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Morphological results of customized microvascular mandibular reconstruction: A comparative study

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ABSTRACT

Introduction: Virtual planning and guided surgery with customized reconstructive plates are becoming more and more common for mandibular reconstruction with fibular free flaps. Although the literature describes many potential applications, no systematic analyses have been made about morphological results regarding computer-aided reconstruction compared to traditional freehand bent plate.
Materials and methods: In the present study, we propose a comparative study in this innovative field, analysing a case series of 30 CAD/CAM reconstructed mandibles, compared to traditional reconstructed mandibles, in terms of morphological results. All patients were evaluated by pre-operative and a post-operative CT scan. To evaluate the morphological results, several anatomical landmarks were measured on CT scan: 1) the midline deviation; 2) the amplitude variation, in grades, of the mandibular angle; 3) the bi-gonial diameter of the mandibular and 4) the chin protrusion.
Results: The mean differences registered between pre-operative and post-operative CT scan were significantly better for test group regarding mandibular angle ($p = 0.034$), bi-gonial diameter ($p = 0.041$), chin protrusion ($p = 0.05$). No significant differences were registered for midline deviation ($p = 0.092$).
Conclusion: CAD/CAM reconstructive technique appears to be a valid method to accurately restore the pre-operative morphological situation.

1. Introduction

Virtual planning and guided surgery with customised reconstructive plates are becoming more and more common for mandibular reconstruction with fibular free flaps (Ciocca et al., 2015; Tarsitano et al., 2014). Modern planning techniques, including computer-aided design/computer-aided manufacturing (CAD/CAM), afford new ways by which to plan surgery, optimising reconstructive outcomes and functional rehabilitation (Mazzoni et al., 2013). A reasonably high level of accuracy was achieved in CAD/CAM-based template-assisted mandibular reconstructions (Roser et al., 2010; Zheng et al., 2012; Ciocca et al., 2015).

Although the literature describes many potential applications (Antony et al., 2011; Hou et al., 2012), no systematic analyses have been made about morphological results regarding computer-aided reconstruction compared to traditional freehand bent plate. To date, many authors have simply described reconstructive outcomes, often with the aid of photographs. Results are not categorised by anatomical landmarks, and comparative studies do not exist. In the present study, we propose a comparative study in this innovative field, analysing a case series of 30 CAD/CAM reconstructed mandibles, compared to a same-sized sample of traditional reconstructed mandibles, in terms of morphological results.

2. Materials and methods

The CAD/CAM surgical protocol was applied to 30 mandibular reconstructed patients between September 2011 and January 2015. All patients were affected by tumour lesions that required mandibular resection and reconstruction using microvascular free flaps. All patients were treated at the Maxillofacial Unit of S. Orsola-Malpighi Hospital, Bologna, Italy. The study was approved by the S.

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Orsola Hospital Ethical Committee in September 2011 (approval no. 57/2011/O/Disp). All patients were evaluated by a pre-operative CT scan and a post-operative CT scan 6 month after the end of the treatment. The patients were divided into test and control groups (Table 1).

2.1. Test group

The test group included 30 patients who underwent mandibular reconstruction using the CAD/CAM method. Virtual planning began with the acquisition of a high-resolution CT-scan of the craniofacial region and of the lower leg or ankle as a donor site. DICOM format data were processed by the surgeons using Rhino software, version 4.0 (Robert McNeel & Associates, Seattle, WA, USA). Using this software, the surgeon created 3D virtual models of the maxillofacial skeleton and the donor site. The software allows the surgeon to plan mandibular and fibular osteotomies.

Mandibular cutting guides were used to reproduce the osteotomy site, as planned virtually preoperatively. Reconstructive plates were manufactured by a direct metal laser sintering method, as described previously: a metal powder was fused into a solid component and melted locally using a focused laser beam (Leiggener et al., 2009). The solid-to-layer files of the guide and plate were then manufactured by direct metal laser sintering (DMLS) using an EOSINT M270 system (Electro-Optical Systems, GmbH, Munich, Germany). DMLS was used to fuse the titanium powder into a solid form and then melt it locally with a focused laser beam. As with other additive manufacturing technologies, the components were built up in layers.

The customized reconstructive titanium plate that supported the bony free flap was designed by thickening the outer surface of the healthy side of the mandible to obtain an ideal aesthetic contour and avoid bone deformities on the side affected by the tumour (Fig. 1). It was fixed to the native mandible using a locking system 2.4.

Next, a customized cutting guide for bony free-flap was designed in order to allow the surgeon to precisely segment the osseous free flap (Ciocca et al., 2015). Cutting guides were manufactured using a 3-D Printer in polyamide. Since the guide is temporarily implanted on the patient, it can be sterilized using the steam sterilization settings pre-vacuum cycle. The guides are designed to fit the patient's anatomy. When a stable position for the guide is obtained, it was fixated to the bone using mono-cortical screws system 2.0. The number of reconstructive bony segments was identified in relation to the site of the defect according to our recently published reconstructive algorithm (Table 2) (Tarsitano et al., 2015).

Since the holes of the fixing screws of the guides are the same of those in the bone plate, it is very easy to insert all fibular segments in the final planned position anchored to the reconstructive plate. The straight fibular flap is contoured to resemble a neo-mandible using a surgical cutting guide that is virtually planned to guide osteotomy's site and orientation on the fibular fragment (Ciocca et al., 2015) (Fig. 2). Usually, we tried to avoid maintaining a gap between bone surface and plate. This is achievable by increasing the number of bone segments and designing the internal plate surface in order to maximize the bone-plate contact. The intra-operative procedure is summarized in a descriptive movie included as supplementary materials (see Supplementary materials).

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jcms.2016.03.007.

Table 1
Patients characteristics between study groups.

	Test group (*n*)	Control group (*n*)	Total
Type of defect			
Anterior defect	9	7	16
Lateral defect	16	21	37
Sub-total defect	5	2	7
Skin involvement	6	5	11
Adjuvant radiotherapy	13	14	27
Type of flap			
Fibula	29	28	57
Iliac crest	1	2	3

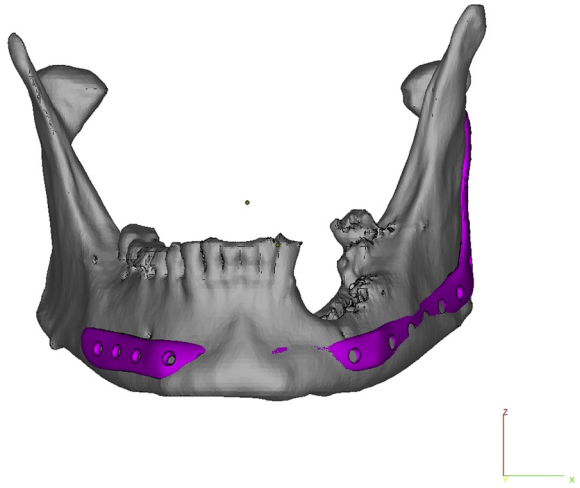

Fig. 1. Reconstructive plate designed using the original external cortical bone as a template; this reproduces the ideal mandibular contour.

Table 2
Reconstructive algorithm considering the different types of defect.

Class of defect	Mandibular subsites	Number of corners	Number of osteotomies needed
I	R + B	1	1
Ic	C + R + B	1	1
II	B + S + B	2	2/3
III	R + B + S	3	3/4

Legend: B = body; R = ramus; C = condyle; S = symphysis.

2.2. Control group

The control group included 30 patients reconstructed by free-hand technique. For these patients, the osteotomies of the fibula were performed freehand to obtain maximum proximity of the bone cuts: the standard osteosynthesis plates were manually bent using pre-plating technique (Marchetti et al., 2006).

The native mandible has been used as a template while molding the titanium plate. In particular, when the external cortical bone of the mandible was not affected by the tumour, the plate has been molded on the vestibular surface of the mandible. The plate was placed across the entire defect and was secured to the bone on each side of the resection line. Then, we removed the plate, and performed segmental resection. The plate was then replaced and fixed with the holes and screws used previously (Marchetti et al., 2006).

2.3. Evaluation method

To evaluate the morphological results, several anatomical landmarks were measured on CT scan: 1) the midline deviation; 2) the amplitude variation, in grades, of the mandibular angle; 3) the bi-gonial diameter of the mandibular, and 4) the chin protrusion.