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Alterations in surgical interventions to improve the prosthetic prognosis in patients with mandibular defects: a review of the literature

G. RUGGIERO[1], N. BOCCA[2], M. CAROSSA[2], G. GASSINO[2]

[1]Department of Neurosciences, Reproductive and Odontostomatological Sciences, University "Federico II" of Naples, Naples, Italy
[2]Department of Surgical Sciences, Interdipartimental Center of Research (CIR), Dental School, Oral and Maxillofacial Rehabilitation, University of Turin, Turin, Italy

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ABSTRACT

Aim The present review was aimed to identify the surgical procedures to enhance the prosthetic prognosis in patients with mandibular defects.
Methods A literature search was performed on the databases PubMed/Medline, Scopus, Embase, Google Scholar, Dynamed and Grey Literature, in addition to congress proceedings and books written in Italian or English language. The literature search was conducted using the following keywords: ("prosthesis" or "prosthetic") AND "prognosis" AND "mandibulectomy"; ("prosthesis" or "prosthetic") AND "prognosis" AND ("defect" or "reconstruction" or "resection") and ("mandibular" or "mandible").
Results The selection process yielded 43 papers after the databases search, while 7 books and 3 congress proceedings were included after the manual search.
Conclusion To enhance the prosthetic prognosis, the surgeons must preserve the tongue mobility and as many teeth as possible; vestibuloplasty could be needed, while intraseptal bone cuts and specific resection lines are recommended. The use of fibula graft, osseointegrated implants, and digital technologies can improve the prosthetic prognosis.

KEYWORDS Mandibulectomy, Prosthetic prognosis, Microvascularized graft, Mandibular defect, Maxillofacial prosthesis.

INTRODUCTION

Mandibular defects may result from surgical interventions for benign or malignant tumors, inflammatory diseases, or trauma. Reconstruction of the mandible and soft tissue defects should be done at the time of the surgery. If the mandible can not be reconstructed at the time of tumor ablation, minor alterations in the surgical resection may improve rehabilitation prospects (1). The more extensive is the surgical resection, the worse is the patients' prognosis for maintaining dentition (2).
Several systems of classification were described for mandibular defects, but no one of them is universally accepted (3-12). Among the most recent classification systems, the one described by Iizuka et al. included 4 classes based on the type of mandibular defect and the number of fibular osteotomies required. Class I: no osteotomy; Class II: one osteotomy; Class III: two osteotomies; Class IV: three or more osteotomies; this last class was a special type of Class III, which applied to females with small chins. Additional anterior osteotomies in Class IV were required for the reconstruction of the chin contour; however, the extent of the bony defect was the same as in Class III. Vascularized flap accessory soft tissues (skin and muscle) were used in all the classes to reconstruct the corresponding soft-tissue defect (11, 13).
As a consequence of the mandibulectomy, a series of complications can occur: partial or complete loss of chewing ability, difficulty in swallowing, reduced phonetic capability, incontinence of saliva, insufficient width of the oral orifice and serious psycho-social complications, deriving not only from functional alterations but also from aesthetic complications. Furthermore, in cases of loss of mandibular continuity, the patient becomes monocondylar, with negative alterations of the mandibular dynamics.
The prosthetic rehabilitation represents a valid solution to improve the aesthetic-functional status altered by the surgical resection that caused a mandibular defect.

Unfortunately, not all mandibulectomy interventions are always performed considering the prognosis of a subsequent prosthetic rehabilitation; so, it is very important that during surgical planning, the clinical team considers some surgical procedures to improve prosthetic prognosis. The use of free fibula bone graft, osseointegrated implants, and digital technologies could improve the prognosis of such prosthetic rehabilitation. The present literature review aimed at assessing the surgical modifications to enhance the prosthetic prognosis in patients with mandibular defects after mandibulectomy.

METHODS

Search strategy

An extensive literature search was performed on the databases of PubMed/Medline, Scopus, Embase, Google Scholar and Dynamed in addition to Grey Literature, congress proceedings, and books related to the prosthetic rehabilitation of the mandibular defects; the authors examined the reference lists of the identified records to prevent losing relevant studies.
Literature search was conducted using the following keywords combinations:

- ("prosthesis" or "prosthetic") AND "prognosis" AND "mandibulectomy";
- ("prosthesis" or "prosthetic") AND "prognosis" AND ("defect" or "reconstruction" or "resection") and ("mandibular" or "mandible").

The literature search was completed in April 2020, and the studies included in the present review were published between 1968 and January 2020.
The number of records for each database is reported in Table 1.

Inclusion and exclusion criteria

Studies were considered as suitable for the present review if they met the following inclusion criteria: studies that provide useful indications about the surgical procedures to enhance the prosthetic prognosis in patients with mandibular defect; *in vivo* studies and studies published in Italian or English language.
Exclusion criteria were the following: *in vitro* studies and studies written in languages other than English or Italian.

Data extraction

Three authors separately chose the papers reading the titles, abstracts, and keywords according to the inclusion criteria. The full text of each identified paper was read to

Database	Search strategy	Records
PubMed/Medline	("prosthesis" or "prosthetic") AND "prognosis" AND "mandibulectomy"; ("prosthesis" or "prosthetic") AND "prognosis" AND ("defect" or "reconstruction" or "resection") and ("mandibular" or "mandible")	52
Scopus	("prosthesis" or "prosthetic") AND "prognosis" AND "mandibulectomy"; ("prosthesis" or "prosthetic") AND "prognosis" AND ("defect" or "reconstruction" or "resection") and ("mandibular" or "mandible")	95
Embase	("prosthesis" or "prosthetic") AND "prognosis" AND "mandibulectomy"; ("prosthesis" or "prosthetic") AND "prognosis" AND ("defect" or "reconstruction" or "resection") and ("mandibular" or "mandible")	66
Google Scholar	("prosthesis" or "prosthetic") AND "prognosis" AND "mandibulectomy"; ("prosthesis" or "prosthetic") AND "prognosis" AND ("defect" or "reconstruction" or "resection") and ("mandibular" or "mandible")	1715
Dynamed	("prosthesis" or "prosthetic") AND "prognosis" AND "mandibulectomy"; ("prosthesis" or "prosthetic") AND "prognosis" AND ("defect" or "reconstruction" or "resection") and ("mandibular" or "mandible")	0
Grey Literature	("prosthesis" or "prosthetic") AND "prognosis" AND "mandibulectomy"; ("prosthesis" or "prosthetic") AND "prognosis" AND ("defect" or "reconstruction" or "resection") and ("mandibular" or "mandible")	0
Congress Proceedings	Manual search of the congress proceedings carried out during the events of the "International Congress on Maxillofacial Prosthetics" and of the "International Congress on Pre-Prosthetic Surgery"	3
Books	Books published in Italian or English regarding maxillofacial prosthetic rehabilitation	7

TABLE 1 Number of records for each database.

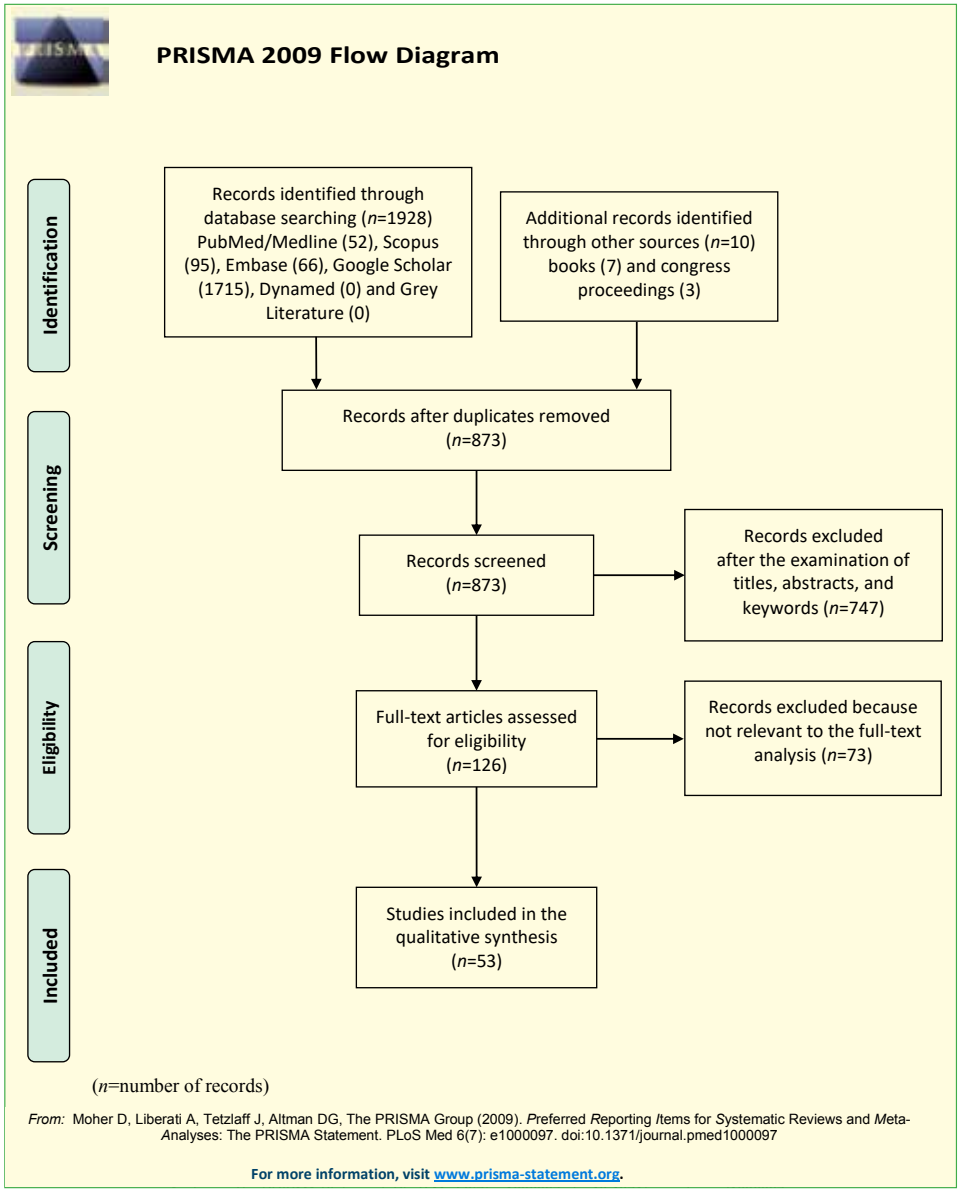

FIG. 1 Search flowchart as described in the PRISMA guidelines.

decide whether it was appropriate for inclusion. Where the investigators disagreed, a majority criterion (i.e. 2 out of 3) was used.

RESULTS

Study selection

The search strategy produced 1928 records, many of which were duplicates, 52 from PubMed/Medline, 95 from Scopus, 66 from Embase, 1715 from Google Scholar, 0 both from Dynamed and Grey Literature. All the duplicates were deleted, so 863 records were considered from all the selected datasets. After evaluating titles, abstracts, and keywords, the reviewers excluded 747 records that did not meet the criteria for inclusion. Of the remaining 116 records, 73 were excluded because they did not provide useful information to evaluate which surgical procedures should be followed to enhance the prosthetic prognosis after mandibular resection. The remaining 43 articles were included in the present review.

Moreover, a manual search was performed through books of maxillofacial oncology and maxillofacial prosthesis and congress proceedings of the following events: the "International Congress on Pre-Prosthetic Surgery" and the "International Congress on Maxillofacial Prosthetics". After the manual search, 3 congress proceedings and 7 books were included because they met the criteria for inclusion.

The search flowchart, as described in the PRISMA guidelines, is shown in Figure 1 (14).

Evaluated surgical procedures

After the review of the literature, the authors identified

the surgical procedures on which to focus to improve the prosthetic prognosis in patients with mandibular defects: the need of a sufficiently large oral orifice, the intraseptal bony cut and the direction of the mandibular resection lines, the importance of both tooth and tongue preservation, the usefulness of skin grafting and vestibuloplasty, the management of the radiotreated patient and the possible removal of the coronoid process. Free flaps, implant rehabilitation, and new digital technologies were also thoroughly assessed.

Oral orifice

The oral orifice must be sufficiently large for the oral function and the insertion of prostheses. If the oral orifice is too narrow, it will not be possible to insert the prosthesis as well as it will be even difficult to insert the impression tray or the prosthetic bases, essential for carrying out the procedures that allow the prosthodontist to make the prosthesis.
Surgery that affects the lips should try to maintain or restore mobility and sensation, contour, intercommisure distance, and labial vestibules. Surgical procedures that violate the structural integrity of the lips or cause sensory or mobility dysfunction, especially of the lower lip, may jeopardize oral competency and therefore the prosthetic prognosis (15-17).

Intraseptal bony cuts and mandibular resection line

Through the dentulous region of the mandible, the bony cuts should be intraseptal, rather than interproximal. This would lead to a higher bone level for the tooth adjacent to the surgical defect, making the tooth more suitable as an abutment for partial dentures and without compromising its pulp vitality or periodontal status. To avoid dehiscence of approximated soft tissue or flaps over the cut bone surfaces, these last should be recontoured and smoothened (1, 15).
If mandibular reconstruction is not planned at tumor ablation, but at a later date, each mandibular fragment must maintain its presurgical position. Both fragments are susceptible to displacement by contracture of the scar and/or contraction of the mastication muscles. The posterior resection line should be made vertically in a resection of the lateral portion of the mandible, from sigmoid notch to angle, rather than horizontally across the ramus (18). The unopposed contraction of the temporalis muscle, when the mandible is resected horizontally, displaces the fragment superomedially under the zygomatic arch, making it difficult to recover later during reconstruction. If the mandible is vertically resected the fragment remains in a relative usual anatomical location (1).

Tooth preservation

When osseous resections are needed, it is important to save as many teeth as possible.
Sporadically, if the remaining teeth are too close to the margins of a segment that is to be reconstructed, they may be damaged or lost due to improper positioning of stabilizing devices to maintain the grafted bone in place. Remaining teeth allows reconstruction as they help to orient the segments into proper maxillomandibular and occlusal connections.
Also, they can be used with intermaxillary fixation to stabilize the segments.
Patients with fewer residual teeth reported worse prosthodontic performance when compared to individuals with more remaining teeth (19). More teeth present in the arch enhance retention, support, and stability of the dental prostheses. Furthermore, the use of abutment teeth bilaterally to the midline allows obtaining prostheses with retentive elements, which enhance prosthesis support (20). For this purpose, the preservation of mandibular canines is particularly beneficial (1, 15, 16).

Skin graft and vestibuloplasty

A split-thickness skin graft is the ideal tissue surface for prosthesis-bearing on a resected site. This graft is hairless, thin, tightly attached to the mandible, and it would not move with tongue, mouth floor, or cheek movements (21).
In extensive defects, the absence of attached mucosa and obliteration of vestibules may need a combination of skin graft and vestibuloplasty. The vestibule loss does not enable prosthesis to be retained satisfactorily. When there are neurological deficiencies and soft-tissue defects, this will be further compromised (10, 19, 20). Bands of scar tissue are also frequently found to cross the residual alveolar ridge between the lip and the tongue in anterior defects. Thus, without vestibuloplasty and the creation of denture-bearing surfaces with attached tissue, there will be displacement of these tissue bands on the movement of the lip or tongue. There will not be an effective engagement of the load-bearing surfaces by the prosthesis and there will be irritation of these tissues because of the prosthesis (22).

Free flaps

Free flaps were introduced in the mid-1980s to restore large hard and soft tissue defects associated with resection of mandible and tongue tumors. Like musculocutaneous flaps, the procedure is used to cover tissues lost to the resection of the tumor. The use of microvascularized flaps allows the simultaneous reconstruction of hard and soft tissues. Several donor sites were used to restore oral cavity defects, including iliac crest, fibula, radial forearm, thigh, and scapula. The iliac flap or the fibula is indicated for the jaw, while the forearm flap is indicated for the oral floor (1, 23).
Currently, the free fibula bone graft can be considered the "gold standard" for mandibular reconstruction for composite oral cavity defects (24).
The fibula is a straight bone, unlike the mandible. To

restore the mandibular anatomical configuration and continuity, the fibula can be osteotomized conforming to the location and extent of the defect. The bone fragments could be fixed in a functional relationship to the maxillary teeth and the maxilla using a reconstruction plate (11).
In many cases, the thickness of the fibula (average diameter of 1.3 cm) is smaller than the basal bone plus the alveolar bone of mandible. This situation leads to a serious discrepancy between the occlusal plane identified by the old prosthesis and the residual one after the healing of the fibula.
This graft could be placed to recover the basal portion of the mandible, according to the aesthetic concept of reconstruction of the external profile of the face: this principle requires that, in order not to alter the features of the lower third of the face and, therefore, the profile of the chin, the fibula must be positioned following the line identified by the lower margin of the residual mandibular body; however, this principle is independent of the prosthodontist's final prosthetic-rehabilitation needs. When the thickness of the fibula is not ideal for implants insertion, the improvement of the additional fibula bone can be obtained by two surgical techniques. The first technique is osteodistraction. The second one is the "double barrel" technique at the time of reconstructive surgery; this surgical technique involves a doubling of the fibula thickness, that is folded back on itself to give a double thickness to the bone graft.
When it is not possible to use these surgery techniques, it is preferable to use a removable prosthesis that provides for the recovery of both dental and osteomucous components lost due to the intervention. It is worth noticing that in this case, it is necessary to restore with a skin graft the adherent gingiva lost after surgery (23). However, other authors suggested fixing the fibula bone more cranially and posteriorly than the base of the original mandible to imitate the course of the mandibular alveolar crest and to allow the implant-supported dental suprastructure to be located in a functional relationship with the residual maxillary teeth or maxillary prosthesis (11).
Among the microvascularized free flaps, only 3 have favorable characteristics for the insertion of osseointegrated implants: the flap of the iliac crest, scapula, or fibula; the success rate of the implants varies from 85.7% to 100%, without statistically significant differences on the animal model (25).
Conversely, differences in clinical behavior are present above all about the adaptability of the various flaps to prosthetic rehabilitation with implants: the iliac flap seems to be the most suitable, followed by the scapula and fibula (23).
The choice between fixed or removable prostheses depends on some factors such as the availability of bone, the number and the location where the implants can be placed, the patient's hygiene ability, and the psychological complications (26).
It seems there is no difference in the quality of life between patients with fixed prostheses and patients with removable prostheses, though about chewing efficiency, using implant-supported fixed protheses is recommended in patients who had undergone free fibula flap surgery (27).
A fixed prosthesis may stimulate the bone but may be more difficult to adjust due to anatomical conditions and particularly a reduced opening of the mouth. It also needs a large number of implants, which in these patients is not always possible. A fixed prosthesis is advised in case of short grafts and it can be either screwed or locked.
As regards the removable prosthesis, it needs fewer implants and oral hygiene, follow up and rehabilitation are easier. The removable prosthesis allows the clinician to obtain very satisfactory aesthetic results, quickly and generally with reduced costs compared to the fixed prosthesis, but mucosal problems could arise particularly in patients treated with radiotherapy.
According to the classification system proposed by Iizuka et al., either fixed denture (or bridge) or removable partial dentures are recommended in class I. For classes II, III, or IV, a removable denture bar-supported is recommended. This needs fewer implants (2 to 4), enables occlusal adjustment, reduces stress on implants, and simplifies hygiene (13, 28).

Implantology

Quality and quantity of residual and reconstructed tissues available

During preoperative treatment planning, the selection of flaps must be considered. The bone site must provide enough width and length to accommodate implant fixtures of appropriate size to support prosthesis function over time (29, 30). For predictable results, it was proposed that 10 mm of vertical bone height and 6 mm of horizontal bone width should be available (31).
The fibula and iliac crest bone flaps typically have a sufficient bone volume for implant placement (32). It is recommended that a minimum of 2 mm of circumferential keratinized, attached tissue be available to provide the optimal peri-implant environment (16, 22, 29).

Number of implants and healing time

According to literature, in patients with malignancies affecting the lower oral cavity region, a minimum of 4 implants are required for sufficient implant support for the prosthesis and soft tissue relief, particularly after radiotherapy.
The abutment connection could be performed after 3 months, as in non-oncological and non-irradiated patients. Moreover, for the patient who has undergone irradiation in the implant region, it is advisable to wait 4-6 months after implant placement before the

abutment connection. With this method, the implants get more time for their osseointegration and at the time of the abutment connection the early effects of the radiation on the soft-tissue are solved. Nevertheless, it is unclear whether the implants need this additional time because osseointegration mostly occurred before radiotherapy began.
Ideal treatment-related healing time of implants before loading is still needed for further research for these oncology patients. By contrast, there is an agreement that prosthodontic rehabilitation should start two weeks after the connection of the abutment.
A minimum of 4 implants is recommended in irradiated patients. These implants should be located in optimally spaced locations for the best possible distribution of occlusal loads (33).
In case of defects with loss of continuity, if the residual defect permits and the inter-foramina portion is edentulous, the placement of 2 or more implants with anchor ball attachment is recommended. In this way, it is possible to improve the support, but also retention and stability of the prosthesis (23).

Flaps' mobility and thickness
Soft tissues covering bone flaps are often mobile or excessively thick (34-35). Secondary surgical procedures may be needed to debulk and decrease soft tissue mobility and create a conducive peri-implant soft tissue environment. If the soft tissue is too thick there is the possibility of deep peri-implant pockets resulting from implant abutments passing through thick tissue beds before entering the oral cavity (22, 36). This condition predisposes to infection that may spread to the underlying bone and contribute to implant failure (16, 22).

Reactive hyperplasia
Serious mucous problems occur when bone reconstruction is not associated with a skin graft, that recreates a tissue similar to the adherent mucosa. In the absence of this tissue, in effect, the mucous membrane undergoes reactive hyperplasia (due to plaque accumulation) in the areas adjacent to the prosthesis anchored on implants. This hyperplasia seems to be particularly relapsing and massive, so much that continuous gingivectomy operations are necessary. For these reasons, it has become imperative, in the case of insertion of implants on microvascularized fibula grafts, the reconstruction of a tissue similar to the adherent mucosa (skin graft) in the area of the emergence profile of the implants (23).

Tongue reconstruction

The tongue is the most important oral structure regarding speech, swallowing, mastication, and control of saliva. Its bulk should be restored, and the reconstruction should be designed to maximize the mobility of the tongue remnant (1).
Impairment of motor and/or sensory control of the tongue adversely affects the patient's ability to control saliva, food bolus, speech, and removable prostheses (16, 37). Functional disabilities associated with resections of the tongue and mandible depend mainly on the amount of tongue resected and the method of closure. When the surgical wound is closed primarily by suturing the edges of the wound together (for example, by connecting the midline of the residual tongue to the buccal mucosa), the functional disabilities are exacerbated. As a consequence, the treatment could leave many disabled patients unable to control their saliva, speech, swallow, or appear presentable (1).
Patients with severe tongue impairment will not regain complete masticatory efficacy even with implant prosthetic treatment. Implant use does not overcome the functional limitations of an immobile, insensitive tongue, nor does it improve the mandibular motion (17, 22).

Coronoid process

For edentulous cases, the condyle and remaining ascending ramus will have to be removed if the mandibular reconstruction is not performed at the time of tumor ablation. If a condylar-coronoid fragment remains, it is often retracted anteriorly and medially and approximates the maxillary tuberosity and it may cause the inflammation of the adjacent mucosa. Moreover, this condition prevents proper extension of the maxillary complete denture into the buccal pouch area so important for the stability and retention of the prosthesis (38-40).

Radiotherapy

Radiation therapy leads to a reduction in periosteum remodeling capacity (41). After completion of radiation therapy, the overlying mucosal epithelium is thinner and shows decreased keratinization (42-43), while the submucosa slowly increases in collagen content and becomes less vascular and more fibrotic (44). Such conditions lead to an impairment in the load-bearing ability of both the reconstructed and native tissues (34). These variations in tissue make the prosthesis tolerance more difficult and may increase the risk of tissue abrasion and potential tissue necrosis (42-43). Furthermore, irradiated patients usually have xerostomia, which can reduce the vacuum effect of the prosthesis base on the soft tissues, thereby reducing their retention (13).
If the use of radiotherapy is not planned, then the placement of implants will be indicated at the time of surgical resection of the tumor, but if the use of radiotherapy is planned, the placement of the implants must be made at least one and a half months before the first radiotherapy session (45-48).
Furthermore, there is an increased risk of failure if

implants are placed within a period of fewer than 12 months after radiation therapy, however, there is no evidence from clinical trials to validate this risk (38, 49).

Digital technologies

It is undisputed that digital technologies have become popular in all fields of dentistry. These technologies can improve the prosthetic prognosis, through the production of a more accurate and highly biocompatible prosthesis and with innovative surgical procedures that enhance the biological and mechanical conditions of the tissues on which the prosthesis interfaces.

More specifically, between these technologies, computer-aided design (CAD) systems, computer tomography (CT), reverse engineering, rapid prototyping, and the milling process, allow following a digital workflow that represents a valid alternative to the conventional procedure to make a maxillofacial prosthesis (50). Through CAD systems it is possible to design both the denture and the framework on which the denture will be placed. Polyetherketoneketone (PEKK) and zirconia are biocompatible materials that can be used as a framework for dental prostheses on implants inserted in fibula grafts (51-52).

To date, unfortunately, scanning a mandibular defect with an intraoral scanner is not a procedure that allows obtaining an accurate reproduction of the jaw. This is due to soft tissue mobility. For this reason, it is recommended to use the conventional procedure of making the impression with elastomeric materials, to develop the gypsum model that can be scanned with a laboratory scanner. Alternatively, it is possible to scan the elastomeric impression directly with a laboratory scanner and then reverse the scan of the impression to obtain a digital reproduction of the mandible. In this second choice, there is not the inaccuracy caused by the dimensional changes that occur during the setting of the gypsum (53).

Moreover, thanks to digital planning technologies, it is possible to prepare the shape of the new mandible from the fibula graft and place the implants on it before that the graft is placed. The surgical approach that allows this requires 2 main phases. In the first phase, the implants are inserted into the fibula and covered with a split-thickness skin graft to create a gingival-like tissue. In the second phase, the fibula is harvested, osteotomized, and fixed with the denture on the pre-inserted implants. Therefore, guided by the occlusion, the fibula is placed in its final position (54).

CONCLUSION

The clinical team must perform some surgical procedures to improve the prosthetic prognosis of patients undergoing mandibulectomy. In this regard, the surgeon must try to preserve the tongue mobility and save as many teeth as possible; moreover, it could be necessary to perform the vestibuloplasty, while intraseptal bony cuts and specific resection lines are strongly suggested. Furthermore, using free fibula bone graft, osseointegrated implants, and digital technologies can significantly enhance the prosthetic prognosis after mandibulectomy.

Conflict of interests

The authors declare no potential conflict of interests.

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