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Improving the accuracy of mandibular reconstruction with vascularized iliac crest flap: Role of computer-assisted techniques

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ABSTRACT

While vascularized iliac crest flap is widely used for mandibular reconstruction, it is often challenging to predict the clinical outcome in a conventional operation based solely on the surgeon's experience. Herein, we aimed to improve this procedure by using computer-assisted techniques. We retrospectively reviewed records of 45 patients with mandibular tumor who underwent mandibulectomy and reconstruction with vascularized iliac crest flap from January 2008 to June 2015. Computer-assisted techniques including virtual plan, stereomodel, pre-bending individual reconstruction plate, and surgical navigation were used in 15 patients. The other 30 patients underwent conventional surgery based on the surgeon's experience. Condyle position and reconstructed mandible contour were evaluated based on post-operative computed tomography. Complications were also evaluated during the follow-up. Flap success rate of the patients was 95.6% (43/45). Those in the computer-assisted group presented with better outcomes of the mandibular contour ($p = 0.001$) and condyle position ($p = 0.026$). Further, they also experienced beneficial dental restoration ($p = 0.011$) and postoperative appearance ($p = 0.028$). The difference between postoperative effect and virtual plan was within the acceptable error margin. There is no significant difference in the incidence of post-operative complications. Thus, computer-assisted techniques can improve the clinical outcomes of mandibular reconstruction with vascularized iliac crest flap.

1. Introduction

Oral and maxillofacial surgeons are often faced with the challenging task of achieving functional and cosmetic reconstruction of mandibular defects after tumor ablation. Nowadays, vascularized bone grafts have become the first choice for mandibular reconstruction because of the associated high survival rates and satisfactory long-term outcomes. Free fibula flap and free iliac crest flap are most widely used (Hidalgo, 1989; Disa and Cordeiro, 2000; Munoz Guerra et al., 2001; Lyons et al., 2005). The iliac crest flap is more favorable than the free fibula flap for some surgeons because of the large amount of bone volume, rich cancellous blood supply, and compact cortex, which make it an ideal choice for plate fixation and implant placement for dental restoration (Munoz Guerra et al., 2001; Lyons et al., 2005).

The free iliac crest flap is also known as deep circumflex iliac artery (DCIA) flap, which was first introduced for mandibular reconstruction by Taylor in 1979 (Taylor et al., 1979). Traditionally, surgeons have had to use their experience and skill to determine the method of performing osteotomy and graft harvesting and shaping. The functional and cosmetic outcomes are sometimes dissatisfactory owing to the inaccuracy of the reconstruction procedure.

With the rapid development of radiological and digital technologies, computer-assisted techniques have been widely used in oral and maxillofacial surgeries. Techniques such as virtual surgical plan, rapid prototyping, and surgical navigation could offer more effective and predictable outcomes (Cinquin et al., 1995; Schubert et al., 2002; Fernandes and DiPasquale, 2007; Yu et al., 2010). Therefore, the aim of our study was to evaluate the benefit of computer-assisted mandibular reconstruction using free iliac crest flap with respect to the functional and cosmetic results.

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2. Material and methods

2.1. Patient demographics

Between January 2008 and June 2015, 45 patients (21 men, 24 women) with mandibular tumors underwent mandibulectomy and simultaneous reconstruction with free iliac crest flaps at our institute. The inclusion criteria were as follows: (1) mandibular pathology required for mandibulectomy, (2) simultaneous mandibular reconstruction with free iliac crest flap, and (3) the lesion should have only invaded the mandibular body and part of the ramus of the mandible so that the condyle could be preserved. Patients with a history of tumor ablation and jaw reconstruction were excluded.

The patients were divided into two groups: those who underwent computer-assisted surgery (n = 15; mean age, 36.7 ± 17.5 years) and those who underwent reconstruction based on the surgeon's experience (n = 30; mean age, 36.4 ± 13.2 years). All patients in the computer-assisted surgery group had benign tumors, of which 10 were ameloblastomas and the other 5 were ossifying fibromas. In the other group, 26 patients had benign tumors and 4 had malignant tumors. Patients in both groups were followed up for at least 6 months. No local recurrence occurred, and all patients lived without disease until the last follow up (December 2015) (Table 1).

2.2. Virtual planning

Preoperative virtual planning was performed in the computer-assisted surgery group. Computed tomography (CT) of the head, neck, and iliac bone were performed (field of view, 20 cm; pitch, 1.0; slice, 0.75 mm; 120Y280 mA). The CT data of head and neck in the Digital Imaging and Communications in Medicine (DICOM) format were imported to the ProPlan CMF software (ProPlan CMF, Materialise NV, Leuven, Belgium). First, the mandible and maxilla were segmented. Then, we performed virtual mandibulectomy according to clinical and 3D radiological examination and evaluation (Fig. 1). Meanwhile, the CT data of the iliac bone was also imported to the ProPlan CMF software and the donor site was segmented, following which we superimposed the 3D iliac image on the mandibular defect in its desired orientation according to the ideal mandibular contour (Fig. 2). If the contour of the mandible was destroyed by the tumor, mirroring image based on the unaffected side was used to form the ideal mandibular contour. After the computer-assisted virtual plan was generated, an ideal reconstructed stereomodel was manufactured using 3D printing technology. A reconstruction plate was prebent and fixed on the reconstructed mandibular model using titanium screws (Fig. 3). In addition, the designed part of the iliac crest was printed as a resin model, in order to make an iliac crest-cutting template with thermoplastic resin to guide the harvest and molding of the iliac flap (Fig. 4).

Next, the mandibular model with the reconstruction plate was subjected to CT scanning (field of view, 20 cm; pitch, 1.0; slice, 0.75 mm; 120Y280 mA), and the CT data were imported to the ProPlan CMF software in DICOM format. The model was segmented and registered with the reconstructed mandible that we had previously virtually designed. The positions of the titanium screws were marked for the accuracy of locating the plate during surgery.

Finally, all the planned data was transferred into iPlan CMF 3.0 software (Brainlab, Feldkirchen, Germany) and an individual navigation protocol was generated for presentation during the surgery.

2.3. Surgical procedure

In the computer-assisted surgery group, tumor resection and mandibulectomy were performed according to the virtual plan, completely guided by a computerized navigation system (BrainLAB, AG, Feldkirchen, Germany). The osteotomy lines were confirmed and marked by the navigation system (Fig. 5). After the tumor resection and mandibulectomy, the occlusion was fixed by the arch bar and the osteotomy site would be confirmed again by the surgical navigation. Then, the reconstruction plate was fixed on the remaining mandibular segment guided by the navigation system, according to the six marked points indicating the position of the titanium screws (Fig. 6). The donor site was ipsilateral to the maxillectomy site. The iliac crest flap was harvested, as described by Taylor et al. (1979), simultaneously with the mandibulectomy. The flap was harvested and molded by the resin model and cutting template as mentioned earlier (Fig. 4). The flap was transferred to the recipient site, and the pedicle was placed within a tunnel in the submandibular region to promote anastomosis. The three-dimensional position was confirmed to match the position in the virtual plan by using the navigation system (Fig. 6).

In the traditional surgery group, tumor resection and mandibular reconstruction were based on the surgeon's experience without any virtual planning or model design. The flap was fixed to the mandibular segment with reconstruction plate or mini plate (12 reconstruction plates and 18 mini plates) based on the surgeon's decision.

2.4. Outcome evaluation

Postoperative CT scan was performed for all patients. Both the preoperative and postoperative CT data were imported into

Table 1
Patient characteristics.

Groups		Computer-assisted group (n = 15)	Traditional group (n = 30)
Age (years)		36.7 ± 17.5	36.4 ± 13.2
Gender	M/F	6/9	15/15
Primary disease	Ameloblastoma	10	15
	Ossifying fibroma	5	7
	Odontogenic myxoma	0	3
	Odontogenic ghost cell tumor	0	1
	Gingival carcinoma	0	3
	Osteosarcoma	0	1
Type of plate	Reconstructing plate	15	12
	Mini plate	0	18
Complications	Flap failure	1	1
	Plate exposure	0	0
	Plate breakage	0	0
	Infection	1	3
	Malocclusion	0	2

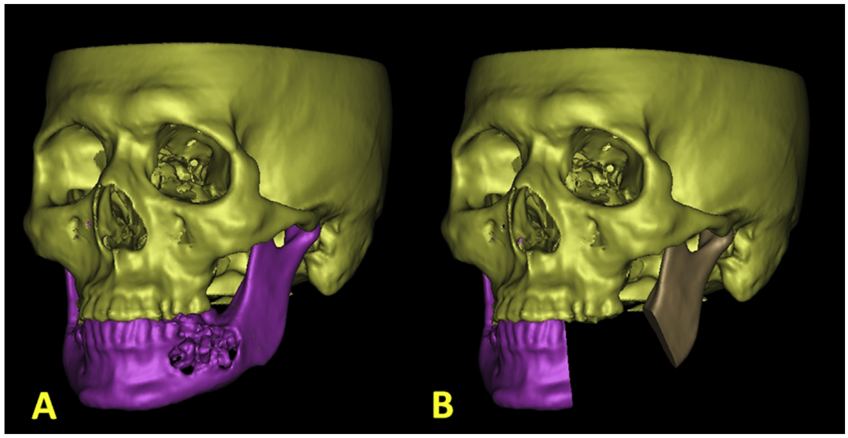

Fig. 1. Generation and segmentation of 3D skull model (A) and virtual mandibulectomy (B) on ProPlan CMF software.

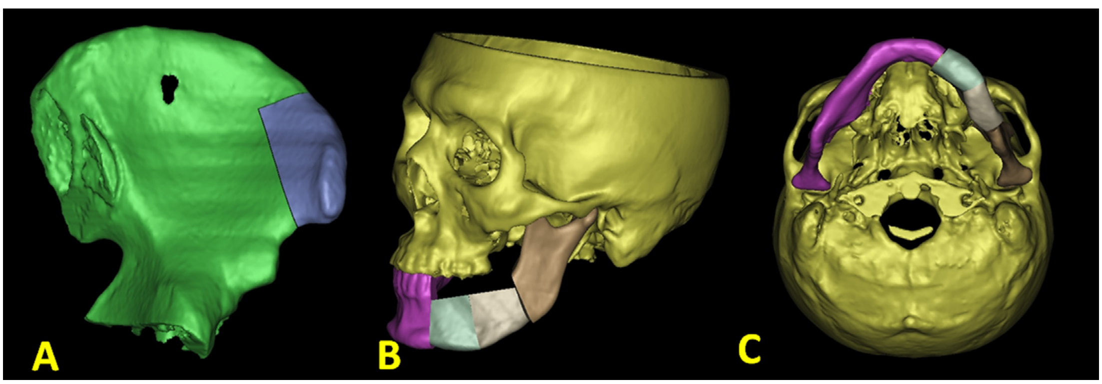

Fig. 2. Generation and segmentation of the donor iliac crest (A) and simulating the mandibular reconstruction with iliac crest flap (B and C) on ProPlan software.

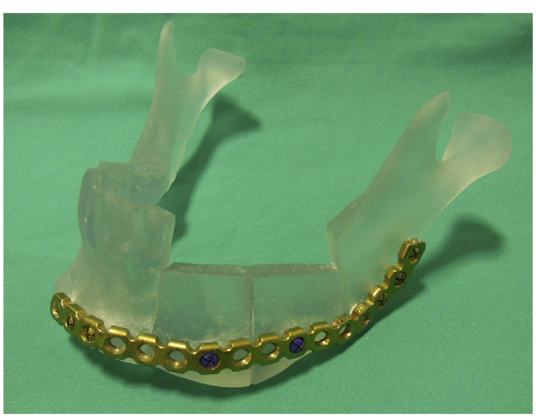

Fig. 3. A stereomodel of the reconstructed mandible was printed and an individual titanium reconstruction plate was pre-bent and fixed on the model.

Geomagic Qualify/Studio software (Geomagic, Cary, NC, USA). The preoperative and postoperative mandibular images were registered and compared with each other. The preoperative and postoperative data of the whole skull will be imported into the software as STL format. The maxilla part and the unaffected side of mandible were matched to each other, then the difference on the reconstructed side was evaluated on the chromotography. The difference was generated by the software. The differences of the condyle position and the contour of the lower mandibular border on the reconstructed side were analyzed and calculated using chromatographic analysis on Geomagic (Fig. 7). Meanwhile, for the patients in the computer-assisted group, we also compared the difference between the postoperative image and the preoperative virtual planned image (Fig. 8). For each mandible, there were always two osteotomy lines. The osteotomy line anterior to the lesion was defined as the "anterior osteotomy line," while the one posterior to the lesion was the "posterior osteotomy line." When the two images matched with each other, we evaluated and calculated the difference of these two osteotomy lines, as well as the condyle position and the contour of the mandible's lower border. Furthermore, cosmetic appearance was self-evaluated and scored by the patients, and the results were classified as satisfactory (8–10), fair (4–7), and poor (0–3).

All the patients were followed up at least for 6 months. Postoperative complications such as plate breakage, plate exposure, infection, and malocclusion were evaluated and recorded. The patients were offered dental implantation or traditional denture prosthesis at 6 months after surgery. The condition of dental restoration was also recorded. All statistical analyses were performed using SPSS 17.0 (SPSS Inc., Chicago, Illinois, USA).

3. Results

The overall flap success rate was 95.6% (43/45), with only two flap failures, one in each group. For the patients in the computer-assisted group, free iliac crest bone graft was performed as the secondary surgery. While in the traditional surgery group, the flap was removed and the reconstruction plate was retained for cosmetic purposes. At the mean follow up time of 44.0 ± 21.8

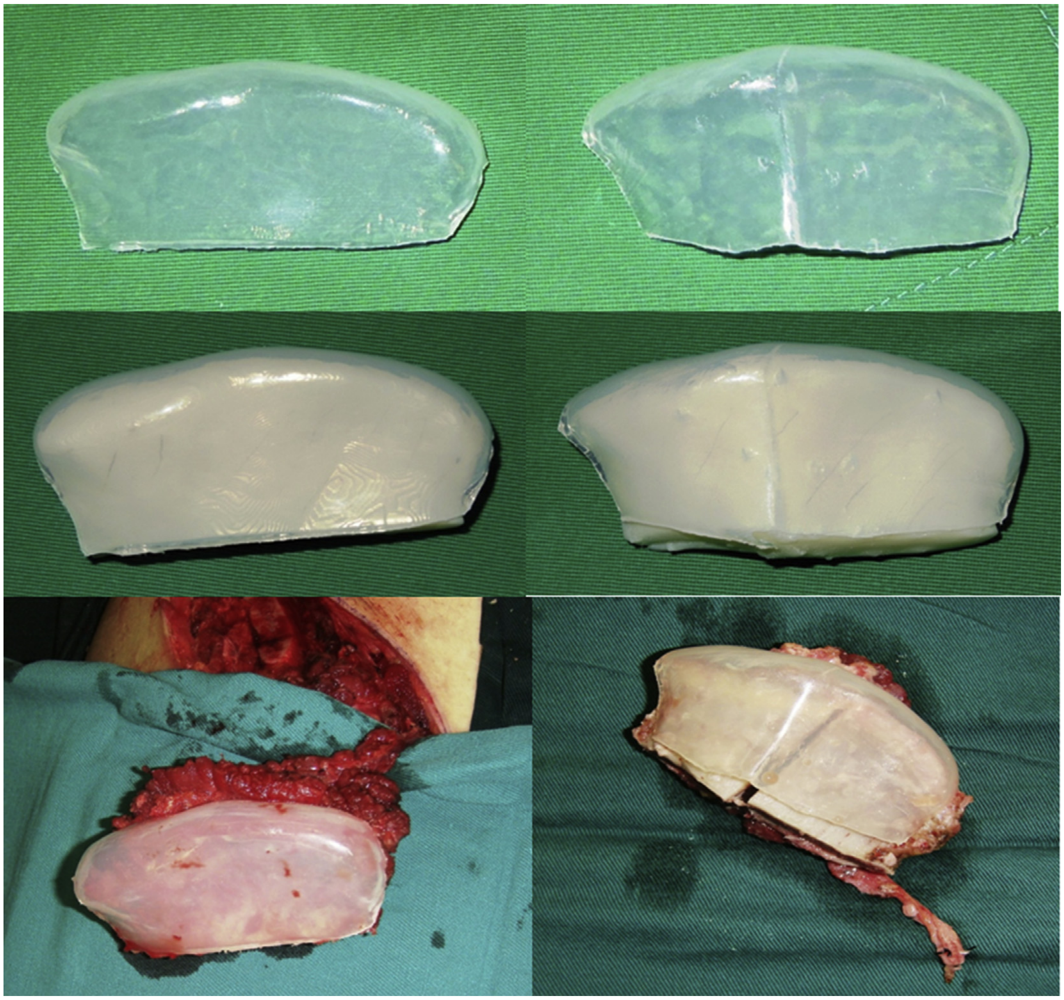

Fig. 4. A stereomodel of the iliac crest was printed to make a cutting template with thermoplastic resin to guide the harvesting and molding of the flap.

months (range, 6–98 months), postoperative complications were evaluated in both groups. In the computer-assisted group, only one patient presented with local infection in the submandibular area and was cured after general antibiotic therapy and local treatment that comprised changing the dressing and wound irrigation. No other complications such as plate breakage or exposure and malocclusion were detected. While in the traditional surgery group, three patients presented with local infection and were cured with

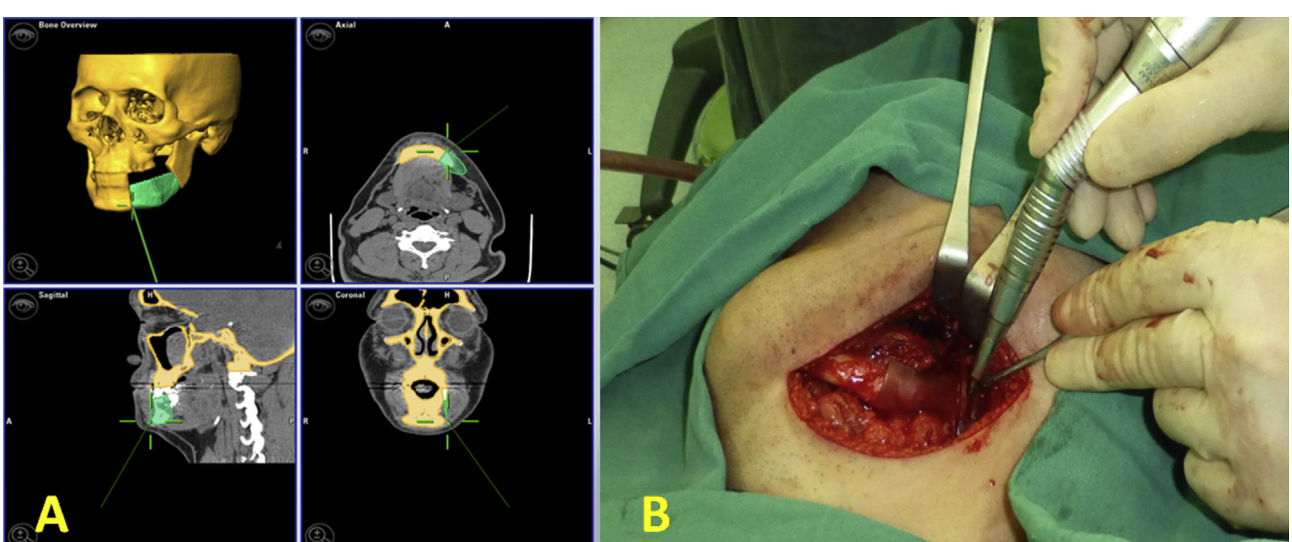

Fig. 5. Using the navigation system to confirm position of the osteotomy line (A) and performing mandibulectomy and tumor resection (B).

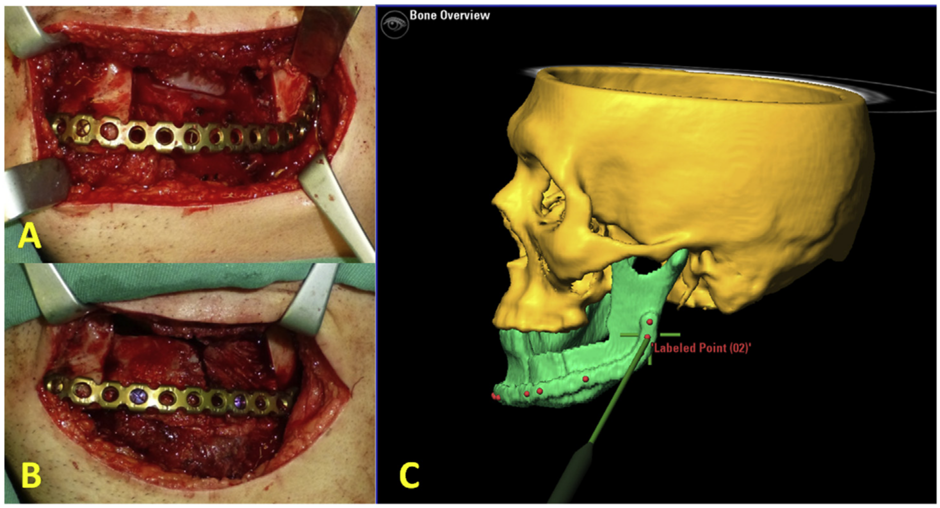

Fig. 6. The reconstruction plate is fixed to the mandible (A) and the molded flap is fixed into the defect (B), guided by navigation system (C).

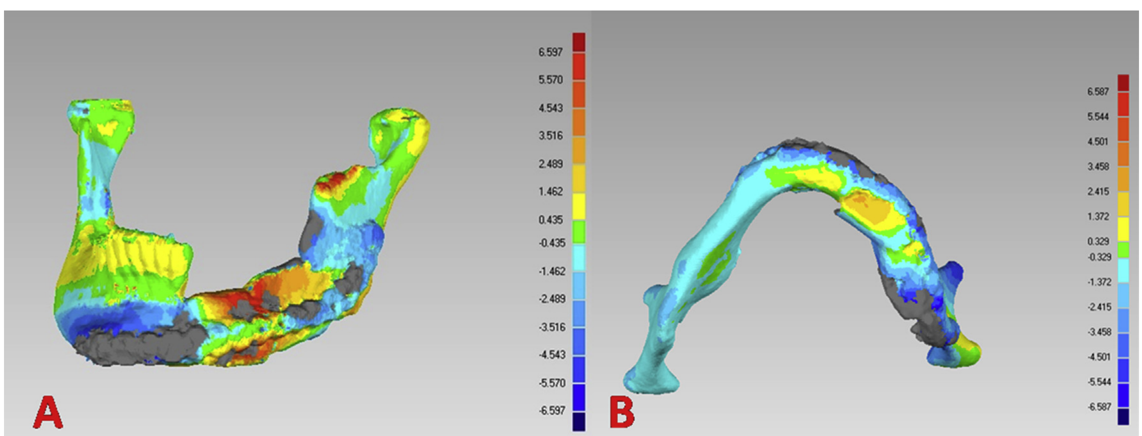

Fig. 7. The difference of the condyle position and the mandibular contour between the preoperative and postoperative mandible image is evaluated by chromatographic analysis method with the Geomagic Qualify software.

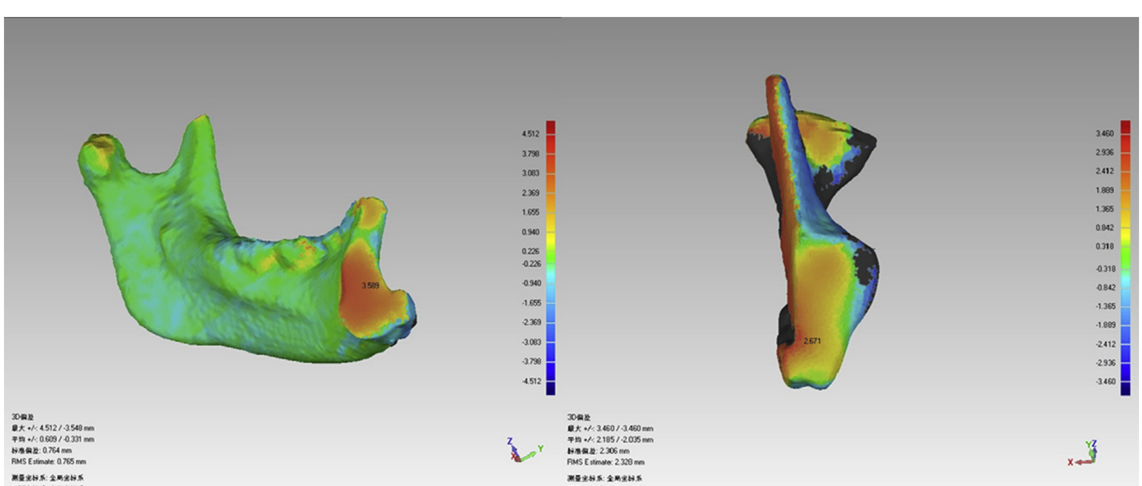

Fig. 8. The difference of the condyle position and the osteotomy line between the postoperative mandible image and the virtual planned image is evaluated by chromatographic analysis method with the Geomagic Qualify software.

Table 2
Postoperative outcome evaluation between the two groups.

Groups	Computer-assisted group (n = 15)	Traditional group (n = 30)	p Value
Length of defects	6.2 ± 1.0 cm	5.9 ± 1.0 cm	0.261
Difference of condyle position	2.0 ± 0.6 mm	2.5 ± 0.6 mm	0.026
Difference of the lower border of mandible	3.7 ± 1.0 mm	5.1 ± 0.9 mm	<0.01

antibiotic and local therapy. Malocclusion occurred in two patients in this group, and occlusion adjustment was surgically performed by using prosthesis. Plate breakage or exposure was not detected in this group either (Table 1).

All patients received postoperative CT scan at the 6-month follow up after surgery. For patients in both groups, the preoperative and postoperative CT data of the mandible were imported to the software. In the computer-assisted group, the average length of defects was 6.21 ± 0.96 cm, while that in the traditional surgery group was 5.85 ± 1.03 cm ($p = 0.261$). When the two images matched with each other, the average condyle shift on the reconstructed side was 2.03 ± 0.56 mm in the computer-assisted group and 2.45 ± 0.57 mm in the traditional surgery group ($p = 0.026$). The average difference of the lower border contour of the mandible was 3.72 ± 1.01 mm in the computer-assisted group and 5.10 ± 0.90 mm in the other group ($p < 0.01$). The results indicated that patients in the computer-assisted surgery group presented with better condyle position and mandibular contour than the other group (Table 2).

In the computer-assisted group, we compared the postoperative CT image of the mandible with the virtually planned image to identity the accuracy and reliability of the computer-assisted clinical procedure (Table 3). The average shifts of the anterior and posterior osteotomy lines were 0.70 ± 0.16 mm and 1.47 ± 0.37 mm, respectively. In these patients, the condyle shift was 1.45 ± 0.50 mm and the average lower border difference was 1.92 ± 0.34 mm when compared with the planned mandible images. This difference showed an acceptable and reliable result of the computer-assisted clinical procedure.

Owing to the long-term follow up, about 80% (12/15) of patients in the computer-assisted group received dental restoration, while only less than half (12/30) of the patients in the other group had a new denture ($p = 0.011$). For the patients who underwent dental restoration, both implants and traditional dentures were found acceptable ($p = 0.219$) (Table 4).

All the patients in the computer-assisted group reported positive results with the post-surgical facial symmetry and appearance In contrast, only half of the patients receiving traditional surgery were satisfied with their postoperative appearance; three patients felt upset with their post-operative appearance. These results proved that computer-assisted surgery had significant esthetic benefits (Table 5).

Table 3
Postoperative outcome evaluation in the computer-assisted group.

Difference of	Maximum	Average
Anterior osteotomy line	1.2 ± 0.2 mm	0.7 ± 0.2 mm
Posterior osteotomy line	2.1 ± 0.4 mm	1.5 ± 0.4 mm
Condyle position	2.3 ± 0.5 mm	1.5 ± 0.5 mm
Contour of lower border	3.3 ± 0.5 mm	1.9 ± 0.3 mm

Table 4
Condition of dental restoration of patients in both groups.

Groups	Computer-assisted group (n = 15)	Traditional group (n = 30)	p Value
With dental restoration			
Implant	7 (46.7%)	4 (13.3%)	0.219
Denture	5 (33.3%)	8 (26.7%)	
Without dental restoration	3 (20.0%)	18 (60.0%)	0.011

Table 5
Cosmetic outcome of patients in both groups.

Outcomes	Computer-assisted group (n = 15)	Traditional group (n = 30)	p Value
Satisfied (8–10)	13	15	0.028
Fair (4–7)	2	12	
Poor (0–3)	0	3	

4. Discussion

Mandibular defect due to tumor ablation is a very common occurrence in oral and maxillofacial surgery. The goals of functional mandibular reconstruction are: (1) recovering the cosmetic contour of the lower 1/3 of the face; and (2) rehabilitating accurate occlusion and masticatory function. Thus, successful bone grafting is the key for mandibular reconstruction. Nowadays, vascularized bone graft has become the first choice for mandibular reconstruction because of the high survival rate and satisfactory long-term outcomes. Free fibula flap and free iliac crest flap are most widely used over time (Hidalgo, 1989; Disa and Cordeiro, 2000; Munoz Guerra et al., 2001; Lyons et al., 2005).

The free iliac crest flap was first used for mandible reconstruction by Taylor in 1979. Although accepted and used by many surgeons, the difficulty of harvesting and molding as well as the donor-site morbidity became the chief limitations of using this flap. In recent years, the free fibula flap has been more widely used for mandible reconstruction because of the relatively feasible procedure for harvesting and molding. However, the free iliac crest flap was still an important choice for mandible reconstruction owing to the following advantages. First, the natural contour of the iliac crest fitted the contour of the mandible better than fibula segments and could achieve better cosmetic effect, especially when used for reconstruction of mandibular body. Second, the iliac crest contained a large amount of bone with rich cancellous blood supply and compact cortex, which make this graft an ideal choice for plate fixation and dental implant placement during dental rehabilitation (Riediger, 1988). Besides, surgeons could refrain from using difficult techniques such as double-barrel or distraction osteogenesis (Klesper et al., 2002; Wang et al., 2015).

In traditional surgery of mandible reconstruction with the iliac crest flap, mandibulectomy, flap harvest and molding, and the reconstruction procedure were entirely based on the surgeon's experience. It was challenging to accurately evaluate the preoperative length and contour of the defect based only on panoramic radiographs and CT images. Thus, surgeons needed to harvest a large piece of the iliac bone flap prepared for reconstruction, which increased the difficulty of flap harvest and molding, as well as the duration of the operation. Furthermore, the three-dimensional position of the iliac bone segment was also difficult to determine because of the mobility of the mandible segment retained on both sides. Although an acceptable result could be achieved at times with a well-experienced surgeon, most patients were unsatisfied, especially when presented with the postoperative 3D image. Not only was the symmetry difficult to achieve but also the normal occlusion and position of the bone segment for accurate rehabilitation, which lead to further challenges in dental restoration (Fig. 9).

Computer-assisted techniques were developed and applied in oral and maxillofacial surgery in the 1990s. Nowadays, it has found wide application in several oral and maxillofacial surgeries such as orthognathic and trauma and reconstructive surgeries (Cinquin et al., 1995; Nakayama et al., 2004; Fernandes and DiPasquale, 2007; He et al., 2009; Cordeiro and Chen, 2012a, 2012b; Zhang et al., 2015). Recently, many studies have reported the application of computer-assisted techniques for maxillary and mandibular reconstruction with free fibula flap, with more accurate reconstruction than traditional surgery (Hohlweg-Majert et al., 2005; Bell, 2010; Austin and Antonyshyn, 2012). Thus, we created a modified approach for mandibular reconstruction with vascularized iliac crest flap as described above (Yu et al., 2016). In our study, computer-assisted techniques also played an important role in promoting the accuracy of mandibular reconstruction with free iliac crest flap.

In computer-assisted surgery, the first step was laying a virtual plan. The whole procedure of surgery was simulated in software as 3D images. A three-dimensional view of the lesion was evaluated and the plan of mandibulectomy could be made objectively and precisely. Then, the length of defect could be measured, which determined the bone graft we needed on the donor site. We could also choose the part of iliac crest that matched the contour of the defect and adjusted it to the ideal position for dental restoration. An individual model of grafted iliac bone and a cutting guide based on the data of this virtual plan helped greatly in flap harvesting and molding, which significantly decreased the difficulty and duration of operation.

There are two main methods for transferring the pre-operative virtual design to the real surgery on the patients: CAD/CAM guides and navigation system. Nowadays, all kinds of resection and cutting guides became very useful and popular in mandibular reconstruction surgery. Wilde et al. (2012, 2015a) invented a transfer-key together with a patient-specific pre-bent reconstruction plate in vitro study and used for mandibular reconstruction. The results of their clinical trial indicated that the transfer-key method was effective and produced more accurate reconstruction results than standard method. Furthermore, a patient-specific CAD/CAM reconstruction plate and resection and cutting guides were also introduced for mandibular reconstruction (Wilde et al., 2014, 2015b). The study provided a broad range of opportunities and benefits for mandibular reconstruction patients compared with the traditional clinical procedure. However, there were still some limitations for these kinds of methods. Firstly, all the CAD/CAM products such as resection and cutting guides as well as CAD/CAM reconstruction plate were designed and manufactured based only on bone tissues. During the surgery, soft tissue that attached to and around the bone could be a non-negligible factor affecting the accuracy of the results. Sometimes, the guides or plate could not be located easily and the incisions needed to be extended leading to enlarged damage to the normal tissue. In some cases such as extensive ameloblastoma or malignancy, the cortex of the mandible was damaged and the mandible was no long in normal contour. The resection guides or transfer-key methods may not be suitable in these situations. Secondly, the CAD/CAM procedure was time and resource consuming compared with traditional surgery or even navigation surgery. The 3D printed guides and plates would increase the cost to the patients (Wilde et al., 2015b).

The computer navigation system provides another virtual-reality bridge for computer-assisted surgeries and is widely used in oral and maxillofacial surgeries (Hohlweg-Majert et al., 2005; Bell, 2010; Yu et al., 2010; Austin and Antonyshyn, 2012). However, it was not considered useful for mandibular reconstruction, because it was difficult to control mandibular mobility. The position of the mandible must be maintained at the right occlusal relation before and during the surgery. There are several solutions to this problem. First, intermaxillary fixation should be maintained during CT and surgery, although this is not feasible for surgeries that employ an intraoral approach. Second, the mandible should be placed in centric relation or centric occlusion, either manually or using a dental splint. Although mandibular movements are convenient for surgery, they undermine the accuracy of intraoperative navigation. Third, we could use a special sensor frame fixed on the mandible. Because of the synchronization between the sensor frame and the mandible, the surgeon can track the jaw position without increasing the navigation error. Although this procedure is time consuming, it provides the theoretical advantage of improved accuracy by facilitating direct monitoring of the mandibular position, rather than determining the position in relation to other fixed cranial structures (Bell et al., 2011). In our study, we selected the second solution to overcome the limitation of mobility. An individual occlusal splint was manufactured for each patient; the mandible was placed in centric relation using the

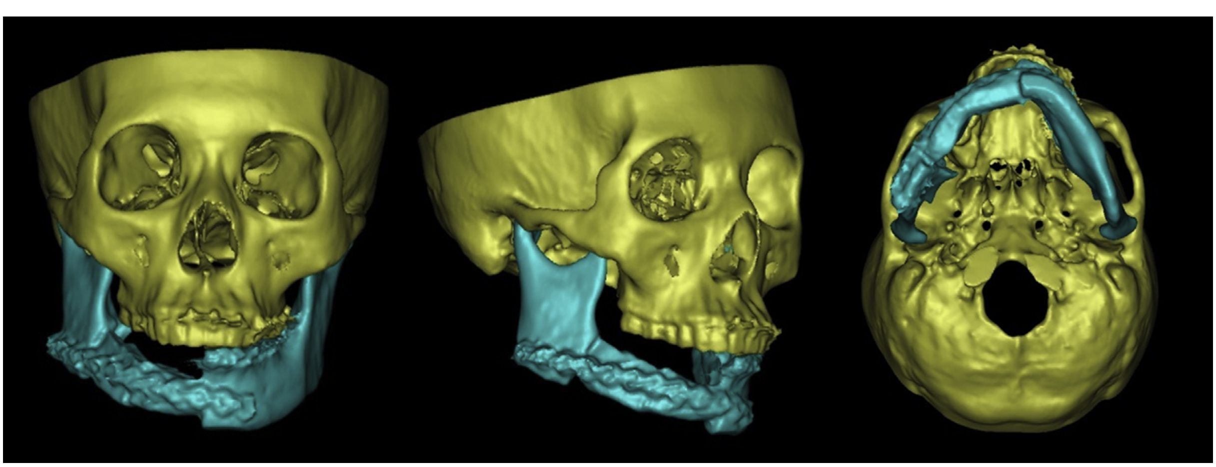

Fig. 9. In traditional surgery, the position of the grafted bone and the mandible segment is challenging to control; hence, satisfactory cosmetic and functional outcome cannot be achieved.

splint when performing the CT scan. During the surgery, this splint was used to maintain the central position of the mandible when the navigation was applied.

As mentioned earlier, rehabilitation of normal occlusal relation is important for functional mandibular reconstruction. In traditional surgery, intermaxillary fixation is usually used to maintain the mandibular position. However, after mandibulectomy, it may be impossible to fix the free part of the mandible without enough teeth. Thus, the fixation of the mandible and the grafted bone depend totally on the surgeon's experience without any accuracy control. This may result in a negligible shift of the condyle and malocclusion or even temporomandibular joint problems after surgery. Marchetti et al. (2006) showed several different preplating techniques to maintain the position of the free segment of mandible before mandibulectomy. However, these methods are associated with increased surgical duration and risk of additional iatrogenic trauma to the patient. In this study, we intended to improve this procedure with an individual pre-bent reconstruction plate combined with navigation in surgery. The individual reconstruction plate was pre-bent on the stereomodel of reconstructed mandible based on the data of virtual plan. The stereomodel fixed with the reconstruction plate could be seen as the ideal result of the reconstruction. We subjected this ideal model and reconstruction plate to another round of CT scanning and imported the reconstruction plate image to the computer for navigation. During the surgery, we matched the position of all three screws on both sides guided by navigation, so that the ideal position of reconstruction plate could be achieved. This method had several advantages over the traditional method: (1) the position of the mandible on both sides could be confirmed by surgical navigation, thus improving the accuracy of the surgery; (2) the duration of both the reconstruction procedure and transplant ischemic time deceased; (3) the error was double checked and could be minimized by verifying the position of both the mandible and reconstruction plate. However, compared with the drill and resection guides or the transfer-key method (Wilde et al., 2012, 2014), the navigation-guided plate positioning procedure may be more time consuming. The surgeons needed to be with enough patience to match and confirm each drill holes on the mandible with the reconstruction plate. Besides, since the reconstruction plate was scant before surgery and included in the navigation plan, the reconstruction plate itself could be seen as a guide for fixation. Once all the position of the holes were confirmed by navigation, the position of the plate and mandible could be confirmed. When the procedure was conducted carefully and critically, the mandible could be fixed at the ideal position. In our cases, the condyle position was maintained within an error of 2–3 mm and the results of accurate reconstruction were achieved. Since there was still lacking study comparing the accuracy on mandibular reconstruction between surgical guide and navigation. We believe this clinical procedure provided an effective and feasible method for mandibular reconstruction based on our results.

In traditional surgery, no virtual plan or navigation is used. Mandibulectomy and reconstruction typically depend on experience. The position of the mandible was fixed by intermaxillary fixation with an arch bar. Both reconstruction and mini plates could be used for fixation. With the development of vascularized bone graft, the methods of rigid internal fixation have been widely reported (Urken et al., 1998; Shaw et al., 2004; Azuma et al., 2014; Sieira Gil et al., 2015). Despite controversies, both reconstruction and mini plates have been used in mandible reconstruction. The principle of the choice should be based on the effect of fixation and long-term complication (Urken et al., 1998). Urken et al. (1998) preferred reconstruction plate for mandible reconstruction and suggested that it helped retain the condyle position and rehabilitate the contour of mandible better than a mini plate did. Shaw et al. (2004) compared the effect of mandible reconstruction with both reconstruction and mini plates and suggested no significant difference between the two methods with respect to fixation and complications. In our study, reconstruction plates were used in all patients in the computer-assisted group as described above. In the traditional surgery group, both reconstruction and mini plates were used for fixation. We did not encounter any fixation problem with either plate type, and complications were seldom found in the long-term follow up.

The computer-assisted techniques were used not only for surgical design and practice but also for outcome evaluation. The outcome of the study was evaluated with regard to two aspects. First, the effect of this clinical procedure was evaluated by comparing the results of two groups. Functionally, the condyle could be maintained at the physical position with a significantly smaller shift in the computer-assisted group and no malocclusion occurred in this group of patients. However, in the traditional surgery group, an obvious change of condyle position was found because of the inaccurate control of the mandible during surgery. Besides, computer-assisted surgery provided an ideal position for dental restoration, and 80% of the patients in this group had a new denture. Owing to the favorable characteristics of the iliac bone, nearly half of the patients could receive dental implantation. On the other hand, most patients who underwent traditional surgery had difficulty in dental restoration. Cosmetic results were also evaluated between the two groups. When we matched the preoperative and postoperative mandible image, the computer-assisted group showed a significantly smaller difference. In subjective evaluation, patients in the computer-assisted group greatly preferred their post-operative appearance than those in the other group. These results indicate that the clinical procedure of computer-assisted techniques could improve the clinical effect and outcome of mandibular reconstruction with free iliac crest flap.

Second, we also evaluated the accuracy and reliability of this method. We compared the postoperative mandible image with the virtual-planned mandible image to determine whether and how well we achieved our aim. We measured the difference between two osteotomy lines, the position of the condyle, and the mandibular contour. Considering the inevitable systematic error of navigation surgery, the results were acceptable and confirmed the reliability and accuracy of this method.

Our research has hence proven that utilization of computer-assisted techniques in mandible reconstruction with free iliac crest flaps is feasible and advantageous. However, as this is a developing technique, some limitations do exist. This clinical procedure comprised step-by-step work with accumulative systematic errors. For example, the virtual plan is a subjective manipulation by the surgeon and engineer. There is no “perfect” or “right” standard for the reconstructed mandible, because virtual planning is subjective and experience-based. Considering the navigation system, the systematic error of registration process remains inevitable. Moreover, while all the virtual plans were based solely on bony structures, soft tissues also require consideration during the actual operation, especially with regard to the cosmetic aspect. Thus, differences or errors may occur in the postoperative evaluation process. Although computer-assisted techniques provided more surgical convenience, the preoperative work required was quite time consuming along with higher total costs than traditional surgery.

5. Conclusion

Compared with traditional mandible reconstructions with free iliac crest flap, computer-assisted techniques such as virtual planning, rapid prototyping, and surgical navigation significantly improve the accuracy of the surgical procedure. Thus, computer-assisted surgery combined with an individual reconstruction plate could enhance the functional and esthetic outcomes of mandibular reconstruction with free iliac crest flap.

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Conflict of interest

None of the authors has a financial interest in any of the products, devices, or drugs mentioned in this manuscript.

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