Journal of Cranio-Maxillo-Facial Surgery 43 (2015) 1785–1791

Contents lists available at ScienceDirect

Journal of Cranio-Maxillo-Facial Surgery

journal homepage: www.jcmfs.com

Mandibular reconstructions using computer-aided design/computer-aided manufacturing: A systematic review of a defect-based reconstructive algorithm

Achille Tarsitano [a,*], Giacomo Del Corso [a], Leonardo Ciocca [b], Roberto Scotti [b], Claudio Marchetti [a]

[a] Maxillofacial Surgery Unit, S. Orsola-Malpighi Hospital, Department of Biomedical and Neuromotor Sciences (Head Prof. C. Marchetti), Alma Mater Studiorum University of Bologna, Via S. Vitale 59, 40125 Bologna, Italy

[b] Section of Prosthodontics, Department of Biomedical and Neuromotor Sciences (Head Prof. R. Scotti), Alma Mater Studiorum University of Bologna, Via S. Vitale 59, 40125 Bologna, Italy

ARTICLE INFO

Article history:
Paper received 26 April 2015
Accepted 11 August 2015
Available online 19 August 2015

Keywords:
Computer-aided design
Computer-aided manufacturing
Mandible
Reconstructive algorithm
Classification

ABSTRACT

Modern planning techniques, including computer-aided design/computer-aided manufacturing (CAD-CAM) can be used to plan reconstructive surgery, optimising aesthetic outcomes and functional rehabilitation. However, although many such applications are available, no systematic protocol yet describes the entire reconstructive procedure, which must include virtual planning, custom manufacture, and a reconstructive algorithm. We reviewed current practices in this novel field, analysed case series described in the literature, and developed a new, defect-based reconstructive algorithm. We also evaluated methods of mandibular reconstruction featuring virtual planning, the use of surgical guides, and laser printing of custom titanium bony plates to support composite free flaps, and evaluated their utility.

1. Introduction

Mandibular reconstruction after ablative tumour removal remains challenging to head-and-neck surgeons (Cordeiro et al., 1999). Currently, microvascular free-flap reconstruction is the method of choice (Bak et al., 2010).

Microvascular free tissue transfer allows the surgeon to critically address the aesthetic and functional outcomes of oromandibular reconstruction. A wide variety of tissues can be used. It is apparent that the extent of the deficit greatly affects the complexity of reconstruction and the probability of a favourable outcome (Urken et al., 1998). Modern planning techniques, including computer-aided design/computer-aided manufacturing (CAD-CAM), afford new ways by which to plan reconstructive surgery, optimising aesthetic outcomes and functional rehabilitation (Mazzoni et al., 2013; Ciocca et al., 2015). Although the literature describes many potential applications (Antony et al., 2011; Hou et al., 2012), no systematic protocol yet guides the entire reconstructive procedure in terms of virtual planning, custom manufacture, and use of a reconstructive algorithm.

To date, many authors have simply described defects, often with the aid of photographs. Defects are not categorised by increasing complexity, which would suggest the most appropriate method of reconstruction. Moreover, various methods are used to plan reconstruction, to prototype bony plates supporting bony free flaps, and to translate virtual positions into real environments. The choice of flap and the harvesting method are often based on individual surgical preference and experience with CAD-CAM rather than the need to optimally restore both form and function. A universally accepted reconstructive CAD-CAM algorithm might help one choose the best option.

In the present study, we reviewed current practices in this innovative field, analysed case series described in the literature, and developed a new, defect-based reconstructive algorithm. We also analysed and newly classified mandibular methods of reconstruction, featuring virtual planning, the use of surgical guides, and the laser printing of custom titanium bony plates to support

* Corresponding author. Tel.: +39 3202773204; fax: +39 0512144160.
E-mail addresses: achille.tarsitano2@unibo.it, achilletarsitano@gmail.com (A. Tarsitano).

http://dx.doi.org/10.1016/j.jcms.2015.08.006
1010-5182/

composite free flaps. We offer evidence supporting the utility of this approach.

1.1. A defect-based reconstructive algorithm

A CAD-CAM reconstructive algorithm that optimises accurate reconstruction is clearly needed. The principle is that CAD allows a surgeon to optimally plan the positioning of reconstructive bony segments. The principal benefit is accurate reproduction of the mandibular contour; bony deformities are avoided. Using computed tomography (CT) data, a reconstructive bony plate may be designed using the original external cortical bone as a template; this reproduces the ideal mandibular contour. Direct-metal laser-sintering yields a patient-specific plate devoid of errors introduced during manual modelling (Leiggener et al., 2009). Next, a custom-made cutting guide for a fibular or iliac crest flap allows the surgeon to precisely segment the osseous free flap (Ciocca et al., 2015). The straight fibular flap is contoured to resemble a neo-mandible using a surgical cutting guide that is virtually planned to guide surgery on the fibular fragment, optimising the orientation of future implant insertion (Ciocca et al., 2015).

The mandibular contour features four principal changes in direction. Two are vertical corners (the crossings between the ramus and the body) that form the angles of the mandible, and two are horizontal corners centred on the canine teeth of either side. Thus, the shaping of any bony flap requires osteotomies. Custom fibular cutting guides allow the surgeon to precisely segment the bony flap. In fact, CAD-CAM increases the number of possible osteotomies without raising the microvascular risk (Ciocca et al., 2015).

We have identified four main mandibular defects (Table 1). Lateral defects cause loss of mandibular continuity, with obvious effects on mastication, regardless of the location of the defect or the status of dentition. Lateral defects may be subdivided based on the functional outcomes of resection of the condyle and ramus. Successful condylar reconstruction significantly affects mandibular function during mastication. The rationale for distinguishing between defects of the body and ramus is based on the functional disturbance evident when the masticator muscle sling is completely disrupted.

A body defect is defined as a horizontal defect that does not include the posterior border of the ascending ramus. When the entire angle is removed, the defect is classified as a ramus defect, reflecting almost complete disruption of the masticator sling. Ramus defects extend to the sub-condylar region. Class I defects should be reconstructed by restoring the vertical corner of the mandibular angle. This goal can be achieved by performing at least one osteotomy (Fig. 1). When the condyle is also involved in resection (Class Ic), the surgical defect is more complex to restore, and reconstruction of the condylar head should be considered to ensure satisfactory joint function after oncological surgery.

In such cases, we seek to maintain a near-normal range of motion, and we preserve mandibular excursion by placing two fibular segments fixed to a CAD-CAM plate with a custom condyle (Fig. 2). Preservation of the meniscus during tumour resection, if possible, enables the surgeon to position the condylar head prosthesis within the glenoid fossa, using surrounding tissue to secure the prosthesis. Displacement is thus prevented.

Anterior segmental defects creating the well-known 'Andy Gump Deformity' compromise the ability to eat and can also cause airway obstruction. In addition, the altered facial appearance can significantly affect self-confidence and the desire to return to pre-disease employment and social interactions. Removal of significant portions of the suprahyoid and tongue musculature when a resection proceeds beyond the midline creates a significant swallowing disturbance. In addition, bone contouring is more difficult when the entire symphysis must be reconstructed.

To treat Class II defects, we restore both of the corners between the symphysis and the body by performing at least two osteotomies (Fig. 3). Finally, Class III defects should be reconstructed by restoring the vertical corner of the mandibular angle and one or two of the horizontal corners of the symphysis, thus necessitating at least three osteotomies (Fig. 4).

2. Material and methods

2.1. Systematic review

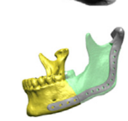
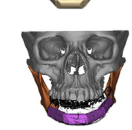
We searched for all articles addressing reconstruction of segmental mandibular defects using CAD-CAM. We interrogated PubMed with the EndNote package, using the following words: computer-aided design, computer-aided manufacturing, reconstruction, and mandible.

3. Results

The search yielded 135 titles and abstracts. Even abstracts reporting CAD-CAM mandibular reconstruction were considered to be potentially valuable. All papers were studied by the corresponding author and are included in this review if the CAD-CAM method and the reconstructive algorithm were described in a manner allowing the cases to be classified. Of all papers, 21 were not in English, and 94 did not match the inclusion criteria, or were studies in animals, or were not available, and were thus excluded. Ultimately, we selected 17 articles for review (Table 2). We recorded author(s), year of publication, institution or place of study, the number of cases described, the CAD method, the CAM method, the defect site, the donor site, and the number of bony segments required for reconstruction. All data were considered when preparing the reconstructive algorithm.

The literature contains data on 178 cases. Table 2 shows the reconstructive criteria and the CAD-CAM modalities applied. The most frequent defect site was the mandibular body, and the fibula was the most commonly used free flap (n = 136, 76.4%). The number of bony segments required varied by the site and size of the

Table 1
Reconstructive algorithm considering the different types of defect.

Class of defect	Mandibular subsites	Number of corners	Number of osteotomies needed	Reconstructive planning
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	

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