconstruction and the selection of the 5th to 8th ribs.

know which rib is most suitable to reconstruct the joint preoperatively.

The advent of computer-assisted surgical simulation (CASS) has allowed many surgeons to develop effective tools with a variety of surgical applications [10]. CASS offered outstanding advantages of designing and simulating the surgical procedure and being fast and accurate, which compensate for deficiencies of the conventional methods [11]. Using this technology to guide the selection of the rib and the osteotomy of the joint and fixation of the rib grafts, we obtained a satisfactory surgical simulation of the CCG with a higher surgical accuracy, excellent TMJ function postoperatively, and minimal complications in 7 patients.

Materials and methods

This is a retrospective study that was approved by the local ethics board of the hospital.

Inclusion and exclusion criteria

The inclusion criteria were as follows: patients who underwent CCG using CASS technique between November 2013 and March 2015. Basic information (gender and age) and clinical data (diagnosis, affected side, and clinical duration) were collected.

Regarding the exclusion criteria, patients with previous CCG operation history of the diseased

TMJ were not considered in the study. Their exclusion was based on the fact that bony irregularities of the ramus after removal the previous rib and the absence of the rib in the chest might affect the results.

CASS technology

Data acquisition and processing: Patients underwent the preoperative cranial-maxillofacial and chest computed tomography (CT) scans (slice thickness, 0.625 mm) (GE Healthcare, Buckinghamshire, England) with a stable molar occlusion. The data were stored and imported into the Mimics software (Version 18.0, Medical, Leuven, Belgium) for the cranial-maxillofacial and chest 3-dimensional (3D) reconstruction. Next, the 3D cranial-maxillofacial reconstruction was separated into the upper and lower jaws, and the inferior alveolar neurovascular bundle was drawn at the same time [12, 13].

Preoperative position determination and selection of rib: The mandible was virtually corrected into the right position based on the measurements of X-ray, and the height from the fossa to the mandibular angle was measured because the height was equal to the length of the rib needed. The contralateral 5th to 8th ribs were selected and exported with STL format from the chest 3D reconstruction (**Figure 1**). The 5th rib was firstly imported into the cranial-maxillofacial 3D reconstruction. The rib cartilage side was positioned and corrected into the middle of the TMJ fossa based on the original condylar head position, and then the other side was rotated parallel to the mandibular posterior edge, matching the lateral surface of ramus (**Figure 2A**) and positioned away from the inferior alveolar neurovascular bundle (**Figure 2B**). Similarly, the 6th to 8th ribs were also imported into the cranial-maxillofacial 3D reconstruction, and then positioned and corrected as the 5th rib.

Following matching each rib with the lateral surface of ramus, the surgeon selected the best one based on the bended situation of the rib and the matched area between the rib and ramus. Next, the titanium plate (usually 6 holes) with STL format was imported into the cranial-maxillofacial 3D reconstruction, and was positioned on the surface of the rib. According to the length from the titanium's hole to the medi-

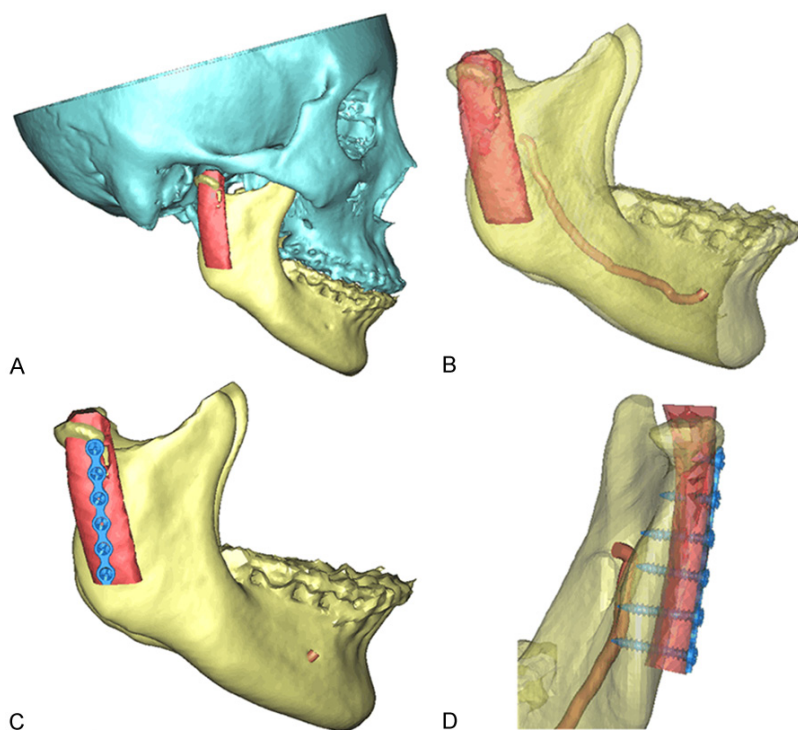


Figure 2. Ideal placement position of CCG and selection of the titanium plate and screws. A. Determination of the grafted rib position; B. Relationship between the rib and the inferior alveolar neurovascular bundle; C. Placement and selection of the titanium plate and screws; D. Measurements for the length of the titanium plate and screws.

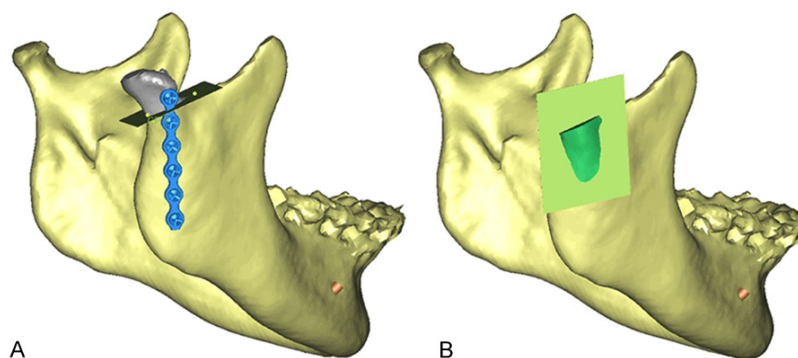


Figure 3. Osteotomy plane for jaw segmentation and trimming. A. Osteotomy plane 1 for condylar neck; B. Osteotomy plane 2 for the lateral surface of ramus. The grey and green parts indicate the bone to be removed.

al surface of ramus, the titanium screw (STL format) with the same length was imported and positioned into the hole, respectively (**Figure 2C, 2D**). Then, the condyle was cut by using the first osteotomy plane located between the first and second titanium holes (**Figure 3A**), and the superficially overlapped ramus was also removed by using the second osteotomy plane based on the medial surface of rib (**Figure 3B**).

Measurements in the cranial-maxillofacial 3D reconstruction: Several measurements should be confirmed preoperatively in the cranial-maxillofacial 3D reconstruction to guide the surgical procedure. 1. The height from the TMJ fossa to the mandibular angle. 2. The height from the condylar head to the first osteotomy plane. 3. The scope of the overlapped bone on the lateral surface of the ramus. 4. The length of the titanium plate. 5. The length of all titanium screws.

Surgical procedure

All patients underwent the reconstruction surgery under general anesthesia. The TMJ was approached by the preauricular incision. The condyle was removed based on the previous measurements, but the release of the bone mass in TMJ ankylosis case was performed first. The overlapped bone in the lateral surface of the ramus was trimmed to obtain a good bony interface based on the preoperative measurements and to facilitate the rib setting the same as preoperative placement position in CASS. For the TMJ ankylosis case, bilateral coronoidectomy was also performed. If an intact disc was identified, it is

maintained in line with the glenoid fossa. Otherwise, the disc was replaced with a pedicled TMF, based on the middle temporal vessels. All patients were placed with the preoperative occlusion in CASS fixed with a digital splint. The chosen rib was harvested in the standard manner through an inframammary incision. The length of the rib was equal to the previously measured height from the fossa to

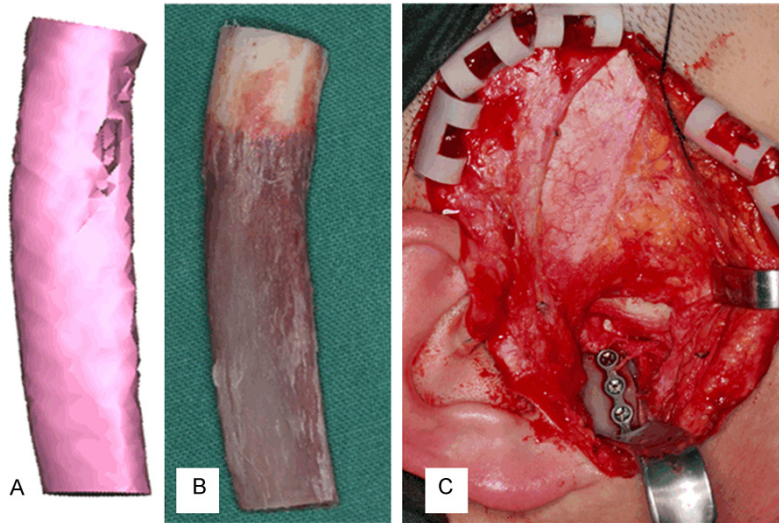


Figure 4. The CCG surgical procedure with the help of CASS. A. The rib in the chest 3D reconstruction; B. The intraoperative rib; C. The fixation of rib with titanium plate and screws during surgery.

Table 1. General patient information

| Patient No. | Gender | Age (yr) | Diagnosis | Affected side | Clinical Duration (yr) | Selection of rib |
|-------------|--------|----------|----------------|---------------|------------------------|------------------|
| 1 | Female | 45 | Osteoarthritis | Left | 6 | 6 th |
| 2 | Female | 35 | Osteoarthritis | Right | 5 | 6 th |
| 3 | Male | 22 | Ankylosis | Right | 15 | 6 th |
| 4 | Female | 29 | Osteoarthritis | Left | 3 | 7 th |
| 5 | Male | 32 | Ankylosis | Right | 3 | 7 th |
| 6 | Female | 21 | ICR | Bilateral | 0.5 | 6 th |
| 7 | Female | 26 | ICR | Bilateral | 1 | 6 th |

the mandibular angle, as calculated in the cranial-maxillofacial 3D reconstruction, but comprised at least 1 cm of cartilage (**Figure 4A, 4B**). The cartilage was trimmed and contoured to facilitate the setting of the cartilage side properly into the centre of the TMJ fossa. A titanium plate with 6 holes was fixed to the CCG with a 6 mm long screw placed in each end-hole of the plate. The CCG/plate unit was then placed based on the preoperative position in CASS. After the desired position of the unit has been achieved, the graft was rigidly secured to the mandible with 4 bi-cortical screws with their length measured preoperatively. For the distal end hole of the plate, the screw 6 mm long, which was placed previously in the CCG/plate unit, was replaced with a longer one to reinforce and complete the fixation (**Figure 4C**). Following the CCG setting, the occlusion was checked. Then a drain was inserted, the inci-

sions were closed in layers, and a pressure dressing was applied [14].

Effect evaluation of the CCG using CASS

Clinical and radiographic parameters were used to assess the efficacy of CCG using CASS. Clinical parameters involved the following points: ① Whether was the rib trimmed or contoured intraoperatively? ② Did the clinical symptoms included maximum interincisal opening (MIO), pain in the affected joint assessed by a visual analog scale (VAS), and occlusion improve significantly? ③ The third involved numbness: Had the patient complaint of numbness of the lower lip?

Postoperative CT scans of each patient were performed within 1 week after surgery, and the data were imported into the Mimics software for the 3D reconstruction. The postoperative cranial-maxillofacial 3D reconstruction was determined to separate the

upper and lower jaws, rib, titanium plate, and screws. The matching situation between the rib and the lateral surface of ramus, the bi-cortical screw exposure in medial surface of ramus, and the position relationship between the inferior alveolar neurovascular bundle and the screws were examined and measured in Mimics software. Then, the preoperative cranial-maxillofacial 3D reconstruction including the lower jaw and the rib was merged with the postoperative 3D reconstruction. Several markers were selected as the points of comparison to merge the preoperative and postoperative images. These included the most occlusal point of the lower incisor, the cusp of the lower canine, and the mesial and buccal cusps of the lower first molar. When the 2 images were merged accurately, the implanted deviation of the rib was measured or calculated in Mimics software [12, 13].

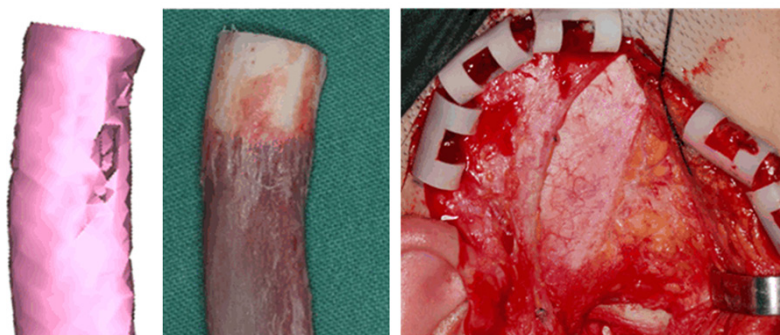


Figure 5. Postoperative CT examination. A. The rib had an accurate postoperative position; B. The rib matched with the lateral surface of ramus excellently.

Statistical analysis

The SPSS software package (version 16.0, Chicago, IL) was used for the statistical analysis of the differences of the MIO and VAS from pre to postoperative points, which were compared using the paired *t* test. $P < 0.05$ was considered to be of a significant difference.

Results

7 consecutive patients (9 joints) with diagnoses including osteoarthritis (2 joint), ankylosis (3 joints), and idiopathic condylar resorption (4 joints) of the TMJ underwent CCG reconstruction guided with CASS from November 2013 to March 2015. There were 5 female and 2 male patients with a mean age of 30.2 years (range, 21 to 45 years). There were 5 patients with unilateral affected joints and 2 patients with bilateral joints. The mean duration of the disease was 4.8 years (range, 0.5 to 15 years) (**Table 1**).

The 6th rib was selected for 7 joints reconstruction, and the 7th rib was selected for the other 2 joints (**Table 1**). All the grafted ribs were not trimmed or contoured intraoperatively. The mean preoperative MIO and VAS were 18.1 mm (range, 1 to 37 mm) and 5.1 points (range, 1 to 8 points), whereas the mean postoperative MIO and VAS were 32.0 mm (range, 26 to 39 mm) and 2.4 points (range, 1 to 4 points) at 6 months after surgery. There were significant improvements for MIO and VAS from pre to postoperative points ($P < 0.001$). In all patients, the desired postoperative occlusions were achieved. No patients had any complaints about the numbness of the lower lip on the reconstructed side.

Postoperative CT scans indicated that all patients had successful reconstructions of the mandibular condyle with the CCG using CASS (**Figure 5A**), and all ribs had an excellent fit with the lateral surface of ramus (**Figure 5B**). 46 titanium screws in total were implanted and located behind the inferior alveolar neurovascular bundle. There were 16 titanium screws protruding from the medial surface of ramus, and the mean exposed length was 0.7 mm (range, 0.2 to 1.3 mm). The merged CT scans indicated that the distal end of the CCG was implanted obliquely and anteriorly compared with the predesigned positions, and the mean deviated degree was 5.4 (range, 1.7 to 7.3).

Discussion

Being a widely used technology, CASS is a predictive procedure simulated many different surgeries [15]. It has been also integrated into many maxillofacial surgical applications, including dentofacial deformities, congenital deformities, defects after tumor ablation, post-traumatic defects, reconstruction of cranial defects, and reconstruction of the TMJ over the past decades [15, 16].

For TMJ reconstruction, a preoperative segmentation and osteotomy planning was performed using CASS, and the final cranial-maxillofacial model was printed by the 3D printer to guide the reconstruction surgery, or shape the titanium plate for intraoperative using [1, 16]. Also, the digital template based on CASS could be produced to guide the osteotomy plane [12, 13]. In 2013, CASS was firstly introduced to design a TMJ custom-fitted total joint reconstruction in combination with orthognathic surgery. This application decreased the preoperative workup time of the design and the manufacture of the TMJ prosthesis and increased the accuracy of the model surgery [17]. In this study, we utilized the CASS technology to guide the surgical procedure of TMJ reconstruction using the CCG. With the help of the CASS, the design could be transferred into the operation. First, the contour of the selected rib could be

guaranteed the adequate matching with the lateral surface of ramus in shape. Second, the better fixation position of the bone grafts could be determined preoperatively without the damage of the inferior alveolar nerve. Third, the osteotomy and bone trimming would be guided accurately intraoperatively. Moreover, the length of the titanium plate and each titanium screws also could be confirmed, with no need to measure during surgery. Therefore, CASS makes the TMJ reconstruction with CCG more predictive and easier, and avoids the unplanned rib selection and the fixation of the bone graft.

From the clinical results, the 6th and 7th ribs were used to reconstruct 77.8% and 22.2% of the joints. Reviewing the previous studies, many surgeons harvested the 5th to 7th ribs for reconstructing the joint [18, 19]. But no study reported which one was the fit rib. This study provided the exact answer that the 6th or 7th ribs (especially the 6th rib) could be harvested for most of the joint reconstructions. In 2009, Qiu et al reported 122 patients treated with CCG using the endoscope for TMJ reconstruction. 5 patients of them had an injury of the inferior alveolar nerve, and some of the ribs were trimmed and contoured [14]. In current study, all the grafted ribs were not trimmed or contoured intraoperatively. No patient had complaints of malocclusion or numbness. The TMJ pain and mouth opening improved significantly in a short term follow up. The postoperative position of the bone grafts was similar with the presurgically designed position and the titanium plate and screws were implanted accurately. In other words, the use of CASS for TMJ reconstruction with CCG might decrease the postoperative complications, enhance the strength of the rib grafted, and increase the accuracy of the operation. However, our study just analyzed a small sample (only 7 patients) with a short-term follow up (6 months after surgery). Afterward, we hope to report the results of the long-term follow up with a big sample for this technique in the next study.

In conclusion, the application of CASS for TMJ reconstruction with CCG enhance the clinical accuracy by selecting a matching rib, facilitating accurate osteotomies, and guiding precisely the implantation of the rib grafts in an ideal position.

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Disclosure of conflict of interest

None.

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