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Accuracy of fibula reconstruction using patient-specific CAD/CAM reconstruction plates and dental implants: A new modality for functional reconstruction of mandibular defects

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ABSTRACT

Background: The purpose of this study was to analyze the accuracy of mandibular reconstruction using patient-specific computer-aided designed and computer-aided manufactured (CAD/CAM) reconstruction plates as a guide to place fibula grafts and dental implants in a one-stage procedure using pre-operative 3D virtual planning.

Methods: Seven consecutive patients were analyzed retrospectively, the 3D accuracy of placement of the fibula grafts and dental implants was compared to the virtual plan.

Results: Six out of seven flaps survived for an average follow-up time of 9.4 months. The outcome was compared to the virtual plan, superimposed on the mandible. For the fibula segments, the mean deviation (SD) was 3.0 (1.8) mm and the mean angulation (SD) was 4.2° (3.2°). For the implants, the mean deviation (SD) was 3.3 (1.3) mm and the mean angulation (SD) was 13.0° (6.7°). The mean (SD) mandibular resection plane deviation was 1.8 (0.9) mm.

Conclusions: A patient-specific reconstruction plate is a valuable tool in the reconstruction of mandibular defects with fibula grafts and dental implants. Implant angulation showed a greater deviation from the virtual plans in patients with a sharp ventral fibula rim, where the guide is removed after pilot drilling of the implants.

1. Introduction

Reconstruction of mandibular defects is often performed by using autologous bone transplants. These bone transplants or free vascularized bone grafts have proven their benefit (Cordeiro et al., 1999). The free vascularized fibula flap is harvested from the lower leg and is the preferred flap for reconstruction of large mandibular defects (Hayden et al., 2012). To enhance functional outcome, in particular to facilitate dental rehabilitation, dental implants may be used.

Implant-supported prostheses have been shown to provide a good cosmetic result and adequate stability for chewing (Zlotolow et al., 1992). To decrease the risk of inappropriate positioning, dental implants may be inserted secondarily after fibula reconstruction of the jaw (Garrett et al., 2006; Hundepool et al., 2008). In the retrospective analysis by Anne-Gaelle et al. (2011), several factors were identified for not accomplishing dental implant placement in fibula grafts used in mandibular reconstruction. The main reasons for not placing implants in the fibula bone graft at the time of reconstruction include incorrect positioning of the graft in the defect, and interference of the implant sites with the osteosynthesis screws. Implant placement after the grafted bone has healed is generally omitted due to risk of osteoradionecrosis (in cases of adjuvant radiotherapy), or due to malpositioning of the graft 'from an implant-prosthetic point of view', or because patients do not want to undergo additional surgery after completing the oncological treatment. Therefore,

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some studies report that implants are employed secondarily in less than 5% of reconstructed cases (Virgin et al., 2010; Barber et al., 2011). Recently, the quality of life has been shown to improve considerably if dental implants are placed to support a dental prosthesis during less complex surgery in oral cancer patients in their native mandibular bone (Korfage et al., 2014). Therefore, in reconstructing complex jaw defects, immediate placement of dental implants in the fibula bone graft is strongly advocated. The current study describes the possibility of using three dimensional (3D) technology to overcome the technical challenges of placing dental implants at the time of fibula reconstruction of jaw defects.

Three dimensional virtual surgical planning is gaining increasing attention, and its potential use in the planning of maxillofacial rehabilitation has been reported before (Roser et al., 2010; Coppen et al., 2013; Schepers et al., 2013). 3D-printed cutting guides abutting on surrounding tissue such as bone, soft tissue or teeth are used intraoperatively to translate a 3D virtual surgical plan into reality. However, the accuracy with which these guides translate the surgical plan to the surgical outcome has rarely been assessed (Roser et al., 2010; Foley et al., 2013; Hanken et al., 2015). A precisely executed reconstruction of a mandibular or maxillary defect combined with implant insertion may reduce the risk of inappropriate positioning of the implants and could be more cost effective. The search for an accurate method to translate a 3D virtual surgical plan to the intra-operative situation, and the report of its accuracy is, therefore, relevant.

Reconstruction plates are used for fixing the bone graft to the jaw. Recently, a patient-specific computer aided design/computer aided manufacturing (CAD/CAM) reconstruction plate that is commercially available was introduced. Such a plate can be integrated in 3D surgical reconstruction planning. These plates are designed to follow the contour of the patients' own bone and can be fixed with locking screws. Angulation of the screws in the plate and the inter-screw distance can be adjusted to some extent during the planning procedure. Besides individualization, patient-specific CAD/CAM reconstruction plates have another unintended potential powerful aspect, as they can be used to guide the reconstruction in the positioning of dental prostheses, and translate the 3D surgical plan to the reconstruction surgery. To our knowledge, the clinical accuracy of patient-specific CAD/CAM reconstruction plates as a guide for fibula graft positioning, including the insertion of dental implants in a one-stage 3D-planned procedure, has not been reported.

The aim of this study was to assess the degree to which the surgical outcome of the fibula graft and the implants, inserted in a one-stage reconstruction of mandibular defects using 3D-planning and a patient-specific CAD/CAM reconstruction plate, correlate with the virtual surgical plan.

2. Materials and methods

2.1. Patients

This retrospective study evaluates the accuracy of positioning of the fibula segments, and the implants inserted in these segments, in patients who required reconstruction of the mandible with a free vascularized fibula flap. The reconstructions were carried out between 2013 and 2014 at the University Medical Center Groningen, University of Groningen, The Netherlands. The inclusion criteria were: (1) mandibular reconstruction using a free vascularized fibula graft, (2) the use of a patient-specific CAD/CAM reconstruction plate, and (3) immediate placement of dental implants in the graft. The only exclusion criterion was the absence of a post-operative CBCT scan.

2.2. Virtual planning

The 3D virtual treatment plan started with a CBCT scan of the maxillofacial region and the mandible (i-CAT, Imaging Sciences International, Hatfield, PA, USA). The scanning protocol dictates that the patient is seated in an upright position using the chin rest and the headband for fixation. Upper and lower dentition must be in maximal occlusion, and in case of an edentulous or partially dentulous jaw, the denture should be worn. Scanning settings used were: 120 KV, 5 mA, 0.4 voxel with a field of view of 23 × 16 cm. A high-resolution CT angiography scan from the lower legs was acquired (Siemens AG, Somatom Definition Dual Source, Forchheim, Germany). An arterial contrast scan was made with a 0.6 mm collimation and a 30f kernel (medium smooth). Images were stored in an uncompressed DICOM format. Both scans were imported into ProPlan CMF 1.3 (Synthes, Solothurn, Switzerland and Materialise, Leuven, Belgium) to plan the reconstruction in a virtual environment. After converting to Simplant Pro 2011 (Materialize Dental, Leuven, Belgium), the implants were imported digitally into the plan. Next, in ProPlan CMF 1.3, the preferred contour of the reconstruction plate was marked. The planning was exported as a standard tessellation language (STL) file and sent to a company for the planning and production of the reconstruction plate (Synthes, Solothurn, Switzerland). In a web-based online planning session, the contour and size of the plate were planned, as well as the number of screws, together with the inclination and screw length. Subsequently, a guide design was made incorporating the bone-abutted resection guide for the mandible, with the drill guide to correctly position the screw holes for the plate. For the fibula segmentation a cutting guide was designed including guiding holes for the implants and for screw fixation of the plate. This guide was designed to be placed on the periosteum with a planned offset in the virtual plan of 0.4 mm to the bone surface. A surgical outcome model of the segmented fibula and the reconstruction plate were printed in acrylic, to check the shape of the planned fibula segments and plate in situ. This model was used intra-operatively to ensure that the planned reconstruction would fit the resection defect before segmenting the fibula. Finally, the guides, the printed outcome model and the patient-specific reconstruction plates (PSPs) were sterilized with gamma irradiation to be used intra-operatively.

2.3. Surgical procedure

The surgery was divided into three parts. First, the tumor or diseased bone (in the case of osteoradionecrosis) was removed by resecting the segment of mandible according to the preplanned, individually-designed cutting and drilling guide. The guide was fixed to the mandible with 8 mm long and 1.5 mm diameter screws (KLS Martin Group, Tuttlingen, Germany) using lateral holes in the guide planned for this purpose (1–2 holes per segment) (Fig 1). This was followed by guided resection of the segment of mandible and guided drilling of the screw holes. Next, the surgical outcome model was placed into the mandibular defect to check the fit of the planned graft (Fig 2).

Second, the harvesting of the fibula was performed using a reciprocating saw with a 35 mm blade (Aesculap microspeed uni, Aesculap Inc., Center Valley, PA, USA). When the fibula was exposed the fibula guide was placed and fixed with 8 mm screws. The guide was used to drill and tap the implant sockets (Fig 3). Subsequently, the implants (Nobel Speedy, Nobel Biocare AB, Götenborg, Sweden) were inserted into the fibula sockets according to the guide. In general, we use 10 mm length, 4 mm diameter implants, because of the high stability we don't feel the need for bi-cortical drilling and implant placement. In the next step, the fibula was cut into