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DOI:10.1007/s00405-014-3078-3

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Step by step surgical technique for mandibular reconstruction with fibular free flap: application of digital technology in virtual surgical planning

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Key words: virtual surgery, mandibular reconstruction, fibular free flap, oromandibular reconstruction

Running title: Digital technology in mandibular reconstruction with fibular free flap

Abstract

BACKGROUND: At present, mandibular reconstruction with a fibular free flap is the gold standard for functional and esthetic rehabilitation after oncological surgery. The purpose of this study was to describe the computer assisted mandibular reconstruction (CAMR) procedure adopting the customized solution Synthes Pro-Plan CMF.

METHODS: The study reports five consecutive patients with benign or malignant disease requiring mandibular reconstruction using a microvascular fibular free flap, pre-operative virtual planning, construction of cutting guides and customized laser pre-bent titanium plates. The surgical technique is discussed in a step by step fashion.

RESULTS: The average postoperative hospital stay was 18 + /- 3 days. Ischemia time was recorded in all five cases, with an average of 75 +/– 8 min. No problems were encountered in any surgical step and there were no major complications. Excellent precision of cutting guides and a good fit of pre-bent plates were found on both the mandible and fibula. There was excellent precision in bone to bone contact and position between mandible and fibula graft. Measurement data from the pre-operative and postoperative CT scans were compared. The average difference (Δ) between programed segment lengths and CT control segment lengths was 0.098±0.077 cm.

CONCLUSIONS: Microsurgical mandibular reconstruction using a virtual surgical planning yields significantly shorter ischemia times and allows more precise osteotomies. The technology is becoming increasingly recognized for its ability to optimize surgical outcomes and minimize operating time. Considering that the extent of resection can be wider than predicted, this results in safer modeling of the fibula only after frozen sections have demonstrated the radicality of resection.

INTRODUCTION

Head and neck tumors can lead to devastating cosmetic and functional deficits with resultant psychological, physical, functional and nutritional impairments [1, 2]. Deformities of the head and neck region can have negative effects on the appearance and function of the patient and are among the most disabling and socially isolating defects having a significant impact on the patient's residual quality of life [1, 2]. Reconstruction of such defects continues to be an extremely demanding challenge for Head & Neck surgeons who aim to restore form and function with minimal surgical morbidity. Successful reconstruction, particularly microvascular, requires a team approach for careful preoperative assessment and development of a treatment plan [3, 4]. In particular, a tumor involving the mandibular bone requires a complex reconstructive plan. In the late 1980s, use of the fibular free flap (FFF) to reconstruct mandibular defects was described [5] and over the following years, many authors have contributed to optimize the technique [6–8]. Today, this option is the gold standard for mandibular reconstruction in many centers. One of the most delicate aspects of mandibular reconstruction is the technique of bone modeling partly because of the non-linear nature of mandibular bone. The risk of prolonging the period of ischemia and not restoring correct bone to bone contact, maxillo-mandibular and occlusal relationships, can ultimately lead to a higher rate of complications and poor esthetic and functional results [9].

Some interesting solutions have been introduced to improve the final outcome of mandibular reconstruction, for example, stereolithographic models allowing pre-bending of plates and the pre-plating technique as described recently by Pellini et al. [10].

The introduction of computer-assisted mandibular reconstruction (CAMR) with the pivotal role of virtual surgical planning has further increased the accuracy of the pre-operative plan which leads to greater precision of the surgical procedure and reduction of surgical time [11–13].

In this paper, we present and describe the CAMR procedure in a step by step fashion adopting the customized solution Synthes ProPlan CMF (Materialise, Leuven, Belgium). The aim is to demonstrate how virtual planning technology may provide a useful approach for a more precise final reconstruction of complex mandibular defects from both malignant and benign disease. We also posit that CAMR technology will significantly improve the overall reconstructive results, allowing for accurate recovery of oral functions and esthetic facial contours.

MATERIALS AND METHODS

The study reports five consecutive patients with benign or malignant disease requiring mandibular reconstruction with a FFF (osseous or osteofasciocutaneous) at Martini Hospital, Turin, Italy, between November 1, 2012 and July 30, 2013. The guidelines from the Helsinki Declaration were followed in this study. Informed consent was obtained from all the patients.

CAMR involves five steps: (1) Virtual surgical planning, (2) design and preparation of the customized mandibular reconstruction plate and cutting guides, (3) ablative surgery and FFF harvesting, (4) reconstruction, (5) post-operative comparison of pre-operative data, pre-operative virtual plan and final data.

Virtual surgical planning

This began with the acquisition of a 64-slice high resolution CT scan of the patient's craniofacial skeleton and angiographic CT scan of the lower leg as the donor site study for bone and for vessels. The Dicom data were sent to the modeling company. 3D rendering was performed using CMF software 6.1 (Materialise, Leuven, Belgium), which produced a three-dimensional model of both the mandible (Fig. 1) and the fibula. After a few days, an online meeting took place between surgeons and biomedical engineers from the modeling company. During the meeting, the following were sequentially determined: (1) the amount of bone resection required (from the clinical and radiological data, i.e. CT scan and MRI) considering at least a 3 cm margin for the osteotomy to fix the plate (Fig. 2), (2) the side of the FFF, (3) the type of reconstruction regarding the number of bone segments (segment length not less than 2.0 cm) (Figs. 3,4), (4) fibula and customized plate insetting and final position in relation to the remaining mandible and craniofacial skeleton (Fig. 3), (5) the degree of obliquity of the osteotomies both on the mandible and fibula (Figs. 4,5), (6) the number and position of screw holes both on the mandible (minimum of two on each mandibular stump) and fibular segments, (7) the shape and position of cutting guides (Fig. 6).

Communication between both teams was necessary to translate the surgical resection and reconstruction into a virtual model that could then be used to create cutting jigs and templates that were individually adapted to the patient's bony anatomy and that would ultimately lead to a seamless fibula–mandible continuity.

Design and preparation of the customized mandibular reconstruction plate and cutting guides

The resection/reconstruction data were used to prepare autoclavable cutting guides to be used during the mandibular resection and fibula harvesting as well as a model of the final reconstructed mandible and the laser pre-bent customized plate (Synthes GmbH, Zuchwil, Switzerland) (Fig. 7).

Ablative surgery and FFF harvesting

Normally, access to the resection block was via a visor flap. After neck dissection (where necessary), access to the mandible was obtained and the cutting guides were secured in the planned position without interfering with the tumor (Fig. 8); the osteotomies were completed with a sagittal or reciprocating saw through the cutting slots and the tumor was safely removed. In oral malignancies, frozen sections of the mandibular periosteum, bone marrow and soft tissues were then taken to check the radicality obtained. The screw holes in the cutting guides were designed to fit specific holes on the laser pre-bent reconstruction plate to maintain accurate maxillo-mandibular relationships of non tooth-bearing segments and provide additional anatomic reference points for mandibular plating. At the same time, a second surgical team proceeded to harvest the fibula according to the technique described by Hidalgo [5]. The fibular guides were secured to the harvested fibula to replicate the cuts for both the end and closing wedge osteotomies that were planned previously (Fig. 9). After positioning the cutting guides, the fibular distal and proximal osteotomies were performed with a margin of about 2 cm, proceeding then to the final shaping upon receipt of the results of the frozen sections. This still retained the excess periosteum/fascia at the level of these margins to 'wrap' the jawbone creating a 'guide' for the ossification [14].

Reconstruction

The shaped fibula was then secured to the laser pre-bent plate in the planned position (Fig. 10). The screw holes from the fibula cutting guides were designed to fit specific holes for the positioning and adaptation of the fibula with the laser pre-bent reconstruction plate. The fibula and plate were then fixed to the native mandible with extremely precise bone to bone contact and positioning (Fig. 11). The fibular pedicle was then positioned and microvascular anastomosis was performed.

Normally, 45 degree osteotomies were performed on both the mandible and fibula to obtain maximum bone to bone contact [15]. Finally, the operation was completed with soft tissue reconstruction (Figs. 12,13).

Post-operative comparison of pre-operative data, pre-operative virtual plan and final data

A 64-slice high resolution CT scan of the patient's craniofacial skeleton was performed within the first 6 months post-operatively and sent to the modeling company. To make the desired comparison, the pre-operative parameters, the pre-operative virtual surgical plan and the post-operative surgical outcomes were superimposed (Fig. 14) and the following measurements were calculated and compared: the intercondylar distance, intergonial angle distance, intercoronoid distance and fibular segment lengths.

RESULTS

The preoperative demographic data, programed fibular segment lengths and CT control segment lengths of the five patients undergoing FFF reconstruction using the preoperative virtual surgical planning are summarized in Table 1.

The average difference (Δ) between programed fibular segment lengths and CT control segment lengths was 0.098±0.077 cm.

All patients were managed primarily with surgical resection of benign or malignant disease involving the mandible. Segmental mandibulectomy and fibula osteotomies were always performed using prefabricated cutting guides; in all patients, surgical margins (soft tissues and bones) were tumor-free. Mandibular defects ranged from 7 cm to 11.8 cm with an average length of 8.5 cm and were grouped following Urken's classification for mandibular bone defects (Fig. 15). In one case, one fibular segment, in three cases, two fibular segments while in one case, three segments were used to create the neo-mandible. In four of the five cases, the symphysis was involved. Ischemia time was recorded in all five cases, with an average of 75 +/- 8 min. No problems were encountered during surgery.

High precision of cutting guides and a good fit of the pre-bent plate were found on both the mandible and fibula. Excellent precision was also noted in bone to bone contact and position between mandible and fibula graft. Intercondylar distance, intergonial distance and intercoronoid distance measurements taken from the pre-operative and postoperative CT scans as well as from the virtual surgical planning were compared and are reported in Table 2.

There were no major complications and the average postoperative hospital stay was 18 + /- 3 days.

Follow up ranged from 8 to 12 months. Two of the five patients received an implant supported dental rehabilitation (Figs. 15–17). Three patients who received radiotherapy will be subjected to corrective intraoral surgery before implant placement. In all five patients, we noted a pleasant esthetic final result (Fig. 18), with good oral function.

DISCUSSION

Fibular free flap is undoubtedly the current gold standard for mandibular reconstruction and its use has evolved in parallel with progress in biomedical technology [17, 18]. The classical technique for reconstruction described by Hidalgo involved manual remodeling of the fibula by one or more subtractive osteotomies and subsequent fixation with standard plates manually bent intra-operatively [5]. This strategy resulted in poor accuracy of reconstruction, a long ischemia time and duration of the entire procedure, and risky maneuvers involving the vascular pedicle and perforators, which resulted in a major complication rate ranging between 25% and 35% [6, 7, 9] with the highest failure rate (35%) in the anterior region [19].

The introduction of stereolithographic models of the mandible has made it possible to bend the plate preoperatively [20], resulting in a positive impact on the accuracy of reconstruction and a reduction in surgical times. Recently, a further refinement of reconstructive strategy was made possible with the introduction of CAMR involving distinct phases of the surgical procedure. This has permitted the development of prefabricated cutting guides and in turn, more precise, efficient osteotomies. Such thorough preoperative planning has created a technique that is meticulously outlined with the potential for error minimized [21].

Our experience with CAMR is only recent, compared to a longer, good experience with stereolithographic models for pre-bending the reconstruction plate. Comparing these two techniques, we found a number of advantages in favor of CAMR. The availability of cutting guides for both the mandible and fibula resulted in increased safety of the whole procedure, but in particular, of the fibular remodeling step, which can be carried out either in the leg or in ischemia. This leads to an appreciable reduction in the duration of surgery, in particular of the time of ischemia. We compared the last five computer aided procedures with a control group consisting of the same number of consecutive procedures, similar in terms of resection and reconstructive choice, in which plate pre-bending and fibular modeling were performed on a stereolithographic model. The mean times of ischemia were, respectively, 75 +/- 8 min and 105 +/- 29 min. The surgical procedure was performed in less time than a conventional procedure, in particular, reducing the time required for plate and bony contouring and fixation of the fibula. The mandibular cutting guides are secured with 9-mm screws distally from the tumor. This is a positive aspect from an oncological point of view, especially when the outer cortex is involved. The guide holes correspond precisely to the holes in the pre-bent plate. Similarly, the fibula cutting guides are secured using holes which also correspond to the holes in the plate. Therefore, excellent precision and speed in mandibular reconstruction are achieved avoiding any form of manipulation of the part of the mandible to be resected. This does not affect the safety of an en-block resection of the tumor especially when associated with neck dissection. The traditional technique of pre-plating can often involve such limitations from an oncological point of view. For this reason, Pellini recently described an interesting, safe and rapid technique for pre-plating using two plates during the pre-plating phase [10].

Another interesting feature of CAMR is the possibility to easily program osteotomy lines oblique to the long axis of the fibula and mandible in an attempt to increase the contact area between the two bone surfaces. In our experience, the choice of a 45 degree oblique osteotomy, towards the inner mandible, has proved to be extremely effective; this allows about 1 cm of further radicality to be gained on the side of the tumor with an increase in the contact area of about 35.3% compared to a traditional 90 degree cut, as demonstrated by Haddock et al. [15]. This detail is also easily obtained by securing cutting guides to the bone surfaces.Laser modeled plate offers precise adaptation to the residual mandibular bone and the new mandibular contour. Moreover the plate is not weakened by manual bending and, in particular, the condylar position is not altered. The use of a single plate stabilizes both the condylar position and its relationships and may be inhibiting volumetric contractions due to bone graft remodeling (especially in length) [22, 23]. In mandible reconstruction, it is still unclear how the fibular free flap changes in volume but there are no studies on length changes. There are too many factors that could influence the fibular remodeling processes [9, 22], so from this point of view, further investigations are needed on the remodeling processes of the fibular free flap in mandibular reconstruction, especially after implant and prosthetic rehabilitation. In our opinion, use of the reconstruction plate is particularly indicated in patients who need radiotherapy after surgery to prevent micro-movements during ossification, especially during radiotherapy.

The reduction of time required for the reconstructive phase allows correct dental implant placement and prosthetic restoration simultaneously in patients not requiring post-operative radiotherapy. With the simulation system, guides for the placement of dental implants could also be prepared [24] but we did not use this service, placing dental implants under optical control in two cases. Ablative and reconstructive teams can work simultaneously following the program previously agreed between all interested specialists and, thanks to very accurate insetting, the esthetic (mandibular edge and contour of the lower third of the face) and functional outcomes (condylar position not altered) are guaranteed. Furthermore, in the case of an altered maxillo-mandibular relationship, this technology allows a correct new "mandible" position to be obtained and to program, when possible, an implant supported prosthetic rehabilitation. Among the disadvantages of CAMR, there is the need to program resection with great precision, in advance of the time of surgery. This decision must be derived from a careful study of the clinical case as well as excellent and complete imaging. In practice, the 'real' time of the decision-making procedure is not at the operating table but during the simulation in the video-conference, at which time, the whole team must have all the information needed to minimize a possible staging error. Nevertheless, we believe it is safer to perform final osteotomies on the fibular proximal and distal segments when frozen sections of the mandibular periosteum, bone marrow and soft tissues have demonstrated the complete radicality of resection.

After positioning the cutting guides, the distal and proximal fibular osteotomies were carried out with a margin of about 2 cm, and then upon receipt of the results of the frozen sections, final shaping was performed. This still retains the excess periosteum/fascia at the level of these margins to 'wrap' the remaining mandible creating a 'guide' for the ossification [14]. This strategy is useful in that the advantage of the reduction in surgical time is not lost and it allows the teams to work simultaneously. The time for completion of the project, cutting guides and customized plate is not fast; in our experience, the average time was 23 + /- 3 days. CAMR, construction of cutting guides and provision of a customized laser pre-bent plate give an additional cost of about 2500 €, compared to a standard pre-bent plate. This cost, although important, will pay for itself with the time saved in the operating theater and the reduction in complications, determined by repeat manipulation of the flap during the remodeling phase and prolonged ischemia. Moreover, CAMR allows fibular segments to be placed in a useful position for possible dental rehabilitation. In fact, the surgeon has to keep in mind that planning for implantation begins before surgery and the positioning of final fibular segments should also be programed as a function of a possible dental rehabilitation with osseointegrated implants that are often an integral part of mandibular reconstruction [25]. This consideration is very important in patients undergoing radiotherapy in whom it will be difficult to make further bone corrections such as onlay bone grafts and osteo-distraction. In the authors' experience, it is very important to perform, when possible, the most precise reconstruction both for esthetic and future functional outcome. In particular, in oral malignancies, a good first reconstruction is better than a secondary one. Secondary microvascular reconstruction could present many problems such as absence of veins and poor local tissue quality, especially after radiotherapy. CAMR was found to be very safe. No major complications occurred and the average postoperative hospital stay was 18 +/- 3 days. Exposure of the plate for a length of about 2 cm occurred in only one case in a patient undergoing resection of the left hemi-mandible extending to the chin, reconstructed with a fibular osteofasciocutaneous flap and subsequently subjected to radiotherapy. The dehiscence occurred due to thinning of the fibular skin corresponding to a prominent angle of the plate, teaching us to avoid sharp angles in the CAMR as much as possible in future, especially if post-operative radiotherapy is programed.

Regarding the accuracy of the reconstruction and the correlation between virtual surgical planning and subsequent achievement, we have confirmed that there were only minimal variations in measurements, in particular, variations in transverse measurements. The same measurements performed on a control group representing the last five cases undergoing reconstruction programed on a stereolithographic model showed a greater variability of these parameters.

CONCLUSION

CAMR fosters multidisciplinary communication and allows accurate pre-surgical planning. This leads to seamless reconstruction in patients requiring mandibular reconstruction by fibular free tissue transfer. The combination of mandibular and fibular cutting guides and templates allows for a precise and efficient surgical reconstruction. Moreover, virtual surgical planning is becoming an increasingly recognized technology for optimizing surgical outcome and minimizing operating time. This technology is especially useful in minimizing operating time in complex defects where an osteofasciocutaneous flap is used for defect reconstruction. In summary, we posit that using CAMR and virtual surgical planning for mandible reconstruction after ablative surgery will significantly improve functional outcomes, allowing for accurate recovery of the facial contour with decreased surgical time. In addition, in meticulous ablative surgery, the extent of resection can be wider than predicted, resulting in safer modeling of the fibula only after frozen sections have demonstrated the radicality of resection.

Conflict of Interest

There are no competing interests for this article.

Financial disclosure

No sponsorships have been disclosed for this article.

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Table 1. Pre-operative demographic data, programed fibular segment lengths and CT control segment lengths

Sex	Age	Pathol	U.C.	Res (cm)	N° SEG	PrSEG. 1	PrSEG. 2	PrSEG. 3	PoSEG. 1	PoSEG. 2	PoSEG. 3
M	59	SCC	BS	8.859	2	2.368	5.057		2.411	5.091	
F	71	SCC	BS	7.064	2	4.111	2.041		4.011	2.151	
M	49	DISP	BS	11.864	3	4.891	3.221	2.885	4.831	3.311	3.171
F	69	SCC	BS	7.759	2	3.921	3.625		3.931	3.501	
F	44	SCC	B	7.685	1	7.721			7.851		

Pathol: pathology affecting the mandibular bone; SCC: squamous cell carcinoma; DISP: fibrous dysplasia
U.C.: Urken classification of mandibular defects: C-condyle, R-ramus, B-body, SH-symphysis (half), S-symphysis.
Res: length of programed resection (cm)
N° SEG: number of fibular segments programmed for mandibular reconstruction
Pr.SEG: programmed average length of fibular segments (cm)
PoSEG: Post-operative average length of fibular segments emerging from control CT scan (cm)

Table 2 Intercondylar distance, intergonial distance and intercoronoid distance measurements taken from the pre-operative and postoperative CT scans as well as the programed fibular segment lengths

Sex	Age	Pathol	U.C.	Res (cm)	N° SEG	COND.PR	ANG.PR	COR.PR	COND.PO	ANG.PO	COR.PO
M	59	SCC	BS	8.859	2	9.327	8.953	9.252	9.371	8.969	9.288
F	71	SCC	BS	7.064	2	8.905	8.107	8.212	8.907	8.115	8.221
M	49	DISP	BS	11.864	3	11.049	9.354	8.357	11.047	9.386	8.386
F	69	SCC	BS	7.759	2	8.703	10.161	8.987	8.718	10.154	9.012
F	44	SCC	B	7.685	1	8.804	8.042	8.128	8.765	8.104	8.145

Pathol: pathology affecting the mandibular bone; SCC: squamous cell carcinoma; DISP: fibrous dysplasia
U.C.: Urken classification of mandibular defects: C-condyle, R-ramus, B-body, SH-symphysis (half), S-symphysis.
Res: length of programed resection (cm)
COND.PR: pre-operative CT-scan intercondylar distance (cm)
ANG.PR: pre-operative CT-scan intergonial distance (cm)
COR.PR: pre-operative CT-scan intercoronoid distance (cm)
COND.PO: post-operative CT-scan intercondylar distance (cm)
ANG.PO: post-operative CT-scan intergonial distance (cm)
COR.PO: post-operative CT-scan intercoronoid distance (cm)

Fig. 1 3D reconstruction of patient's craniofacial skeleton with neoplasm involving the mandibular bone. Frontal, lateral and inferior view.
Fig. 2 3D reconstruction of patient's craniofacial skeleton, inferior view, with programed mandibular resection in red.
Fig. 3 a) Mandibular reconstructive program with three fibular segments; orange parts were trimmed off manually during surgery, b) superimposition (inferior view) of reconstructed and native mandible; removed mandibular part indicated in red (transparent), c-d) superimposition (lateral left and right view) of reconstructed and native mandible; removed mandibular part indicated in red (transparent)
Fig. 4 Lateral and anterior view of patient specific right fibula graft (three segments)
Fig. 5 Mandibular osteotomy plane study
Fig. 6 Guide design: mandibular resection guides (left and right)
Fig. 7 Model of the final reconstructed mandible and the laser pre-bent customized plate
Fig. 8 Right mandibular resection guides fixed on the mandible
Fig. 9 Right fibula cutting guides fixed on patient's fibula
Fig. 10 Modelled fibula fixed on the laser pre-bent customized plate
Fig. 11 Fibula and reconstructive plate fixed on the native mandible; extremely precise agreement between pre-operative program and intra-operative findings
Fig. 12 Suprahyoid muscle repositioning
Fig. 13 Patient's profile immediately after surgery
Fig. 14 Comparison between mandibular reconstructive program (a), fibular segment length program (b), and post-operative CT segment length (c)
Fig. 15 Dental implant positioning 3 months after reconstructive surgery
Fig. 16 Radiologic control immediately after implant positioning
Fig. 17 Patient's profile 6 months after surgery
Fig. 18 Implant supported dental rehabilitation 7 months after reconstructive surgery