Applying Computer Techniques in Maxillofacial Reconstruction Using a Fibula Flap: A Messenger and an Evaluation Method

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Abstract: While the application of computer-assisted maxillofacial surgery becomes increasingly popular, the translation from virtual models and surgical plans to actual bedside maneuvers and the evaluation of the repeatability of virtual planning remain to be major challenges. The objective of this study was to experiment the technique of using a resin template as a messenger in maxillofacial reconstruction involving a fibula flap. Another aim was to find a quantitative and objective method to evaluate the repeatability of preoperative planning. Seven patients who underwent maxillary or mandibular reconstruction were included in this study. The mean age was 25 years, and the mean follow-up period was 18.7 months. Virtual planning was carried out before surgery. A resin template was made according to the virtual design of bone graft through rapid prototyping technique and served as a guide when surgeons shaped the fibula flap during surgery. The repeatability of the virtual plan was evaluated based on the matching percentage between the actual postoperative model and the computer-generated outcome. All patients demonstrated satisfactory clinical outcomes. The mean repeatability was 87.5% within 1 mm and 96.5% within 2 mm in isolated bone graft. It was 71.4% within 1 mm and 89.9% within 2 mm in reconstructed mandible or maxilla. These results demonstrated that a resin template based on virtual plan and rapid prototyping technique is a reliable messenger to translate from computer modeling to bedside surgical procedures. The repeatability of a virtual plan can be easily and quantitatively evaluated through our three-dimensional differential analysis method.

Key Words: Virtual planning, resin template, postoperative evaluation, fibula flap, maxillofacial reconstruction

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The advent of microsurgery techniques has contributed to the widespread practice of one-stage maxilla and mandible reconstruction. Functional and aesthetic mandibular reconstructions after ablative tumor surgery continue to be a challenge for surgeons even after the introduction of microsurgical bone transfer. The availability of a three-dimensional computer planning software and the use of three-dimensional models in various surgical disciplines allow for an improved and more predictable reconstruction outcome.[1,2] Computer-assisted surgical planning is useful to appreciate the three-dimensional nature of lesion boundary and allows for operative maneuvers to be simulated on a computer before their implementation in the operating room.[3] Computer-assisted life-sized visual images are produced for accurate measurements and prosthesis design. These embraced the use of computer-assisted techniques in diagnosis, preoperative planning, and even in intraoperative navigation.[4]

Dissatisfactory postoperative surgical outcome and disturbed function often result in inadequate shape and location of bone graft, thereby affecting the patient's quality of life. Many surgeons concentrated their work on this procedure. Some performed a surgical design on two-dimensional images.[5] Most of them used three-dimensional images for preoperative planning,[6] whereas others used medical models.[2,7] However, the challenge remains while the need for an effective translation of computer modeling into real surgical procedures remains.

In this work, we first applied a resin template as a guide when surgeons shaped the fibula flap and thus transferred virtual information into real surgery, and then, we evaluated the reliability of this messenger

PATIENTS AND METHODS

Patients

During the period between May 2006 and May 2008, 7 patients (2 women and 5 men) accepted reconstruction by fibula flap using computer-assisted techniques at our department. The mean age of the patients was 25.1 years (range, 10–45 y). Five patients underwent primary reconstruction, and 2 patients underwent secondary reconstruction. The mean follow-up period was 18.7 (range, 7–28 mo; Table 1).

Computed Tomography

Computed tomographic (CT) scans of the head and neck regions were performed using specific parameters (field of view, 20 cm; pitch, 1.0; slice, 0.75 mm; 120–280 mA); the Digital Imaging and Communications in Medicine data were transferred to the computer work station by discs. The boundary and anatomic structure of the lesions were studied carefully on transversal, coronal, and sagittal slices. The lesion, mandible, and maxilla were three-dimensionally reconstructed separately for virtual planning by

TABLE 1. Patient Information

Patient	Sex	Age	Lesion Location	Surgery	Pathology	Reconstruction Part	Follow-up, mo
1	Female	10	Mental	Primary	Ewing sarcoma	Middle part of mandible	28
2	Female	14	Mental	Primary	Chondrosarcoma	Middle part of mandible	24
3	Male	45	Left mandible	Primary	Central carcinoma	Left ramus and body of mandible	19
4	Male	21	Left ramous	Primary	Ameloblastoma	Left ramus and body of mandible	16
5	Male	18	Bilateral maxilla	Primary	Ostosarcoma	Lower maxilla	7
6	Male	31	Bilateral maxilla	Secondary	Comminuted fracture	Lower maxilla	24
7*	Male	37	Mandible	Secondary	Squamous cell carcinoma	Middle part of mandible	13

*The third reconstructive surgery.

OsiriX, a free software that was downloaded from the Internet (OsiriX Foundation, Open Source, Geneva, Switzerland) (Fig. 1).

Virtual Planning

Patients underwent a comprehensive head examination by extirpative surgeons and an initial evaluation by reconstructive surgeons. After the surgical treatment plan was produced, both bone and soft tissue of the involved region were depicted on the reconstruction image. Virtual planning, including resection and reconstruction, was performed on a commercially available software (Surfacer Version 9; EDS Company, Plano, TX). Virtual osteotomy was done, simulating the real surgical course

Virtual reconstruction, including the shape and the location of the bone graft, was done on the virtually resected model. A"⌐" or V-shaped bone graft was applied to maxilla reconstruction, and a"⌐" or L-shaped bone graft was applied to mandibular reconstruction. The width and curvature of the graft depended on the remaining teeth and the maximum length of the donated fibula bone. The location was determined by occlusion, interarch distance, and mental maxilla protrusion. In each case, the design was discussed and modified by a team of surgeons from the extirpative, reconstructive, implantation, and prothodontics divisions (Fig. 2).

Rapid Prototyping Template

After the virtual design was agreed upon by the surgical team, a custom-made resin template was produced using rapid prototyping technique according to the computer model (Fig. 3). The end segments were always prolonged by 5 to 7 mm to allow room for adjustment during operation, but the originally designed length was also marked on the template.

Surgical Course

The fibula-free flap, sometimes with skin paddle, was harvested simultaneously with the tumor resection or defect exposure by way of a 2-team approach, as described previously.[8] Tumor resection and osteotomy were performed after the virtual plan. The boundary was examined by frozen section. The negative pathologic boundary was the same as the virtual boundary in all 5 primary cases. Physicians put the template in the defect area and modified the template according to the boundaries. In 2 cases, some minor modifications from the virtual plan were made, but the surgeons did not deviate from the plans in the other 5 cases. Then, the bone grafts were shaped consistent with the template while still pedicled in the donor field (Fig. 4).

Repeatability Test

The repeatability of the virtual plan was evaluated by comparing postoperative three-dimensional images with a virtual reconstructive three-dimensional image. Postoperative CT scan was performed 14 days after operation. Virtual images from preoperative planning and postoperative three-dimensional images were

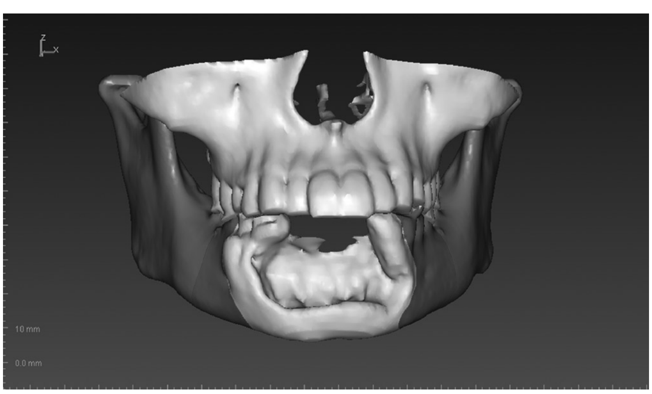

FIGURE 1. Partial three-dimensional reconstruction of the maxillofacial region. The yellow part illustrated a tumor whose boundary was defined on two-dimensional slices and segmented manually by surgeons. The purple area, 1.5 cm outside the boundary of the tumor, from left V to right VI, was to be resected as decided by extirpative physicians.

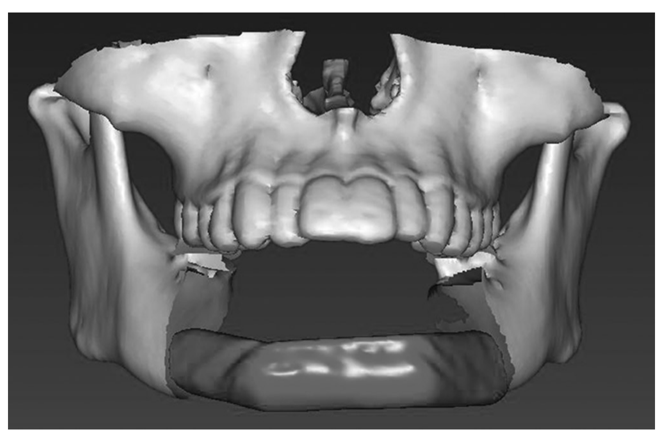

FIGURE 2. Design of the bone graft. Virtual reconstruction using the fibula model was done according to the inferior border of the original mandible and occlusion curve of the maxilla. The vertical location was determined by interarch distance; the sagittal location was determined both by mental protrusion and occlusion curve.

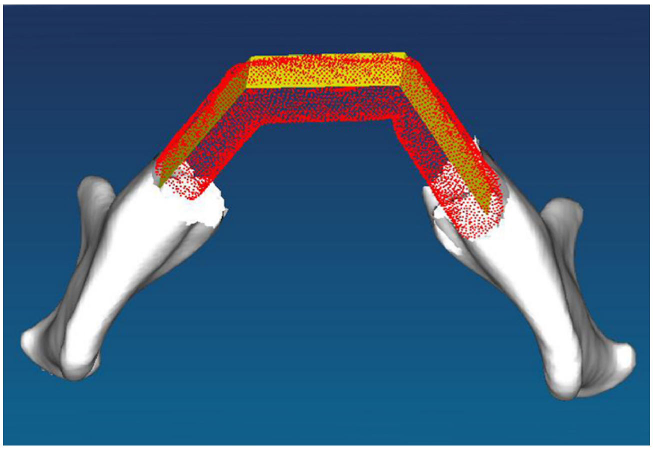

FIGURE 3. Template design. The template was designed according to the outer surface of the virtual bone graft. The red area represented the bone graft, and the yellow surface represented the template.

registered and superimposed onto each other. The program would recognize corresponding points from 2 images and highlight the superimposed image with different colors based on the distance between corresponding points. The resulting error grade color map would give a direct impression of matching between the virtual model and the postoperative model (Fig. 5). When given a certain error tolerance setting, the program would calculate the percentage of points whose deviation fell within that tolerance level, hence quantitatively analyzing the matching level. The percentage of matching was calculated in the unoperated area, usually near the calvarium, representing accuracy of registration. The matching was

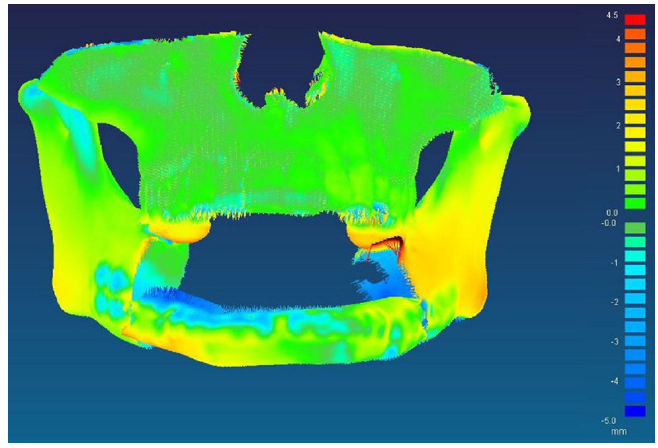

FIGURE 5. Repeatability of the virtual plan matching percentage between the virtual and the postoperative images was calculated and color coded. We could directly see where the deviation occurred (top). The maxilla was green, representing the difference of approximately 0, and registration was reliable. The difference in the yellow area was 2 mm, located mostly in the left ramus and right angle, illustrating an inside rotation of the ramus during surgery. The difference in blue area was within 1 to 2 mm, located in the right superior and left inferior borders of the graft, illustrating a slant compared with the virtual graft.

evaluated in isolated bone grafts and total reconstructed mandible or maxilla for different purposes. Matching in an isolated bone graft represented the repeatability of the shape of the virtual model, which also related to the reliability of the resin template. Matching in total

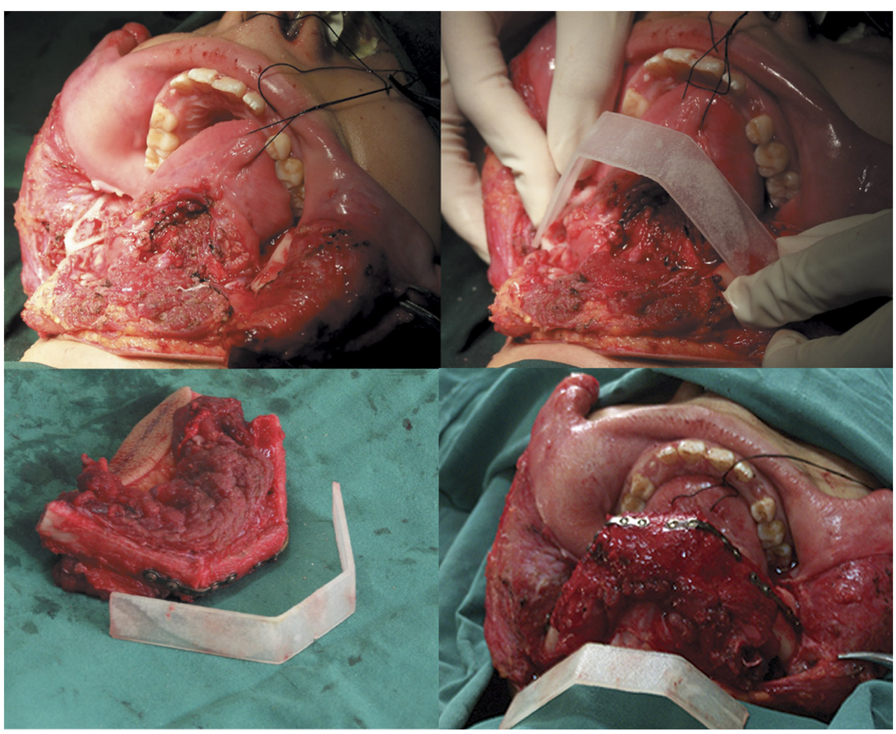

FIGURE 4. Real surgery course. Tumor resection was performed (top left), the template was placed in the defect area and modified for better fitting, the arm of the template was adjusted according to pathologic negative margin (top right), and the bone graft was shaped according to the final template (bottom left) and implanted to the defect area (bottom right).

reconstructions represented the repeatability of both the shape and the location of the bone graft.

CLINICAL REPORT AND PRESENT EXPERIENCE

Patient 1

This patient was a 10-year-old girl with Ewing sarcoma at the mental area, as identified by pathologic examination. The preoperative appearance and occlusal view were shown (Fig. 6). Because of her short stature and the low start point of the vasculature, the length of the bone segments was 9.5 cm at maximum. The position of the temporal-mandibular joint, mental protrusion, and blood supply were taken into consideration during the design of the bone graft model. The mental part was set slightly backwards, and the final design was a 3.5 × 3 × 3-cm bone graft. The surgery was successfully completed with the resin template as a guide. Satisfactory outcome was achieved, and the lateral appearance of the patient was improved (Fig. 7). No airway problem occurred.

RESULTS

Operation Outcome

Five patients had mandibular reconstructive surgery, and 2 patients had maxillary reconstructive surgery using a fibula flap as planned in the virtual condition. At a mean follow-up of 18.7 months (range, 7–28 mo), no complications occurred after surgery. All patients were satisfied with their postoperative facial appearances. One patient with mandibular reconstruction had multiple-tooth implantation.

Repeatability Evaluations

To know the effectiveness of resin template in the shaping course, we isolated the bone graft data from the postoperative three-dimensional images and calculated the variation between the real bone graft and the virtual model. Then, we registered the virtual and postoperative skull to examine the repeatability of the preoperative planning. Results are shown in Table 2.

Error Grade Color Map

The deviation of the corresponding points was calculated automatically by the computer and shown in a different color (Fig. 5). The color map in Figure 5 showed that the ramus was the area where deviation most frequently occurred, and the inside rotation was the main cause of such deviations.

DISCUSSION

Advances in imaging techniques (spiral CT and three-dimensional imaging) and associated technologies (ie, stereo models) have led to improved preoperative planning for craniomaxillofacial surgeries.[9] Most of the computational solutions have already been developed, making use of different specialized systems that introduce difficulties both in the information transfer from one stage to another and in the use of such systems by surgeons.[6,10] Intraoperative pointer-based navigation was used to navigate the

FIGURE 6. Preoperative front and lateral views (above); preoperative intraoral view of the lesion was located at the right side of the mandible, pressing the teeth to the lingual side (below).

FIGURE 7. Two years after surgery, mental protrusion is stable and satisfactory.

contours of the anatomic region and to check the new contour in a real-time manner.[9] However, the stringent requirement on both software and hardware limit the spread of the navigation system. Yeung et al[11] described a method of using acrylic locating splints as a guide to shape the fibula flap. This splint was based on model surgery.

In this work, we applied a resin template based on virtual planning. The satisfactory repeatability of isolate segments, 87.5% within 1 mm and 96.5% within 2 mm, proved that the resin template was sufficient and reliable as a messenger. This result seemed better than that of the navigation system registered by anatomic landmarks of 2 to 5 mm.[12] It was also comparable with the result by Metzger et al.[13] They reported that with the help of a navigation system, a mean difference of 1.49 mm with a maximum modulus of 2.49 mm was achieved in orbital floor reconstruction, and a mean difference of 4.12 mm with a maximum modulus of 5.87 mm was achieved in zygomatic arch reconstruction. To our experience, the template was flexible, easy to handle, carried enough information to guide the physician as a three-dimensional fibula model, and convenient to handle during the operation. The template could be easily modified or rebuilt to meet the alternative boundary during surgery.

However, in our study, a greater variation occurred when we considered the total reconstructed bones. A plausible explanation could be that the ramus rotated when the continuity of the mandible was disturbed by osteotomy.

Apart from investigating the use of a custom-made template as a messenger, we also tried to find a quantitative evaluation system to measure the consistency between the virtual and real

TABLE 2. Matching Percentage Under Different Tolerance

	Matching Percentage, Mean % (Range)			
Tolerance, mm	**1**	**2**	**3**	**4**
Bone graft	87.5 (81.4–91.5)	96.9 (94.2–99.4)	100	100
Registration	96.9 (95.1–98.4)	99.4 (99.1–99.9)	100	100
Reconstructed bone	71.4 (63–79.8)	89.8 (86.3–93)	98.9 (97.9–99.9)	100

Bone graft indicates matching percentage in isolated bone graft; registration, the percentage of matching calculated in the unoperated area, usually near the calvarium, representing the accuracy of registration; reconstructed bone, matching in total reconstructions represented repeatability of both the shape and the location of the bone graft.

postoperative images and thus evaluate the reliability of the resin template. Many authors evaluated the outcome of surgery by detailed measurements on two- or three-dimensional images.[8,12,14] Our evaluation technique was based on registration and comparison of three-dimensional images from postoperative and virtual planning models. A registration tool allowed us to relate these 2 images under one coordinate system. We measured the matching percentage between the virtual and the postoperative images on the unoperated area, isolated bone graft, and reconstructed mandible or maxilla. The close matching of the unoperated area indicated the reliability of the registration. The differences between the corresponding points in the 2 images were calculated automatically by the computer. In our experience, this method was more convenient and accurate than complicated measurements by physicians. When physicians typed in a certain error tolerance, according to their different requirements, in the dialogue box, the percentage of matching could be calculated by a computer. The deviation was coded by a different color; thus, the area of the worst and best matchings could be seen directly.

This method based on three-dimensional registration and difference analysis could give physicians both quantitative and visual information; we supposed it can be further used to evaluate other kinds of maxillofacial surgery.

Despite the reliability proved by our results, resin template had limitations. It did not offer enough guidance for the orientation and position of insertion when physicians tried to fit the bone graft into the defect area, especially in mandibular reconstruction. This limitation was detected by a lower matching percentage of the reconstructed maxilla or mandibular. We are still on our way to find an easy and effective way to guide the bone graft into its correct position.

CONCLUSIONS

Resin template based on virtual design and rapid prototyping technique is a reliable messenger for information transfer between virtual and real surgery. Three-dimensional evaluation based on registration and difference analysis is a quantitative and convenient way to analyze operation outcome.

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