Three-Dimensional Accuracy of Virtual Planning and Surgical Navigation for Mandibular Reconstruction With Free Fibula Flap

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Purpose: Although free fibula flaps are widely used for mandibular reconstruction, their 3-dimensional position is difficult to control during conventional surgery. We aimed to improve this process by using computer-aided design (CAD) and surgical navigation.

Patients and Methods: We retrospectively reviewed 29 benign tumor patients who underwent primary unilateral mandibular reconstruction with free fibula flap. They were divided into 3 groups: group A, comprising 10 patients, underwent reconstruction based on the surgeon's experience; group B, comprising 7 patients, underwent reconstruction based on CAD; and group C, comprising 12 patients, underwent reconstruction based on CAD and surgical navigation. Condyle and gonion positions and mandibular angles were measured. Operative times were recorded.

Results: Among the 17 patients who underwent condylar resection, the average condyle shift was greater in group A than in groups B and C ($P < .05$). The average gonion shift was greater in groups A and B than in group C ($P < .05$). The difference between the reconstructed and contralateral mandibular angles was greater in group A than in groups B and C ($P < .05$). The mean operative time did not differ among the 3 groups.

Conclusions: CAD can guide mandibular angle remodeling and condyle placement. CAD and surgical navigation increase reconstruction accuracy without prolonging operative time.

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Mandibular reconstruction is a challenging task in head and neck reconstructive surgery, which aims to achieve the best possible functional and esthetic outcomes. In 1989 Hidalgo[1] demonstrated the utility of free vascularized fibula flaps for mandibular reconstruction. Since then, the fibula flap has become a highly reliable and popular flap for mandibular reconstruction.[2] This flap has many advantages, including a long pedicle length, a wide vessel diameter, and the ability to incorporate skin, muscle, and bone components, which are required for mandibular reconstruction.[3] The mobility of the mandible increases the difficulty in achieving fibula flap inset and influences the accuracy of mandibular reconstruction.

Computer-assisted surgery is becoming increasingly popular in the field of oral and maxillofacial surgery.

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In the past, the 3-dimensional (3D) position of the free fibula flap was very difficult to control because the operation was based solely on the surgeon's experience. Thus, such operations occasionally resulted in dissatisfying occlusion and appearance. However, with the application of virtual technology, mandibular reconstructions are becoming increasingly accurate.[4-6] The first such technology used for mandibular reconstruction was computer-aided design (CAD). CAD can be used to mark osteotomy lines and calculate the lengths and angles of bone segments by simulating the operative process. Soon afterward, CAD–computer-aided manufacturing (CAM) and rapid prototyping, which were introduced in the past decade, improved the precision of mandibular reconstruction.[7] At the same time, it became possible to import virtual data to a navigation system, which was used to provide guidance for the accurate and safe placement of hardware or bone grafts, movement of bone segments, tumor resection, and osteotomy design. Finally, newly designed, mobile, intraoperative computed tomography (CT) scanners became available and could be used to confirm the accuracy of reconstruction before patients left the operating room.[8] Many appliances and studies about navigation surgery have concentrated on the midface region.[9,10] Navigation surgery has rarely been used for mandibular reconstruction because of the mobility of the mandible. The purpose of this study is to improve the process of mandibular reconstruction by using CAD and surgical navigation.

Patients and Methods

PATIENTS

We retrospectively reviewed the cases of 29 patients who had undergone mandibulectomy for the removal of benign tumors and mandibular reconstruction with free fibula flaps at Peking University School and Hospital of Stomatology between June 2013 and June 2014. The inclusion criteria were *1)* stable occlusal status, *2)* unilateral mandibular lesion including the mandibular angle, and *3)* division of the free fibula into 2 or more segments fixed by miniplates.

The patients were divided into the following 3 groups according to the type of surgery: group A (10 patients), reconstruction performed based on the surgeon's clinical experience; group B (7 patients), reconstruction performed using CAD; and group C (12 patients), reconstruction performed using both CAD and computer-assisted navigation. In all groups, miniplates were used to fix the fibula bone with the residual mandible. The condyle was resected in 4, 5, and 8 patients in groups A, B, and C, respectively. All tumor resections and mandibular reconstructions were performed by the same chief surgeon (X.P.).

TECHNIQUES

Computer-Aided Design

The process of CAD began with the acquisition of high-resolution CT scans of the maxillofacial skeleton and lower extremities. The imaging and planning platform used in this study was Surgicase CMF (Materialise, Leuven, Belgium). This software allowed the creation of 3D virtual models of the maxillofacial skeleton and fibula, as well as the simulation of mandibular osteotomies. Then, we superimposed the 3D fibular image onto the mandibular defect in its desired orientation. If the contour of the mandible was destroyed by the tumor, mirroring tools were used.[11] The length of every fibular segment and the angle between 2 fibular segments were measured and provided to the surgeon to facilitate intraoperative positioning and placement. The position of the osteotomy line and relevant parameters regarding shaping the fibula flap also were provided to the surgeon.

CAD and Navigation Surgery

Intraoperative navigation is comparable to global positioning systems commonly used in automobiles and is composed of 3 primary components: a localizer, which is analogous to a satellite in space; an instrument or surgical probe, which represents the track waves emitted by the global positioning system unit in a vehicle; and a CT scan data set, which is analogous to a road map. The navigation system used in this study was iPlan 3.0 (Brainlab, Feldkirchen, Germany). Mandibular reconstruction with CAD and navigation surgery included a planning phase and a surgical phase. CAD was completed during the planning phase. CT images of the CAD in stereolithography (STL) format were imported to iPlan 3.0 to register with the original CT imaging data. The navigation data were exported into a universal serial bus (USB) drive, which was then connected with the CT scan data set during the operation. The intraoperative navigation consisted of 3 primary components: CT scan data set, surgical probe, and localizer.

In the surgical phase, the first step was to secure fixed markers to the patient's head by way of screws inserted through small incisions in the scalp. The operator registered a series of points on the face with the CT data set to match the actual maxillofacial skeleton and the navigation images. The precondition for using the navigation process was that the mandible could be kept closed against the maxilla in centric occlusion and could be maintained throughout the navigation process. This closure could be accomplished by 2 methods. One method was to fix the mandible in centric occlusion with arch bar splint fixation, if possible. The other was to choose 3 distinctive anatomic landmarks on the