Oral Oncology 75 (2017) 133–139

Contents lists available at ScienceDirect

Oral Oncology

journal homepage: www.elsevier.com/locate/oraloncology

Utilization of a pre-bent plate-positioning surgical guide system in precise mandibular reconstruction with a free fibula flap

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ARTICLE INFO

Keywords:
Virtual planning surgery
Fibula flap
Pre-bent plate
Mandibular reconstruction
Navigation
Surgical guide
Plate positioning

ABSTRACT

Objectives: We evaluated the effects of three-dimensional virtual planning and the use of a plate-embedded surgical guide in mandibular reconstruction with microvascular fibula flaps.
Materials and Methods: We retrospectively reviewed 35 patients who underwent primary mandibular reconstruction with a free fibula flap. They were divided into three groups according to the therapy they received. In group A, 12 patients underwent reconstruction using the modified surgical guide system, including virtual surgeries, pre-bent titanium plates, screw-predesignated cutting guides for mandibular and fibular osteotomies, and plate-embedded shaping guides. In group B, 14 patients underwent reconstruction using the common surgical guide system, including virtual surgeries, cutting guides and pre-bent plates. In group C, 9 patients underwent reconstruction based on the surgeon's experience. All cases were reviewed for the total operative time, ischemia time of the fibula flaps, accuracy of surgery, and postoperative complications.
Results: All of the fibula flaps survived. In group A, the ischemia time was shorter than that of groups B and C ($P < .05$). The average gonion and condyle shift was lower in group A than in groups B and C ($P < .01$).
Conclusions: Application of the screw-predesignated and plate-embedded surgical guide system can reduce the ischemia time and operation time in mandibular reconstruction with a fibula flap, and can increase reconstruction accuracy. This method is a precise and highly reliable technique for improving the clinical outcome of mandibular reconstruction.

Introduction

Extensive repair of mandibular defects is challenging. Reconstructive options have included the use of microvascular free flaps, non-vascularized bone grafts, and alloplastic implants, including titanium reconstruction plates. In 1989, Hidalgo [1] reported the usefulness of free vascularized fibula flaps for mandibular reconstruction. This flap has many advantages, including a long pedicle, wide vessel diameter, sufficient bone components, and the ability to incorporate the skin paddle [2,3]. Since then, the fibula has been commonly chosen as the donor site for mandibular reconstruction.

In contrast to the arch contour of the mandible, the harvested fibula flap has a straight shape. To achieve the best possible functional and esthetic outcomes, the fibula should be osteotomized and reshaped. Traditionally, fibular shaping is performed after cutting the pedicle, which increases the ischemia time and may influence flap survival. In addition, reconstruction using traditional techniques is performed based on the surgeons' clinical experience. It is difficult to accurately rebuild the jaw contour and, in cases of extensive bony defects, particularly when the ramus and a large anterior area of the mandibular body are missing, the results can be especially poor.

Because of the problems mentioned above, preoperative surgical simulations based on three-dimensional (3D) technology, virtual surgical planning (VSP), and computer-aided design/computer-aided manufacturing (CAD/CAM) have become the focus of interest [4,5]. The most commonly used method is to create a rapid prototype model using data from computed tomography scans; this allows visualization of tumor margins, precise definition of surgical margins and the manufacture of customized cutting guides [6–8]. Surgical steps, including mandibular resection, are then simulated in this model, which has achieved some success in reducing the operating time and minimizing errors during surgery. Kääriäinen et al. [9] reported a mean ischemia time of 99 min when using CAD/CAM, compared with an ischemia time of 120–180 min when using conventional techniques. Mottini et al. [10]

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https://doi.org/10.1016/j.oraloncology.2017.11.011
Received 14 July 2017; Received in revised form 31 October 2017; Accepted 5 November 2017
1368-8375/

fabricated an intermediate surgical guide and pre-bent titanium plate using the CAD/CAM technique to transfer the result from the computer simulation to the operating room.

However, any remaining proximal fragments will be in an unstable position, and it is often difficult to adapt the pre-bent plate to the desired position without anatomical orientation. Previous studies have not presented a suitable device for precise positioning of the pre-bent titanium plate. The purpose of this article was to present an improved surgical guide system for fibular reconstruction of segmental defects of the mandible. Surgical navigation was applied intraoperatively to confirm the position of the fibula flap. The results were evaluated in terms of the accuracy of the surgery, clinical complications, ischemia time of the flaps and the operation time.

Patients and methods

Ethical approval for this study was obtained from the local university hospital research ethics board. This study was performed in accordance with the ethical standards of the responsible committee on human experimentation and the Declaration of Helsinki of 1975, as revised in 2013.

This retrospective study reviewed the consecutive cases of 35 patients who had undergone mandibulectomy and mandibular reconstruction with free fibula flaps at the oral and maxillofacial surgery department of the First Affiliated Hospital of Zhejiang University between April 2014 and November 2016. The inclusion criteria were (1) a stable preoperative occlusal status, (2) lateral mandibular defects extending from the canine to the base of the articular process with or without the condyle, including the mandibular angle (25 cases of condyle removal and 10 cases of condyle preservation), and (3) division of the free fibula into three segments fixed by 2.0-mm reconstructive titanium plates.

Twenty-three male and twelve female patients involved participated in this study. The patients were divided into three subgroups according to the type of surgery. In group A (12 patients), the plates were pre-bent preoperatively using the 3D-printed neomandible model. Using reverse engineering, customized cutting guides and shaping guides were manufactured to help osteotomies and plate positioning. Surgical navigation was used during surgery. In group B (14 patients), reconstructions were performed using cutting guides and pre-bent plates. In group C (9 patients), reconstructions were performed based on the surgeon's clinical experience, without use of CAD/CAM or a pre-bent plate. Among all cases, 30 (85.71%) benign tumors and 5 (14.29%) malignant tumors were diagnosed. The primary tumor in most patients was an ameloblastoma (n = 24, 68.57%). The condyle was resected in nine, nine and seven patients in groups A, B and C, respectively. Details of the patient characteristics are listed in Table 1. All tumor resections and fibular transfers were performed by the same chief surgeon (Huiyong Zhu).

Preoperative virtual planning and design of the guides

Preoperatively, computed topography (CT) of the mandible and maxilla (0.67-mm slices) and fibula (3-mm slices, with concomitant CT angiography) was performed. The Digital Imaging and Communications in Medicine (DICOM) data were imported into Magics software (Materialise Ltd, Leuven, Belgium) to create a 3D virtual model for surgical planning (Fig. 1A). Magnetic resonance imaging (MRI) and positron emission tomography/computer tomography (PET/CT) examinations were used to define a safe distance for the osteotomy margins of the malignant tumors. After virtual osteotomy was performed, the mirror image of the contralateral unaffected mandible was obtained using the central plane as the reference position for virtual mandibular reconstruction. Next, the fibular stereo lithography (STL) file was imported into the bony defect to reproduce the reference points, including the condylion, gonion and mental tubercle. Cutting, rotation, and positioning of bone segments was simulated, and a reconstructed mandible model using the fibula segments was then generated (Fig. 1B). Subsequently, a resin model was fabricated for manual pre-bending of a 2.0-mm reconstruction titanium plate. The plate was adapted and screwed to the model in a manner identical to that during the actual operation (Fig. 2A).

The model fixed with a pre-bent titanium plate was then scanned using a 3D coordinate measuring machine (FARO Technologies, Inc., Montreal, Canada). A new 3D model was created using the Magics software (Fig. 1C). A template (3-mm thick) was then generated by offsetting the bone surface on the buccal side of the shaped fibula segments. The templates provided adequate coverage, including the entire pre-bent plate. Columns (4.0 mm in diameter) were subtracted from the template overlapping the position of screws, and screw holes were formed. The pre-bent plate model was also subtracted from the template for intraoperative embedding of the plate. The template model was saved as an STL file, representing the shaping guide (Fig. 1D).

The mandibular cutting guides were designed based on virtual surgery results (Fig. 1E). The virtual fibula segments were placed at their original locations to design fibula cutting guides. The columns (2 mm in diameter) were subtracted from the cutting guides to create the drill holes, the positions and directions of which overlapped with those of the screws (Fig. 1F). The occlusion template for navigation was then designed. The shaping and cutting guides, as well as the occlusion template, were 3D-printed using a 3D printer (Objet Connex350™; Stratasys Ltd, Eden Prairie, MN, USA) and sterilized before use in surgery (Fig. 2B–D). The inner sides of the drill holes and cutting slots were enhanced by stainless steel.

Surgery in group A

The first step was to fix the dynamic reference frame to the patient's head using screws inserted through small incisions in the scalp (Fig. 3A). The surgeon registered a series of points on the face using the CT data set to match the actual maxillofacial skeleton and navigation images. During the navigation process, the occlusion template is used to maintain the position of the mandible.

After exposure of the mandible, sterile mandibular cutting guides were temporarily secured to the mandible. A piezoelectric saw (Stryker, Kalamazoo, MI, USA) was used for the osteotomies by referring to the cutting slots and effectively replicating the virtually planned mandibular osteotomies (Fig. 3B). After that, the cutting guides were removed, and in subsequent steps the holes in the residual mandible would be used to fix the pre-bent plate.

During tumor resection, a fibula flap was harvested under tourniquet control. Distal and proximal osteotomies were performed at least 6 cm from either terminus. The surgeons ligated the distal pedicle and followed the peroneal vessels to their takeoff at the posterior tibial artery. The fibula cutting guides were then placed using screws (Fig. 3C), and wedge osteotomies were performed following the guides. After the cutting guide was removed, all of the holes in the fibula would be used to fix the pre-bent plate. The fibula segments were then positioned into the shaping guides, in which the pre-bent plate had been embedded (Fig. 3D). By simply tightening the screws, the fibula segments can be fixed easily in the preplanned position. When the shaping guides were removed, the fibula segments fitted to the pre-bent

Table 1
Patient demographic data.

	Group A	Group B	Group C
Age (mean, range), years	40.5, 17–64	44.1, 29–55	45.2, 29–61
Gender (male/female), n	8/4	9/5	6/3
Follow-up (mean), months	9.1	12.3	12.4
Smoking, n	7/12	8/14	5/9
Benign /malignant tumor, n	10/2	12/2	8/1
Previous radiation therapy, n	0/12	0/14	0/9