Computer-Aided Mandibular Reconstruction With Vascularized Iliac Crest Bone Flap and Simultaneous Implant Surgery

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The intention of oral rehabilitation in patients with mandibular defects is an early prosthetic treatment with maximum possible functionality and high accuracy. The present study describes a new computer-aided technique for mandibular reconstruction using a free vascularized iliac flap and simultaneous insertion of dental implants into the flap while it is still pedicled at the donor site. Based on preoperative computerized tomography data of the facial skeleton and the iliac crest donor site, a surgical guide transferred the virtual plan including information on the transplant dimensions and shape as well as the position of the dental implants into real-time surgery. Using postoperative computerized tomography scans, the actual situation were compared with the preoperative simulation. A mean difference of 0.75 mm (SD $\pm$ 0.72) for the flap shape and 0.70 mm (SD $\pm$ 0.44) for the implant position analysis was determined. A calculation of the closest point distance showed a surface deviation of $<$2 mm for the shape analysis in 93.3% of the values and $<$1 mm for implant position in 75.2% of the values. The mean angular deviation was 3.65°. Virtual surgical planning is a suitable method for mandibular reconstruction with vascularized iliac crest flaps and simultaneous implant surgery. It can be used to restore the anatomy of the mandible with a high accuracy and can help to shorten subsequent dental rehabilitation.

Key Words: computer-aided surgery, virtual planning, vascularized iliac crest bone flap, surgical guide, mandibular reconstruction, simultaneous implant surgery

Introduction

Extensive jawbone defects that are a result of severe atrophy, trauma, or tumor resection can lead to significant facial deformities. Some of the deformities include oral dysfunction and bad facial esthetics. The reconstruction of the jaw is, therefore, one of the most demanding procedures in maxillofacial surgery.[1,2] The purpose is to achieve the maximum possible functionality, which requires the restoration of masticatory function, speech skills, and esthetics. In this context, microsurgical techniques have made it possible to design different types of composite flaps for 3-dimensional reconstructions based on skin, muscle, and bone. These are particularly useful after tumor ablation. Revascularized free flaps such as the iliac crest flap, fibula flap, radial forearm flap, and scapula flap have been proposed for reconstructive procedures. Here, we will discuss the iliac crest flap, which is characterized by a large volume of well-vascularized bone with a huge number of stem cells. The compact cortex of this flap allows for good plate fixation and a high primary stability of dental enossal implants after insertion.[3]

Three-dimensional modeling assisted by computerized tomography has been an ideal method of obtaining information for reconstructive surgery, especially for explantation of the flap with subsequent transplantation into the defect. Translation of the digital computerized tomography (CT) data and the 3-D software simulation to the operative field and the donor region provides a detailed and precise analysis of these regions from all aspects. It serves as a diagnostic tool to plan the size, shape, and exact placement of the bone flap,[4] which may be of significant clinical benefit.

Dental implants have high survival rates in combination with related prostheses.[5,6] This is why they are important for

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oral rehabilitation after the restoration of oromandibular oncologic defects as well as for the treatment of partially or totally edentulous patients. Implant placement is a time-consuming procedure, and its ideal timing is a matter of some controversy. Oral reconstruction treatments can be classified as primary or secondary reconstructions with immediate or delayed implantation. The advantage of an immediate insertion is osseointegration at an early stage with the potential for early dental rehabilitation.[7] On the other hand, implant insertion at the correct position and inclination can be difficult to plan, and therefore is not often considered during the planning of a jaw reconstruction. In these cases, the prosthetic treatment is a compromise between the ideal position and the available bone supply. In addition, implantation prolongs the operating time. This is important because there is a significant relationship between the ischemic time and the survival of the flap.[8] Implantation should not impair the basic survival of the vascularized bone flap nor should it extend the operation.

Computer-aided surgery is a common way to restore jawbone defects. It is based on preoperative cone beam computerized tomography (CBCT), or CT. Data from scans are imported into surgical planning software to design a template that will help translate the virtual surgery plan into the operation site. It is an effective method to shorten the ischemic time period between flap delivery and revascularization. Another benefit is the reduction of harvested bone and an optimized esthetic outcome.[10]

Computer-aided surgery is another useful concept in dental implant planning. It offers the opportunity for more detailed planning, which is important for the protection of anatomical structures such as the maxillary sinus, the nasal cavity, and the alveolaris inferior nerve, as well as the prosthetics being installed; it also saves time during surgery. Full-guided and half-guided implant surgery techniques are available. Full-guided treatment is characterized by template-based guided cavity preparation and guided implant insertion, while half-guided implant surgery uses a template-based guided cavity preparation and free-handed, manual implant insertion.[11]

The acceleration of implant insertion and prosthetic treatment during augmentation with a free vascularized fibular flap is already described in the medical literature.[12] In such cases, another surgical procedure that includes the insertion of the implants into the fibula is necessary before proceeding with reconstruction of the alveolar ridge. After the osseointegration of the implants, flap delivery is possible. The benefit of this technique is it allows for immediate treatment with definite prosthetics, however, it does increase the time required for reconstruction.

Therefore, the purpose of this study is to describe a new computer-aided technique for mandibular reconstruction using a free vascularized iliac crest flap in combination with the simultaneous insertion of dental implants on the donor site. The key elements of our technique are:

(1) Preoperative planning and fabrication of a drilling template for iliac osteotomies and implant cavity preparation,
(2) Placement of implants during the same surgical procedure at the donor site during flap conditioning and before flap delivery,
(3) Reconstruction of the mandible with the prefabricated free vascularized iliac crest flap.

Materials and Methods

After institutional approval and written informed consent, the translation from a virtual plan to the operating site with a surgical guide was performed in a patient with a defect of the left mandible due to previous ameloblastoma resection.

Preoperative CT scans of the facial skeleton and iliac crest were performed with a 128-row multislice CT scanner (Somatom Definition Flash, Siemens, Erlangen, Germany). To investigate the arteries at the iliac donor site, angiographic CT scans were used. These CT data in the DICOM file format were imported into the ProPlan CMF Planning Software (Materialise N.V., Leuven, Belgium). A segmentation process followed, in which artifacts were removed and all bony structures of interest were isolated. A high-quality 3-dimensional visualization of the maxilla, mandible, and iliac crest was generated. The mirrored healthy right side of the mandible served as a reference for the virtual reconstruction of the affected left mandible. The position of the vessels nourishing the iliac flap was also taken into account and, therefore, the afterwards selected flap was determined at the left iliac crest. Additionally, the part of the left iliac crest that was best suited for use in the virtual reconstruction of the left mandible in terms of shape and relation to the maxilla was selected (Figure 1). The donor site was virtually osteotomized and transplanted into the left mandible.

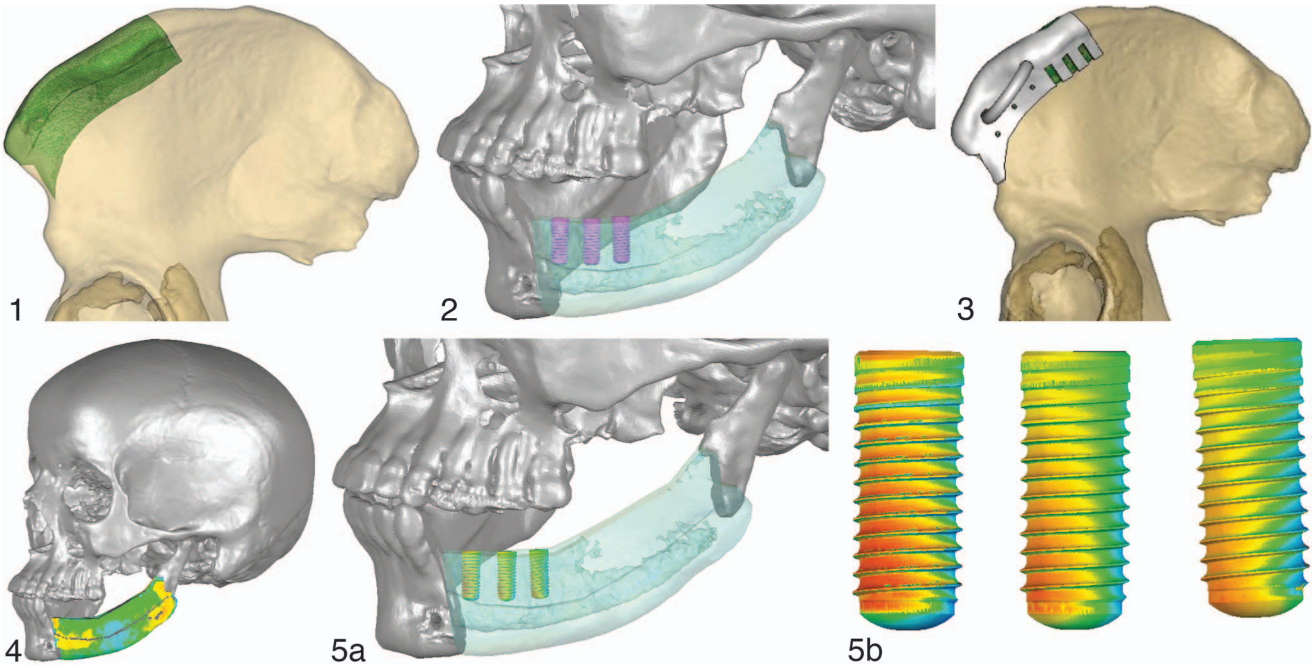
After fine adjustments, STL files of the virtual planning and of Bone Level Implants, Ø 4.8 mm RC, SLA 12 mm (Straumann, Basel, Switzerland), were imported into the Geomagic Qualify software program (Geomagic, Morrisville, NC) for virtual implant positioning (Figure 2).

The final planning data were imported into the 3-matic software program (Materialise N.V.) as STL files. Thus a surgical guide was custom made for this patient's iliac crest, and indicated the desired osteotomy lines, flap size, and angulation (Figure 3). Furthermore, the surgical guide showed the exact horizontal position of the virtually planned implantation. The sagittal position was identified as the middle of the planned alveolar ridge.

With the aid of the rapid prototyping selective laser sintering method, the guide was produced out of polyamide powder and solidified with a carboxide laser (Materialise N.V.). The surgical guide linked the computer-aided plan to the real-time surgery.

A postoperative CT scan was obtained after surgery, and 3-dimensional computer models of the final reconstruction were compared with the preoperative virtual plan.

First, the preoperative and postoperative 3-dimensional objects were aligned using the Geomagic Qualify software program. Automatic surface registration was performed based on an iterative closest point algorithm. The actual postoperative flap shape (Figure 4) and the position of the implants (Figure 5a and b) were compared with the preoperative virtual simulation. Therefore the preoperative 3-dimensional objects acted as the reference model, whereas the postoperative 3-



Figures 1–5. Figure 1. The best fitting part of the left iliac crest in terms of shape and interface with the affected left mandible was selected virtually prior to surgery. **Figure 2**. Virtual implant positioning using STL files of 3 bone level implants (Straumann, Basel, Switzerland). **Figure 3**. Three-dimensional design of the surgical guide generated from the optimally constructed virtual transplant data and located on the left iliac crest. **Figure 4**. Comparison of the actual postoperative iliac bone flap shape with its preoperative planned shape. **Figure 5**. Comparison of actual postoperative position of the implants with their preoperative planned positions. (a) Overview of the implants in the flap; (b) Detail view with color gradient.

dimensional object was set as the test model. The 3-dimensional compare operation in Geomagic Qualify measures the deviation between the surfaces of the test and reference objects. The measured deviation indicates the shortest distance from the object set as "test" to any point on the object set as "reference." This completely automatic process generates a full-color deviation map and a histogram comparing the 2 surfaces. The color map overlay histograms represent objects in close proximity to the preoperative plan as green, and objects at greater distances from it as red.

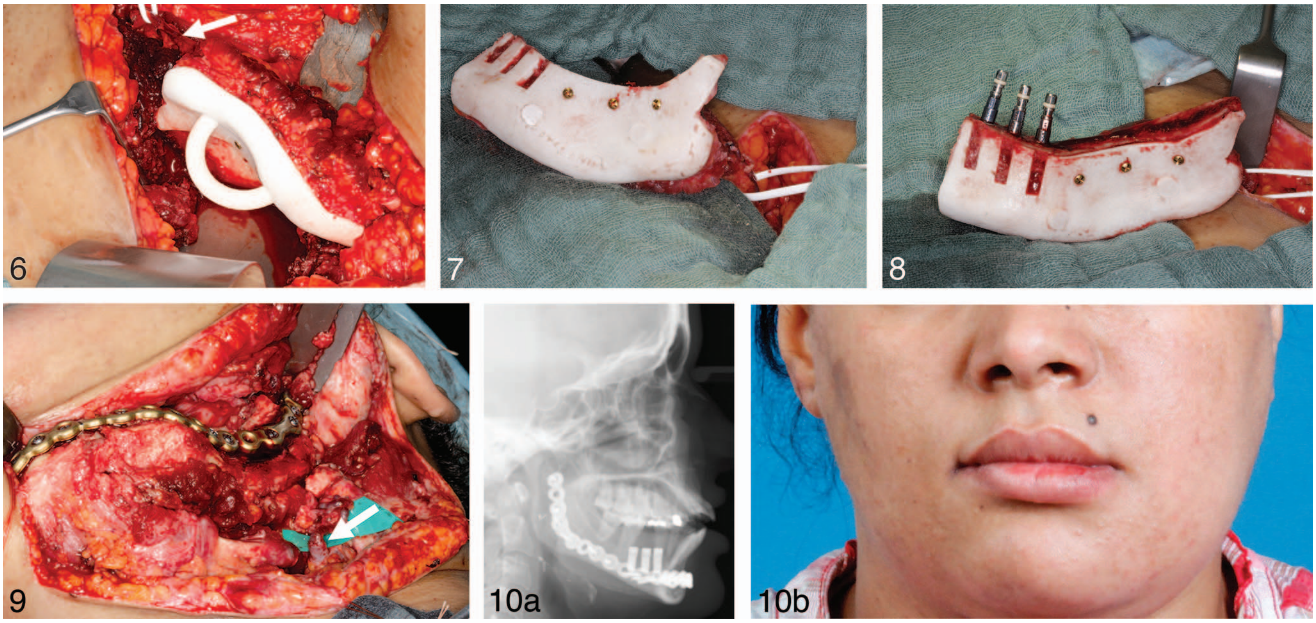
To measure the accuracy with which the implants were inserted, the preoperative and postoperative deviation of each implant was measured at the top and the bottom. In addition, the implants' 3-dimensional angulations were measured by comparing the cutting angles of the longitudinal axis of the implants' preoperative and postoperative centerlines.

Results

The surgical method of mandibular reconstruction and simultaneous implant surgery described here allowed the ability to identify the best available portion of the iliac bone flap with regard to its shape and size as the site of the osteotomy, as well as the best possible implant position on the harvested flap, in advance of the surgery. The temporary fixation of the surgical guide onto the donor site simplified the surgical procedure (Figure 6). After harvesting the iliac bone flap using the surgical guide (Figure 7) and inserting 3 endosseous dental implants into the still pedicled flap (Figure 8), the transplantation of the flap into the mandibular defect followed without major adjustments (Figure 9). No complications were encountered during the surgery or healing phase (Figure 10a and b). A comparison of preoperative and postoperative 3-dimensional computer models using a surface comparison algorithm showed a mean difference of 0.75 mm (SD $\pm$ 0.72) in the transplant shape analysis, and a total value of 0.70 mm (SD $\pm$ 0.44) for all implant positions. A surface comparison based on the closest point distance of the absolute values indicated that the surface deviation was less than 2 mm in 93.3% of the values in the shape analysis. In the implant position analysis, the surface deviation was less than 1 mm in 75.2% of the values. The color map overlay histograms (Figure 11a and b) shows the results of the surface deviation analysis for the shape of the iliac crest bone flap and for implant position. A mean deviation of 0.71 mm (range, 0.04 to 1.26 mm) on the top and 0.54 mm (range, 0.17 to 0.83 mm) at the apex of the implants were calculated. The measured angular deviation was 3.65° (range, 3.36° to 3.84°).

Discussion

In order to achieve rapid oral rehabilitation after bony reconstruction, an early prosthetic treatment is necessary.[7] The use of computer-aided techniques in combination with free flaps provides good functional and esthetic results with predictable outcomes.[13] Performing dental implantation at the donor site during microvascular reconstruction can help reduce the total treatment time as the transplant and the implants heal



Figures 6–10. Figure 6. The surgical guide is temporarily fixed on the external side of the left iliac crest using osteosynthesis screws. The arrow indicates the deep circumflex iliac artery on the medial side of the iliac crest. **Figure 7**. The precision-cut and osteotomized left iliac crest bone flap. **Figure 8**. Insertion of the 3 endosseous dental implants in the iliac crest bone flap while it is still pedicled. **Figure 9**. Positioning and fixation of the iliac crest bone flap for reconstruction of the left mandible. The arrow points to the anastomosis of the deep circumflex iliac vessel to the left cervical vessels. **Figure 10**. (a) and (b) The postoperative lateral cephalogram shows the iliac crest bone flap including the dental implants (a). The frontal view of the left side of the face shows a timely healing phase with decreasing swelling 1 week after surgery (b).

simultaneously. Thus an additional surgical procedure can be avoided and dental rehabilitation can be accelerated. Previous techniques for jaw reconstruction using a free fibula flap and simultaneous implant surgery have described the insertion of the implants after dissection of the vessels using a side table.[1,14] On the other hand, the present study proposes an innovative technique for implantation in a transplant that is still pedicled, thereby avoiding any increase in ischemic time.

However, the implant placement often depends on bone supply and inconvenient position for future dental prosthetics. In this case, the anatomical contour of the mandible was achieved with computer-aided virtual planning for microvascular bony reconstruction. This approach provides the base for inserting the implants in an ideal position. Yet simultaneous implantation can be limited by the shape and dimensions of the transplant. In addition, it is important to maintain a safe

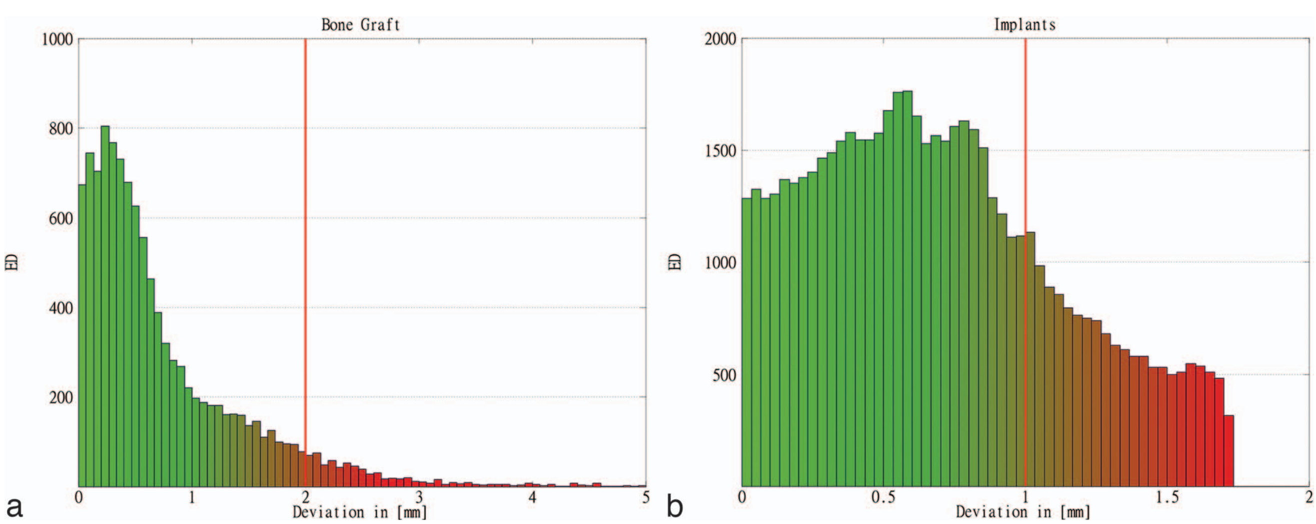


Figure 11. (a) and (b) The surface deviation analysis for shape of the iliac crest bone flap (a) and implant position (b). The calculation showed a surface deviation of <2 mm (red line) in 93.3% of values for the shape analysis of the iliac flap and of <1 mm (red line) in 75.2% of values for implant position. ED indicates element distribution.

distance to the transplant border to avoid a fracture during implant insertion. For this reason, during the virtual planning it was decided to insert only three instead of the 4 possible implants. After uncovery of the implants, the final prosthetic treatment is going to be provided with a splinted, implant-supported, free-end fixed partial denture with mesial cantilever unit. Another potential source of inaccuracy is the insertion of the iliac crest bone flap including the implants into the mandibular defect. The use of virtual planning plays a very important role in achieving high accuracy in mandibular reconstruction as well as in the final implant position.

Computer-guided implant surgery is an established technique in dentistry. Its main benefit is that it allows for a high accuracy of implant positioning. This is necessary to protect important anatomic structures from injury and to achieve the ideal position for any subsequent prosthetic treatment. In the present study, implant placement was also virtually planned using the same surgical guide to transfer all information regarding the iliac bone flap and the horizontal position of the implants. If full-guided implantation is intended, a second guide is needed to determine the exact implantation axis. Many studies have described the accuracy of dental implant insertions with the aid of templates.[15–20] Currently, comparisons between virtually-planned and surgically-achieved implant positions are made in terms of certain distinctive points on the dental implant such as the tip, base, angular and high deviations and their deviation from each other.[11,15,21] In a systematic review on the accuracy and clinical outcomes of computer-guided implant surgery, it was found that the mean horizontal deviation is within approximately 1.0 mm at the entry point and around 1.6 mm at the apex. The deviation in height was about 0.5 mm and in the axis was 5–6°.[15] On the other hand, another meta-analysis found the mean deviation at the entry point to be about 0.74 mm while that at the apex was about 0.85 mm.[17] Higher maximum deviations are also possible: Jung and colleagues, for example, have published a maximum deviation at the entry point of about 4.5 mm and one at the apex of about 7.1 mm, while Schneider has reported one of about 1.22 mm at the base and one of about 2 mm at the tip.[15,17] Based on these reports, Kühl and colleagues showed that the type of template surgery, that is, half-guided or full-guided, does not matter, as the accuracy of half-guided implant surgery is comparable with that of full-guided implant surgery.[11] Accordingly, in the present study, the 3 dental implants were inserted freehand after a template was used to determine the required implant position.

In contrast to the results of the other studies mentioned above, our data show a mean deviation on the top of 0.71 mm with a maximum of 1.26 mm, and a mean deviation at the apex of 0.54 mm with a maximum of 0.83 mm. The angular deviation was 3.65° with a maximum of 3.84°. While 2 different landmarks on an implant are usually located in relation to each other before and after surgery, in our study we used a surface comparison algorithm to compare the total virtual implant surface with the real implant surface from the postoperative CT data. The use of preoperative and postoperative data for a comparison of the virtual and actual postoperative situations was very helpful in determining whether the surgery had been performed in accordance with the preoperative virtual plan.[22,23]

The mean absolute surface deviation of 0.7 mm, with 75.2% values having a deviation less than 1 mm, is slightly lower than the deviations reported in the abovementioned literature. The advantage of our measurement method is that it is user-independent, which allows for repeatable and comparable results.

Conclusion

The present method shows that using a custom-made surgical guide with a vascularized iliac crest bone flap and simultaneous implant surgery is an accurate and effective method for mandibular reconstruction and can help to shorten subsequent dental rehabilitation. We are aware that studies with larger sample sizes will be required to further evaluate the benefits of computer-aided bony jaw reconstruction using microvascular flaps and simultaneous implant surgery.

Abbreviation

CBCT: cone beam computerized tomography

CT: computerized tomography

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