Angle-to-Angle Mandibular Defect Reconstruction With Fibula Flap by Using a Mandibular Fixation Device and Surgical Navigation

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Purpose: Although free fibula flaps are widely used for mandibular reconstruction, 3-dimensional (3D) position is difficult to control in angle-to-angle mandibular defects. The present study describes a revised approach for angle-to-angle mandibular reconstruction with fibula flaps by using mandibular fixation device and surgical navigation.

Methods: Preoperative maxillofacial and fibular computed tomography (CT) scans were acquired, and CT data were imported into ProPlan CMF software. Virtual mandibulectomy was performed, and 3D fibula image was superimposed on the mandibular defect. The fibula flap was shaped according to virtual parameters and the stereo model. Surgical navigation was used to check and correct shaped segments. Position of the osteotomy lines and relevant parameters regarding the shape of the fibula flap were provided to the surgeon. A mandibular fixation device (Cibei, China) was fixed to bilateral mandibular ramus before mandibulectomy, which maintained normal mandibular width. Under computer navigation guidance, the fibula flap was accurately positioned in 3D direction, and the defect could be precisely reconstructed despite the lack of stable occlusal relationship after osteotomy.

Results: Postoperative CT and 3D error analysis revealed that osteotomy lines and reconstruction contour matched well with preoperative planning. Using our method, we precisely recovered the original configuration of the mandible. Bilateral condyles were located in the temporomandibular joint fossae, and normal mandibular width was maintained. Compared with preoperative positions, the average shift on the remaining mandible was 0.803 ± 0.502 mm (largest, 1.886 mm). Average shift in the reconstructed mandible was 0.281 ± 0.300 mm, largest being 2.441 mm.

Conclusions: We describe a novel method for angle-to-angle mandibular reconstruction with free fibula flap. A mandibular fixation device combined with computer-assisted techniques involving surgical navigation improved clinical outcomes of this procedure.

Key Words: Angle-to-angle mandibular defect, mandibular fixation device, surgical navigation

(*J Craniofac Surg* 2017;28: 1486–1491)

Free fibula flaps are currently one of the most popular and highly reliable flaps for mandibular reconstruction and were initially described by Hidalgo in 1989, with several advantages including long pedicle length, wide vessel diameter, and ability to incorporate skin, muscle, and bone components.[1–3] However, mobility of the mandible makes achieving fibula flap inset challenging and influences the accuracy of mandibular reconstruction. In the past, the 3-dimensional (3D) position of the free fibula flap was very difficult to control because the surgery was solely based on the surgeon's experience, and such surgeries occasionally resulted in dissatisfying occlusion and esthetics. With development of microvascular surgery and use of computer-assisted techniques, free fibula flap can be used to achieve good functional and esthetic outcomes in most patients with mandibular defects.[4–7] Given the mobility of mandible, stable occlusion is necessary to maintain the position of the remaining mandible during surgery. However, in certain complex cases such as angle-to-angle mandibular defects, wherein there are no teeth to accurately position stable occlusion, positioning of the remaining mandible and fibula flap can be extremely challenging, and such mandibular defects cannot be accurately repaired to achieve desirable form and function, and both surgeons and patients are not satisfied with postoperative outcomes. Here we present a new method for angle-to-angle mandibular reconstruction with free fibula flap by using a mandibular fixation device and surgical 'navigation. A mandibular fixation device (Cibei, China) can be fixed to the bilateral mandibular ramus before mandibulectomy to maintain normal mandibular width. Fibula flaps can be accurately positioned in the 3D direction under the guidance of computer navigation. Accordingly, mandibular reconstruction can ensure the best possible postoperative results for angle-to-angle mandibular defects that lack stable occlusal relationship.

PATIENTS AND METHODS

A 57-year-old man visited our institution with swelling and pain of the mouth floor (Fig. 1). A panoramic radiograph and computed tomography (CT) scan revealed occupancy lesions of the mouth floor involving the lingual cortical mandible (Fig. 2). The diagnosis of this man was squamous cell carcinoma. After preoperative discussions and computer-aided design, the treatment plan comprised neoplasm resection, mandibulectomy, bilateral neck dissection, and use of free fibula flap for mandibular reconstruction.

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Received March 23, 2017.
Accepted for publication April 8, 2017.
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This work was financially supported by National Supporting Program for Science and Technology (No.2014BAI04B06) and Grants from Beijing Municipal Science and Technology Commission (No.Z161100000116053).
The authors report no conflicts of interest.

ISSN: 1049-2275
DOI: 10.1097/SCS.0000000000003891

FIGURE 1. Patient's preoperative photograph.

VIRTUAL PLANNING

Preoperative maxillofacial contrast-enhanced CT and fibular non-contrast-enhanced CT scans with 1-mm slice thickness were acquired, and the former scans were acquired in a stable occlusion position (field of view: 20 cm; pitch, 1.0; slice, 0.75 mm; 120Y280 mA). CT data, in the Digital Imaging and Communications in Medicine file format, were imported into ProPlan CMF software (Materialise, Leuven, Belgium). First, the mandible and maxilla were segmented. Then, we performed virtual mandibulectomy with ProPlan CMF according to clinical and 3D radiological findings, following which the 3D fibula image was superimposed onto the mandibular defect in its desired orientation according to ideal mandibular contour. The length of every fibula segment was measured and provided to the surgeon to facilitate intraoperative positioning and placement (Fig. 3). The surgeon shaped the fibula flap according to these parameters, cross-checking with a protractor and ruler. Surgical navigation was used to check and correct the shaped fibula flap segments. The position of the osteotomy lines and

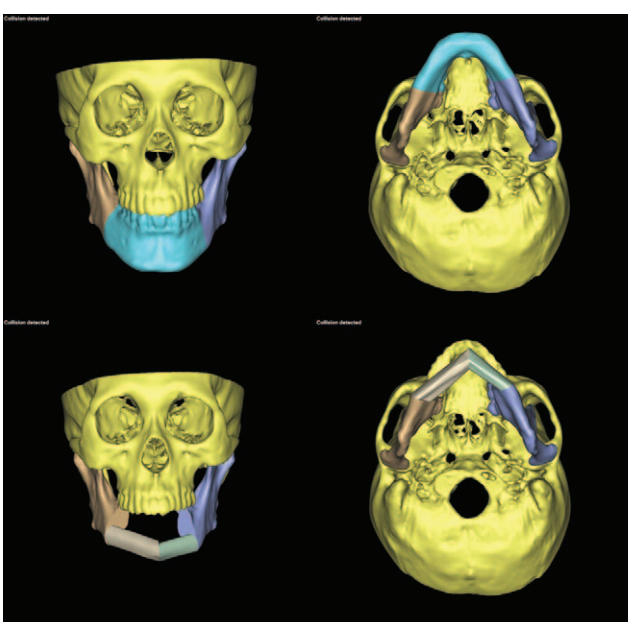

FIGURE 2. Preoperative computed tomography scan showing occupancy lesions of the mouth floor involving the lingual cortical mandible.

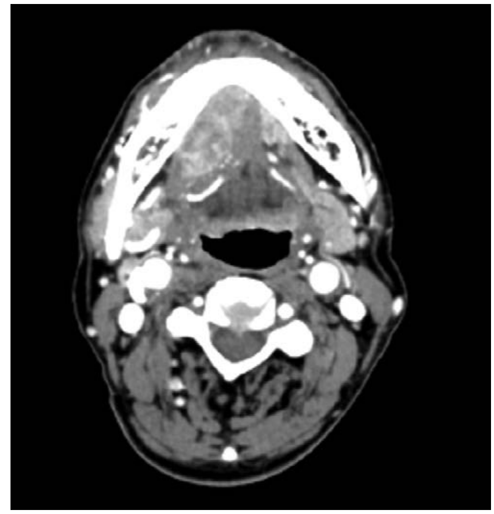

FIGURE 3. Simulation of virtual osteotomy and mandibular reconstruction with the fibula flap on ProPlan CMF software (Materialise, Leuven, Belgium).

relevant parameters regarding the shape of the fibula flap were also provided to the surgeon.

SURGICAL TECHNIQUE

The mandibular fixation device (Cibei, China), which is a Ω-shaped long titanium plate with a bilateral terminal, is L-shaped with 3 holes (Fig. 4). The characteristic of titanium is to ensure the plate was not only conveniently shaped but also could not get easily deformed during surgery. The bilateral terminals could be bent to conform to the shape of the bilateral mandibular ramus. The metallic character of the mandibular fixation device (thickness 2.0 mm; diameter of screw 2.4 mm) was the same as that of the reconstruction plate.

The mandibular fixation device was placed across the entire defect and was secured to the bone on each side of the resection line. The native bilateral mandibular ramus was used as a template while molding this device. This device was placed far away from the inferior border of the mandibular body and fixed using 3 screws in each mandibular ramus, which could avoid removal of the device before mandibular resection (Fig. 5).

The entire surgical procedure was guided by the navigation system according to the preoperative virtual plan. Intraoperative navigation was comparable with global positioning systems that are commonly used in automobiles and comprises 3 primary

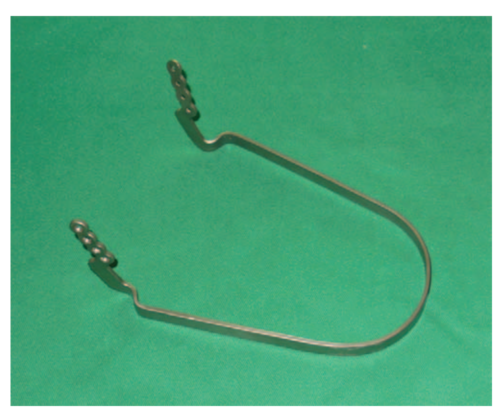

FIGURE 4. Ω shape of the mandibular fixation device (Cibei, China).

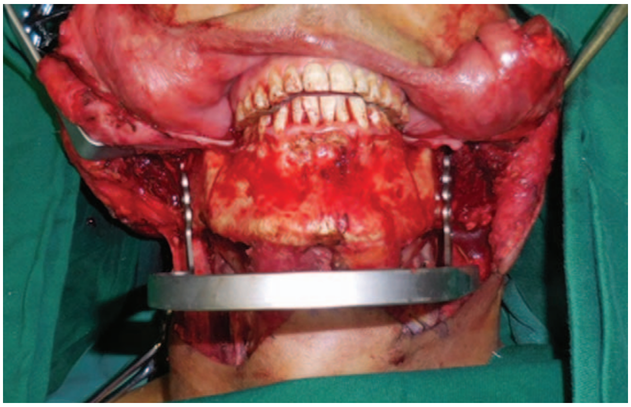

FIGURE 5. Mandibular fixation device fixed bilaterally on the mandibular ramus with titanium screws.

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 the vehicle; and a terminal working station, which is analogous to a road map.[8] The navigation system used in this study was iPlan 3.0 (Brainlab, Feldkirchen, Germany).

Intraoperative navigation was used to implement the virtual plan for patients undergoing mandibulectomy and mandibular reconstruction. The first step of surgery was to secure fixed markers to the patient's head by using screws inserted through small incisions in the scalp. The surgeon registered a series of consecutive points over the periorbital and frontal regions by using a registration equipment (Z-touch; Brainlab) to match the actual maxillofacial skeleton and navigation images on the working station.

The precondition for using the navigation process was that the mandible must be maintained against the maxilla in centric occlusion throughout the navigation process. This could be accomplished by 2 methods. One was to fix the mandible in centric occlusion by using an arch bar splint, and the other was to select 3 distinctive anatomical landmarks on the surface of the remaining mandible and register these points with the virtual image. We used the former method in our study. Both these techniques facilitate placement of the mandible in the planned position. The available sagittal, coronal, axial, and 3D reconstruction images displayed by the navigation system were used during surgery to accurately determine the osteotomy sites as well as trajectory. Under the guidance of a surgical probe, the osteotomy line was marked, and virtual mandibulectomy was transferred to real-time surgery (Fig. 6).

After angle-to-angle mandibulectomy, the mandibular fixation device maintained continuity of the remaining mandible. However, because of the lack of lower teeth, the previous way to fix the mandible in centric occlusion was not successful. Therefore, the second method was selected to determine the previous position of the remaining mandible. The position of the bilateral osteotomy lines was used as distinctive anatomical landmarks to register with the virtual position (Fig. 7). Owing to the mandibular fixation device, normal mandibular width was maintained. With the help of the device and navigation system, the position of the bilateral remaining mandible was determined similar to the previous position before mandibulectomy.

After osteotomy, the shaped fibula flap was placed into the mandibular defect. Positions of the fibula segments were accurately guided and confirmed by the computer navigation system until all segments coincided with the ideal preplanned positions (Fig. 8). After fixation between the fibula segments and bilateral mandible

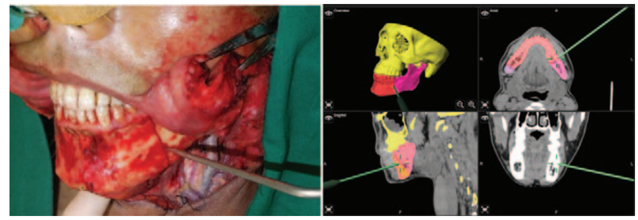

FIGURE 6. Real-time surgery of angle-to-angle mandibular defect reconstruction with fibula flap by using mandibular fixation device and surgical navigation.

with miniplates, the mandibular fixation device could be removed. After inset of the fibula, the facial artery and external jugular vein were used for anastomosis.

The ethical approval was given for our study. The ethical approval document no. is PKUSSIRB-201522048. This study features human subject, and we confirm that we have read the Helsinki Declaration and have followed the guidelines in this investigation.

RESULTS

The operation time spent was 335 minutes. The vascularized fibular flap survived successfully without any complications. With patient's approval, the cost of using the navigation system during surgery was 2800 RMB (approximately 400 USD), and the time spent for preparation of the surgery was 1 day more than that spent for traditional surgery owing to the virtual plan and surgical navigation. The mandibular fixation device was free and reusable.

A noncontrast-enhanced CT scan was obtained 1 month after surgery to evaluate the outcome of mandibular reconstruction with free fibula flap. Chromatography (Geomagic, Morrisville, NC) was used to evaluate differences between postoperative and planned configurations of the mandible.

Using this method, we could precisely recover the original configuration of the mandible. Bilateral condyles were located in the temporomandibular joint fossae, and normal mandibular width was maintained. Compared with preoperative positions, the average shift on the remaining mandible was 0.803 ± 0.502 mm, and the largest shift on this side was 1.886 mm (Fig. 9). Average shift in the reconstructed mandible was 0.281 ± 0.300 mm, largest being 2.441 mm (Fig. 10). At 1 month after surgery, this patient was satisfied with the facial appearance (Fig. 11).

DISCUSSION

The mandible is located in the lower third of the maxillofacial region and is the primary structure that participates in the oral cavity and pharynx and maintains facial appearance and masticatory functions. It is also an important region required for mastication, speech, and respiration. Mandibular defects can occur because of various reasons such as cancer, trauma, and inflammation and have a substantial impact on a patient's appearance and function.[1–5] With

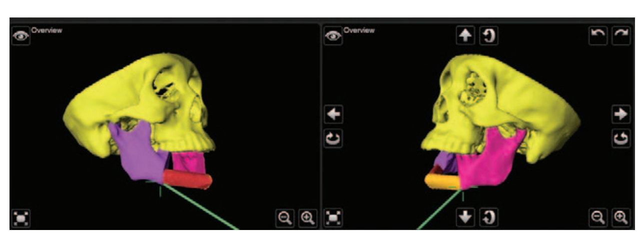

FIGURE 7. The position of the bilateral osteotomy lines was used as distinctive anatomical landmarks to register with the virtual position.

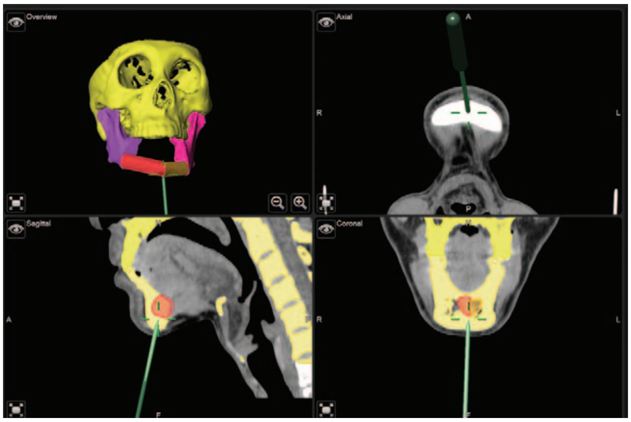

FIGURE 8. Shaping and inset of the free fibula flap by using mandibular fixation device and surgical navigation.

the development of microvascular surgery, free fibula flap has become a popular flap for mandibular reconstruction, but to date, accurately shaping and positioning this flap remains a challenging procedure in the field of head and neck reconstructive surgery.

Miniplates and reconstruction plates are usually used to fix free fibular flaps, the criterion standard in the reconstruction of large segmental mandibular defects. Miniplates and reconstruction plates have different characteristics that provide different advantages and disadvantages with regard to neomandibular fixation. Miniplate fixation, which was introduced by Hidalgo[2] is thought to be associated with greater malleability, lower facial profile, decreased operative time, and decreased risk of disruption of the vascular pedicle[9]. Kennady et al[10] suggested that reconstruction plates were associated with stress shielding and disuse osteoporosis. Robey et al[11] compared patients who had undergone fibular reconstruction of mandibular defects with miniplates with those who had undergone this repair using reconstruction plates. No statistically significant difference was identified between the miniplate group and reconstruction plate group with regard to overall cumulative complication rates, flap failure, plate extrusion, malunion/nonunion, and plate fracture. Furthermore, miniplate fixation can be performed at

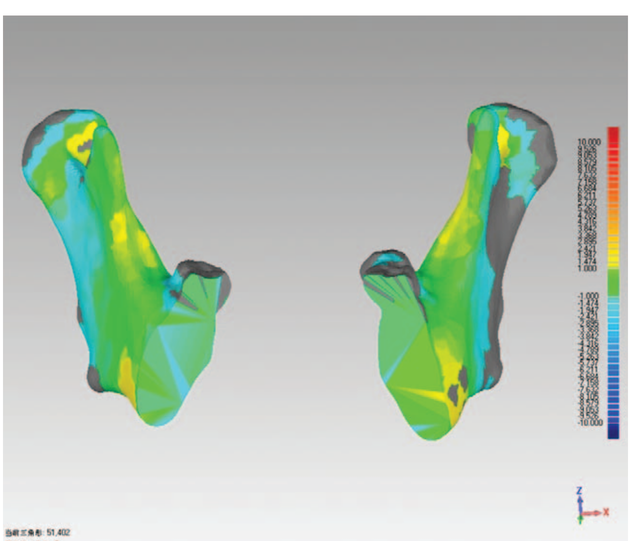

FIGURE 9. Chromatographic analysis of mandibular ramus and condyle of both sides.

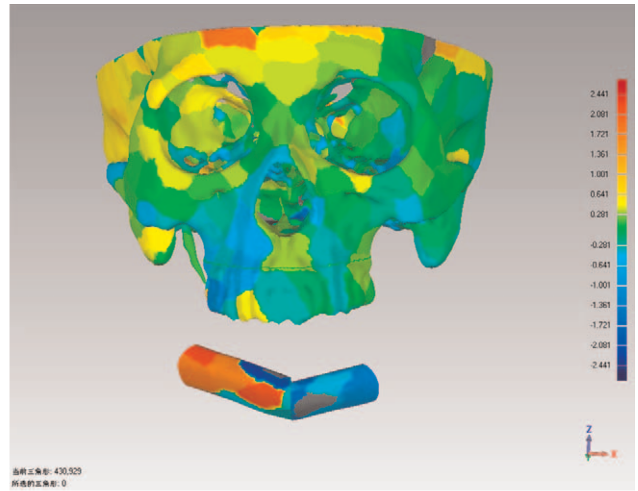

FIGURE 10. Chromatographic analysis of reconstructed mandible with free fibula flap.

the donor site before harvesting the vascular pedicle. In this study, miniplates were used to fix the mandible and fibula because the position of the gonion reconstructed using a fibula flap and the mandibular width can be easily adjusted, but it is not easy to reach the accurate position at the same time.

Typically, traditional surgical reconstruction methods rely on intraoperative trial and error and accumulated surgical experience and may entail constraints in achieving consistent and predictable esthetic as well as functional outcomes. Recently, virtual surgical planning and computer-aided design (CAD)/computer-aided modeling (CAM) are gaining popularity in mandibular reconstruction and offer opportunities for increased accuracy, improved efficiency, and enhanced outcomes.[7,12,13] CAD can be used to mark osteotomy lines and calculate lengths and angles of bone segments by simulating the operative process. CAD/CAM and rapid prototyping, introduced in the past decade, improve the precision of mandibular reconstruction.[14] At the same time, virtual data can be imported into a navigation system, which can, in turn, be used to provide guidance for accurate tumor resection and mandibular reconstruction. Through model surgical techniques, CAD/CAM models, aided by 3D stereolithographic models, preoperative prefabricated osteotomy guides, shaping guides, bite guides, pre-bent plates, preshaped titanium mesh implants, and other models have greatly improved the accuracy of mandibular reconstruction surgeries.[15–17] Principle of 3D printing is a rapid prototyping device that utilizes paper

FIGURE 11. Patient's postoperative photograph.

lamination and light-curing technology, drawing model data through a computerized 3D modeling software and model data into 3D printing can read G-code file, then import professional printer, alternately, heavy superimposed on the final computer-designed model "Print" as kind.[3] 3D printing technology can be used in the field of mandibular reconstruction to assess preoperative and intraoperative bending of customized titanium; in addition, it has the advantages of ease of operation and precise positioning.[3,6,7,12] Reconstruction of mandibular defects by 3D printing and computer-aided planning help to repair the side of the jaw with defects by simulating the normal side of the jaw through mirroring technology. However, it cannot be used in certain specific cases wherein a defect is spread across the midline of the mandibular body, such as angle-to-angle mandibular defects. In recent years, computer navigation systems have been widely used in clinical practice as an outcome of application of medical imaging and image processing technologies in the medical field. By combining dimensional space navigation technology, computerized image processing, and visualization technologies with clinical surgery, computer navigation systems can display the position of surgical instruments in real time to avoid damaging critical anatomical structures and ensure safety of surgery. With precise preoperative design and reliable postoperative prediction, such a system ensures accurate guidance for intraoperative positioning, successful surgery, and restoration of desirable functions and esthetics after surgery. However, navigation surgery has rarely been used for mandibular reconstruction because of mandibular mobility. Several appliances and studies on navigation surgery have focused on the midface region.[18,19] Moreover, newly designed, mobile, intraoperative CT scanners can be used to confirm accuracy of reconstruction before patients leave the operating room.[20] Mandibular reconstruction is a challenging task in the field of head and neck reconstructive surgery because of the mobility of the mandible. Although preoperative CAD provides certain parameters such as defect length and angle between 2 bone segments, accurate 3D contouring of the fibula based on these parameters is extremely difficult, particularly when there are >2 segments in the fibula flap. Once the continuity of the mandible has been destroyed, determining the position of the condyle and gonion can be challenging because of the mandibular mobility, even though the preoperative CAD position may be used for reference.[21] For certain complex mandibular defects, such as angle-to-angle mandibular defects, wherein there are no teeth present, to position stable occlusion after mandibular resection still was a challenge for the surgeon. At present, mandibular reconstruction for angle-to-angle defects largely depends on the surgeon's clinical experience. Even with the use of digital guides, 3D printing technology, or computer navigation guidance, postoperative outcomes are still far from satisfactory. Mandibular reconstruction of angle-to-angle defects poses 2 major issues. The first is that mandibular width is hard to maintain. The bilateral mandibular ramus and condyle cannot be fixed to the maxilla with an arch bar splint because of lack of teeth. The other issue is that the reconstructed gonion is positioned without any reasonable reference points. Position of the mandibular angle and gonion bilaterally is the most crucial factor in maintaining appearance of the lower part of the face, and any deviation in position would influence mandibular functions including chewing, speech, and respiration. Fortunately, these 2 issues can be resolved with the use of mandibular fixation devices and surgical navigation. After segmental mandibulectomy, the remaining mandibular segments become free-floating. Various methods could be used to provide rigid fixation to maintain mandibular alignment. These include preplating,[21] external fixation,[22,23] and intermaxillary fixation using arch bars or splints. The reconstruction plate can be preplated to either the vestibular or the lingual sides depending on the involvement of the internal or external cortical bone. Segmental mandibulectomy can be performed after the fixed prebent reconstruction plate was removed. After the mandibulectomy, the plate is fixed again to guide the shaping and inset of the fibular flap. The external fixation system is a flelxible system, which has particular advantages in certain populations. For the edentulous patients, intermaxillary fixation cannot be applied. In advanced carcinoma eroding the lateral mandibular cortex, the soft tissues on the buccal surface of the jaw are typically involved by tumor extension. In both edentulous patients and in tumors involving the lateral cortex, the external fixation system can be used.[24] The external fixation system also has greater freedom while insetting the vascularized bone graft than the preplating fixation. By placing the bridging extension bow away from the mandible, there is less hardware interference while crafting osteotomies and positioning the flap as compared with a reconstruction bar that overlies the mandibular defect. Meanwhile, for the same reason, the position of the fibular segments is difficult to determine. Each method has advantages and disadvantages. In this study, we described a novel method for angle-to-angle mandibular reconstruction with free fibula flap to solve these 2 problems at the same time. It combines mandibular fixation devices with computer-assisted techniques involving surgical navigation.

Mandibular fixation devices combined with the surgical navigation can be a good solution to this problem: it can control the width of the mandible well, avoid mandibular ramus and condylar from slightly rotating or reversing in different directions, particularly in cases with reconstruction of a wide range of complex mandibular defects that lack a stable occlusion reference after lesion resection, such as angle-to-angle mandibular defects; mandibular fixtures bending shapes cleverly bypass the operative field, which will not affect the operation of the surgeon; the fixture design is reusable, which can be mass produced, making it cheap and easy to promote. The surgical navigation can provide the reference for the shaping and inset of the free fibular flap.

Before the operation, CAD allows the manipulation of 3D representations of the mandible and donor site, which can help surgeons plan the resection, measure the defect, and plan the harvest and contouring of the fibula flap.[25] Multiple software programs are available for this planning, which can reduce operative time and enhance the quality of reconstruction. However, shaping and positioning of fibula flap in the 3D direction may still lead to some rotation or be offset, even after the mandibular width is precisely controlled. Computer navigation systems help to perfectly address this issue. Surgical navigation is a powerful tool that enables accurate execution of a surgical plan.[26] Surgical navigation helps to check and correct shaped segments. Registration technique is the key element that determines precision of surgical navigation. Navigation systems were not considered suitable for mandibular surgery because of the mobility of the jaw. There are 3 possible solutions to this problem. The first approach is to place the patient in maxillomandibular fixation for the CT scan and during the surgery, but this is not feasible for transoral surgeries. The second method is to place the mandible in centric relation or centric occlusion, either manually or by using a dental splint; mandibular movements are convenient for the surgery but can undermine the accuracy of intraoperative navigation. The third method uses a special sensor frame that is fixed onto the mandible.

In this study, before the osteotomy, the mandible was placed in centric occlusion by using arch bar splint fixation. However, arch bar splints cannot be used for angle-to-angle mandibular defects. By using a mandibular fixation device, the relative position between the mandibular ramus and condyle of both sides can be fixed. Moreover, through registration with the osteotomy line, the entire mandible and mandibular fixation device can be fixed to the skull. In the present study, we drilled several landmarks on the residual mandibular surface before osteotomy as reference points. After osteotomy, recovery of the condyle and coronoid process was based on repositioning of these landmarks.

Through intraoperative multipoint positioning, repeated verification, computer navigation system could precisely guide fibula flap positioning in the sagittal direction and greatly improved surgical efficiency and accuracy. Furthermore, the sagittal, coronal, axial, and 3D reconstruction images displayed by the navigation system were used to accurately determine the osteotomy sites, osteotomy, and positioning trajectory during surgery.

CONCLUSIONS

We described a novel method for angle-to-angle mandibular reconstruction with free fibula flap. It combines mandibular fixation devices with computer-assisted techniques involving surgical navigation, which has the potential to improve clinical outcomes of this procedure.

ACKNOWLEDGMENT

The authors thank the professional editor of Elixigen Company for revising and modifying the English language of this manuscript.

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