Mandibular Reconstruction With the Iliac Flap Under the Guidance of A Series of Digital Surgical Guides

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Abstract: The authors aimed to evaluate the accuracy of mandibular reconstruction with the iliac flap under the guidance of a series of digital surgical guides. Seven patients were enrolled to evaluate the accuracy of reconstruction immediately after surgery. Patients underwent mandibular reconstruction with a vascularized iliac flap guided by a series of digital surgical guides at the Department of Oral and Maxillofacial Surgery, Peking University School and Hospital of Stomatology, from September 2017 to June 2018.

All flaps survived. Chromatographic analysis showed that the area with a chromatographic difference of $\leq$1 mm between preoperative virtual surgical planning model and postoperative mandible accounted for 73.97% $\pm$ 3.89% of mandible surface, the area $\leq$2 mm accounted for 87.21% $\pm$ 2.65%, and the area $\leq$3 mm accounted for 94.09% $\pm$ 2.50%. In all of the 7 cases, the mean of maximum deviation was 6.25 $\pm$ 1.00 mm, and the mean of average deviation was 0.95 $\pm$ 0.13 mm. The authors conclude that mandibular reconstruction with the iliac flap under the guidance of a series of digital surgical guides is accurate and effective.

Key Words: Accuracy, digital surgical guide, iliac flap, mandibular reconstruction

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In recent years, functional reconstruction of mandibular defects has become a research hotspot in oral and maxillofacial surgery. Through preoperative VSP, surgery can be intuitively simulated preoperatively to determine the expected surgical effect.[1–3] At present, the main methods used to transform surgical design into implementation include computer-assisted navigation systems (CANSs)[4] and digital surgical guides (ISGs). Most traditional preoperative design transformation programs use both CANSs and ISGs. Here, we propose a new method to complete mandibular reconstruction with the iliac flap using only ISGs. We also discuss the accuracy of design transformation.

MATERIALS AND METHODS

Study Subjects

Seven patients who underwent mandibular reconstruction with the iliac flap under the guidance of a series of ISGs at the Department of Oral and Maxillofacial Surgery of Peking University School and Hospital of Stomatology from September 2017 to June 2018 were reviewed.

Preoperative Design

Before surgery, maxillofacial and iliac spiral computed tomography (CT) scans were performed, and data was stored and exported in DICOM format. Using ProPlan CMF 3.0 (Materialise, Belgium), we three-dimensionally reconstructed CT images and separated the mandible from the skull. We traced the tumor outline layer by layer and designed osteotomy planes according to the tumor outline. Virtual resection was executed to obtain the defective mandible model (Fig. 1A). Then, mirror technology was used to restore the shape of the defect. The corresponding iliac flap was cut to virtually reconstruct the shape of the mandible (Fig. 1B). All three-dimensional models were stored and exported in STL format to design a series of ISGs.

Prebent Titanium Plate

Using three-dimensional printing technology, we used photosensitive resin material to design the mandible model reconstructed with the iliac flap. A 2.0-mm DePuy Synthes reinforcement plate (Johnson & Johnson, USA) was prebent according to the model (Fig. 1C). After fixing the titanium plate on the mandibular model, we used a 3D-Scanner (3Shape, USA) to scan the mandibular model and the titanium plate to determine the relationship between them (Fig. 1D). The three-dimensional model obtained by scanning was stored and exported in STL format to produce a series of ISGs.

Guide design

Using Geomagic Studio 2014 (3D systems, USA), we matched and fused the mandible model with the titanium plate, and the mandible model was reconstructed with the iliac flap to determine the position of titanium plate holes (Fig. 1E). According to the need of surgery, we used computer-assisted-design software to design osteotomy guides of the mandible and iliac, and the retention holes of the 2 guides were used

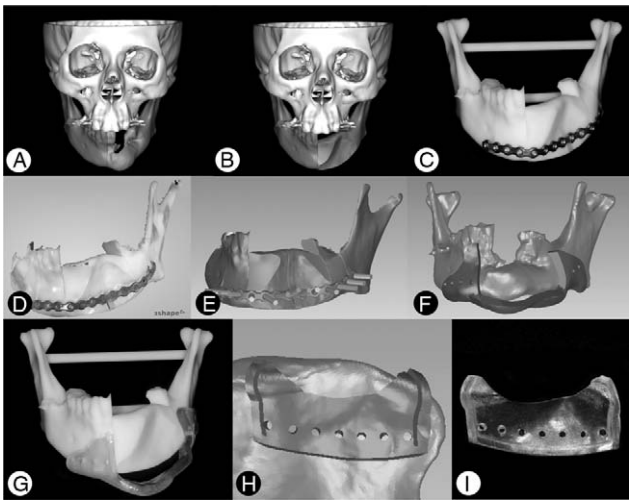

FIGURE 1. Preoperative design process. A: Virtual resection to obtain a mandibular defect model. B: Virtual reconstruction of the mandible. C: Three-dimensional model and precurved titanium plate. D: 3Shape scanning of titanium plate. E: Matching of titanium plate information with the mandibular model. F: Design of the mandibular osteotomy guide. G: Three-dimensional mandibular osteotomy guide. H: Design of the iliac osteotomy guide. I: Three-dimensional iliac osteotomy guide.

to fix the titanium plate during surgery. The ISG plate was printed three-dimensionally (Fig. 1F–I). The prebent titanium plate, mandibular model, and ISGs were sterilized before use.

Intraoperative Implementation

Tumor Resection Guided by the Mandibular Osteotomy Guide

The surgical area was routinely exposed. Intermaxillary fixation was not required. During surgery, we exposed the normal mandible around the lesion and placed the mandible osteotomy guide according to anatomical shape. We drilled holes in the mandible according to the retention holes of the mandible osteotomy guide and fixed the guide with titanium nails (Fig. 2A). Resection was performed according to the osteotomy line on the guide. After removing the osteotomy guide, the prebent titanium plate was fixed according to the remaining holes on the mandible (Fig. 2B and C).

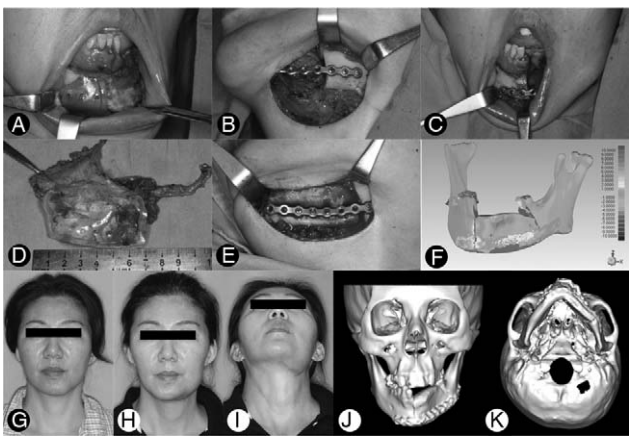

FIGURE 2. Surgical implementation. A: Mandibular osteotomy guide fixed in place. B–C: Titanium plate fixed in place after osteotomy. D: Iliac bone flap preparation. E: Iliac bone flap fixed in place. F: Postoperative three-dimensional chromatographic analysis. G: Preoperative appearance. H–I: Postoperative appearance 3 months after surgery. J–K: Postoperative computed tomography 3 months after surgery.

Harvesting of the Iliac Flap Guided by the Iliac Osteotomy Guide

The surgical area was routinely exposed, and the iliac osteotomy guide was positioned. Then, the iliac flap was drilled according to the retention holes on the guide. The iliac osteotomy guide was fixed with titanium nails. The required iliac flap was harvested according to the osteotomy line of the guide and shaped according to the shaping groove of the guide (Fig. 2D). After cutting the vascular pedicle, harvesting of the iliac flap was completed, and the iliac flap was transferred to the recipient area.

Placement and Fixation of the Iliac Flap

According to the holes left on the iliac flap that corresponded to the holes of the titanium plate, we placed the iliac flap, fixed it, and pre-bent the titanium plate using titanium nails (Fig. 2E). After the iliac flap was fixed, we performed microvascular suture and checked the blood flow of the iliac flap.

Postoperative Evaluation

One week after surgery, spiral CT was performed. Data was stored and exported in DICOM format. Using ProPlan CMF 3.0 (Materialise, Belgium), we three-dimensionally reconstructed CT images and separated the mandible from the skull. The mandibular model was exported in STL format. We imported the preoperative and postoperative mandibular models into Geomagic Control 2014 (3D systems, USA) and used the nonsurgical area of the 2 models as a reference to match and align them. After, we used chromatographic analysis to evaluate the accuracy of surgical transformation (Fig. 2F). Patients also performed a self-evaluation of the symmetry of their postoperative facial appearance (Fig. 2G–K).

This study was approved by the ethics committee of Peking University School and Hospital of Stomatology (PKUSSIRB-201840194). Written informed consent was obtained from all patients.

RESULTS

A total of 7 patients were enrolled in this study, including four males and three females. The average age of patients was 48 years (range, 26–63 years). We used a series of ISGs to complete mandibular resection and iliac flap reconstruction in all patients. We used 2.0-mm DePuy Synthes reinforcement plates (Johnson & Johnson, USA) for internal rigid fixation between the iliac flap and remaining mandible. All iliac flaps survived after surgery, and there were no postoperative complications, such as wound infection and exposure or fracture of the titanium plate (Supplementary Digital Content, Table 1, http://links.lww.com/SCS/C402).

All 7 patients were satisfied with their postoperative appearance. Chromatographic analysis showed that the area with a chromatographic difference of ≤ 1 mm between preoperative VSP model and postoperative mandible accounted for $73.97\% \pm 3.89\%$ of mandible surface, the area ≤ 2 mm accounted for $87.21\% \pm 2.65\%$, and the area ≤ 3 mm accounted for $94.09\% \pm 2.50\%$. In all of the 7 cases, the mean of maximum deviation was 6.25 ± 1.00 mm, and the mean of average deviation was 0.95 ± 0.13 mm. (Supplementary Digital Content, Table 2, http://links.lww.com/SCS/C402).

DISCUSSION

Advantages of a Series of Digital Surgical Guides

Since 2011, our hospital has used intraoperative CANSs to complete digital surgical treatment. At present, intraoperative CANSs are mature, which can help oral and maxillofacial surgeons to accurately achieve surgical goals. Many studies have confirmed this conclusion.[5–7] However, intraoperative CANSs also have some

limitations. First, before using a CANS, it is necessary to install a navigation frame on the head. There are 2 ways to fix the navigation frame; the frame can be fixed to the skull using titanium nails or a headband. Both methods have shortcomings. Use of titanium nails requires additional incisions, which increases surgical trauma in nonsurgical areas, while the stability of the navigation frame is relatively poor when fixed with a headband. After installation of the navigation frame, surgery can be performed after registration, which increases the surgical duration. Second, since the mandible is movable relative to the maxilla and skull, to ensure navigation accuracy, it is necessary to make a splint before surgery and perform intermaxillary fixation to ensure that the relative position of the mandible remains unchanged. This is usually completed using titanium traction nails fixed on alveolar bone, which also increases the degree of trauma to nonsurgical areas. Third, CANSs can only guide placement of the bone flap, but cannot guide shaping. To achieve precise shaping, it is necessary to use ISGs. Moreover, when guiding placement of the bone flap, it is necessary to repeatedly verify the position of different landmarks. For relatively inexperienced doctors, this step will greatly increase the surgical duration. Finally, the initial cost of intraoperative CANSs is relatively high; thus, they are difficult to adopt in primary hospitals.

Many scholars at our hospital have attempted to improve the accuracy of digital mandibular reconstruction. In 2016, Yu Yao proposed digital mandibular reconstruction with the iliac flap. With this approach, mandibular resection is completed under guidance of an intraoperative CANS, and harvesting of the iliac flap is completed under guidance of an ISG. Intermaxillary fixation is still required. Before surgery, the titanium plate is prebent according to the three-dimensional model and fixed to the model. CT is then performed to determine the position of titanium plate holes. This information is successfully transformed into intraoperative navigation, and the CANS is used to guide placement and fixation of the titanium plate and iliac flap.[8] Zheng et al further improved the process of digital mandibular reconstruction with the iliac flap. This group designed the three-dimensional mandible model in 2 parts: the reconstruction segment and the remaining mandible. The 2 parts are detachable and combinable. During surgery, the prebent titanium plate is fixed with the reconstructed segment, and both are transferred to the mandibular defect to assist titanium plate placement and fixation.[9] Unfortunately, the methods mentioned above still utilize CANSs to guide resection and fail to avoid intermaxillary fixation.

Based on previous studies, the present study further improved the process of digital mandibular reconstruction with the iliac flap. The new method has some advantages. First, mandibular resection under the guidance of ISGs avoids additional trauma caused by installing the navigation frame and shortens the surgical duration. Second, different from segmented mandible osteotomy guides in most studies, the integrated mandible osteotomy guide used in our study effectively maintains the relative position of remaining bilateral mandible after resection. It also avoids intermaxillary fixation, maintaining a stable occlusal relationship. Third, both the mandible osteotomy guide and the iliac osteotomy shaping guide contain prebent titanium plate hole information, which can accurately guide titanium plate and iliac flap placement and fixation. Finally, use of a digital scanner to obtain three-dimensional digital information about the titanium plate greatly increases the accuracy of titanium plate information conversion compared with CT, which is prone to artefacts.

Indications and Disadvantages of a Series of Digital Surgical Guides

At present, the indications for mandibular reconstruction using a series of ISGs combined with the iliac flap need to be carefully identified. This method is suitable for patients diagnosed with benign mandibular tumors, patients with a good general condition, and patients with more advanced requirements for postoperative appearance and function. This method is mostly used for patients with defects in the mandibular chin, body, and less than half of the ramus. If the defect exceeds half of the ramus, guide and prebent titanium plate placement and fixation will be more difficult. According to literature statistics, the safe iliac flap harvesting length is $\leq$10 cm.[10] Thus, the method described in this study is not suitable for large-scale mandibular defects.

Use of a series of ISGs has some disadvantages that should be highlighted. First, the preoperative preparation time is long. The preoperative preparation time for intraoperative navigation technology is 1 to 3 days, while the preparation time when using a series of ISGs is approximately 1 week. In patients with malignant tumors, this novel approach will increase the waiting time before surgery, leading to a delay in treatment. Second, the cost of treatment is high. Although the initial investment cost of intraoperative CANSs is high, the cost with each use is low. The cost of using a series of ISGs is approximately 1.5 to 2-times that of using intraoperative CANSs. We hope that the time and cost of ISGs can be reduced in the future through continuous improvement and popularization of digital technologies. Third, the strength of the prebent titanium plate decreases and cannot completely fit the corresponding bone. We hope that this problem can be solved using three-dimensional personalized titanium implants.

In summary, ISGs combined with the free vascularized iliac flap are useful for mandibular reconstruction. This approach can be applied in certain patients and has some unique advantages. The seven patients in this study obtained satisfactory postoperative results. Thus, our study suggests a new option for precise mandibular reconstruction.

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