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CAD/CAM guided secondary mandibular reconstruction of a discontinuity defect after ablative cancer surgery

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A B S T R A C T

A surgical guide is projected to aid the repositioning of the mandibular segments in their original locations, and a reconstruction bone plate is provided to support the fibula free flap. Computer-aided mandibular reconstruction involves three steps: virtual surgical planning, CAD/CAM and rapid-prototyping procedures for the design and manufacture of the customised surgical device and surgery. The duration of the reconstructive phase (<1.5 h intraoperative time) was reduced in comparison with traditional secondary mandibular reconstruction. The bone plate permitted the maximal restoration of the original facial and mandibular contours and the more precise positioning of the residual mandibular ramus in comparison with conventional procedures. No complication was noted during the mean follow-up period of 12 months. The protocol presented in this paper offers some benefits: 1) The virtual environment permitted ideal preoperative planning of mandibular segment repositioning in secondary reconstruction; 2) Intraoperative time was not consumed by approximate and repeated bone plate modelling; 3) Using CT data obtained before primary surgery, the reconstruction bone plate was designed using the original external cortical bone as a template to reproduce the ideal mandibular contour; 4) Prototyped resin models of the bone defect allowed the surgeon to train preoperatively by simulating the surgery.

1. Introduction

Mandibular reconstruction after cancer removal using a vascularised fibula free flap is currently a standard treatment option (Hidalgo, 1989; Cordeiro et al., 1999). Primary reconstruction offers the best opportunity to achieve the optimal aesthetic and functional results (Ferrari et al., 1998). The use of vascularised bone tissue in secondary reconstruction permits superior restoration of articulation, deglutition and mastication; aesthetic improvement of facial appearance; and improvement of the patient's quality of life in comparison with non-vascularised alternatives (Iseli et al., 2009).

Patients scheduled for secondary mandibular reconstruction have a unique set of problems, such as frontal plane rotation during oral function and the presence of soft-tissue contracture, which makes surgical correction more difficult and potentially more hazardous than primary reconstructive surgery performed immediately after bone cancer removal.

Computer-aided design/computer-aided manufacturing (CAD/CAM) technology has recently opened new frontiers in temporal bone reconstruction (Scholz et al., 2007), orbital floor reconstruction (Kozakiewicz et al., 2009), condyle reconstruction (Ramos et al., 2011), zygomatic reconstruction (Herlin et al., 2011), orthognathic surgery (Centenero and Alfano, 2012), and mandibular reconstruction (Juergens et al., 2009; Liu et al., 2009). The direct application of CAD/CAM technology to maxillofacial reconstruction has been examined recently (Ciocca et al., 2009) and is the focus of the present study. We present a CAD/CAM procedure that guides the surgeon in correctly positioning the residual bone and fibula free flap in secondary mandibular reconstruction. In this procedure, computed tomography (CT) data representing the

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patient's current situation are elaborated and compared with CT data obtained before primary surgery for cancer removal to produce a virtual surgical plan. A surgical guide is projected to aid the repositioning of the mandibular segments in their original locations, and a reconstruction bone plate is provided to support the fibula free flap. The stereolithographic files of the guide and plate are then printed three-dimensionally by direct metal laser sintering (DMLS). Here, we describe the CAD/CAM protocol and surgical procedure used in this method and discuss the results of their application.

2. Materials and methods

Computer-aided mandibular reconstruction involves three steps: virtual surgical planning, CAD/CAM and rapid-prototyping procedures for the design and manufacture of the customised surgical device and surgery.

2.1. Virtual surgical planning

Planning begins with a high-resolution CT scan of the patient's craniofacial skeleton and soft tissue. CT imaging was performed using a multidetector CT scanner (HiSpeed CT scanning station; GE Healthcare, Milwaukee, WI, USA) and volumetric data were acquired (1.25 mm slice thickness, 512 $\times$ 512 pixel resolution). The DICOM-format data were processed using the CMF software (ver. 6.0; Materialise, Lueven, Belgium). After a suitable threshold value was set, this software allowed the creation of a three-dimensional (3D) virtual model of the maxillofacial skeleton in which the displacement of the mandibular stumps was clearly highlighted. Preoperative CT data were also elaborated using the same threshold value to obtain a 3D reference model of the original mandible that was used in the simulation of mandibular rami repositioning according to the original contour of the mandible. The repositioning was carried out by shell–shell registration based on the iterative closest points algorithm provided by the Rapidform XOS2 software (INUS Technology, Seoul, Korea) for reverse-engineering post-processing. To evaluate the accuracy of the repositioning process, surface deviation analysis was performed to ensure that the mean distance was $<$1 mm from the position shown in the 3D model of the preoperative native mandible (Fig. 1).

2.2. CAD/CAM and rapid-prototyping procedures

The construction of the customised surgical device, composed of the surgical guide and reconstructive bone plate, involved design and manufacturing steps.

2.3. Design

The CAD of the surgical device was provided by the Rhino software (ver. 4.0; Robert McNeel & Associates, Seattle, WA, USA). The customised surgical guide for the repositioning of mandibular segments was first designed. The main aim of this guide is to allow the surgeon precisely to correct the 3D relationship of the segments and to reposition the mandibular condyle in the glenoid fossa to reproduce the situation before cancer ablative surgery. The guide was designed with three arms (one mesial and two distal) to allow positioning on the mandible as planned and to ensure precise engagement on the lower mandibular margin (Fig. 2A), even when the margin of the sectioned mandible is irregular and non-linear. The guide also included two stopping planes to hold the resected parts of the two stumps in the correct positions, avoiding movement and displacement. Finally, four holes (2.4 mm diameter) were created on both extremities of the guide to allow fixation to the mandible with titanium screws.

The second component is the customised reconstructive bone plate that supports the fibula free flap. The main purpose of the bone plate is to control the anatomical reconstruction of mandibular continuity. It was designed using preoperative CT data to obtain the original mandibular contour. Reference notches were created to delimit the part of the guide meant to support the fibula free flap (Fig. 2B). An array of holes (2.4 mm diameter) was created along the plate to allow fixation of the fibula free flap to the plate and the plate to the mandible. The two components were projected so that the position of each was unique when used in sequence (guide first, plate second), and the same four holes were used to fix each component to the mandible. This feature guaranteed that bone regeneration using the fibula free flap could be guided anatomically according to the natural appearance of the mandibular bone.

2.4. Manufacturing

The two components (cutting guide and bone plate) were manufactured directly using an EOSINT M270 system (Electro Optical Systems GmbH, Munich, Germany). The working principle was based on DMLS, in which metal powder is fused into a solid part and melted locally using a focused laser beam. As usual for additive manufacturing technologies, the parts were built up additively in layers. The repositioning surgical guide (Fig. 3A) was produced using EOS CobaltChrome MP1, a multi-purpose cobalt–chrome–molybdenum-based super alloy powder that has been optimised for DMLS on EOSINT M systems. The bone plate (Fig. 3B) was produced using EOS Titanium Ti64, a pre-alloyed Ti6AIV4 alloy in fine-powder form with excellent mechanical properties and corrosion resistance combined with low specific weight and biocompatibility, which is particularly suitable for the production of biomedical implants.

The bio-model of the actual mandible was manufactured directly using a 3D soluble support technology rapid-prototyping machine (Stratasys, Eden Prairie, MN, USA). The working principle was based on fused deposition modelling of acrylonitrile butadiene styrene plastic material and the use of soluble support material to sustain the prototype under construction. This bio-model allowed the surgeons to conduct preoperative training. Finally, the surgical guide and bone plate were delivered for sterilisation.

2.5. Surgery: case report

A 61-year-old man was referred to our maxillofacial department after primary surgery for oral cancer and reconstruction with a pectoralis (major) local flap. He desired an improvement in appearance and function. The patient was scheduled for surgical treatment consisting of mandibular segment repositioning and reconstruction using a fibula free flap. Mandibular access was obtained by a submandibular/laterocervical incision. The mandibular repositioning surgical guide was introduced into the field and fixed to the two mandibular segments. To stabilise the guide in the correct position, the three arms were used at the lower mandibular margin and the two stopping planes were used on the resected parts of the two stumps. This technique achieved perfect engagement of the mandible in the previously planned position (Fig. 4). The mandible was repositioned, and the surgical guide was fixed with titanium screws and then removed. The reconstructive bone plate was used to support the fibula free flap in the correct position exactly to restore the patient's original mandibular contour. For this reason, the bone plate was projected to host the fibula free flap and provide continuity to the inferior mandibular border. The bone