# REVIEW OF LITERATURE CONCERN RECONSTRUCTION OF THE MANDIBLE AND THE MAXILLA-PAST, PRESENT AND FUTURE

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**Abstract:**

The reconstruction of segmental mandibular and maxillary defects remains a challenge for the reconstructive surgeon, from both a functional and an esthetic point of view. This paper reviews the history of oral cavity, especially of the maxillary and mandibular defects reconstruction over the past 60 years and evolution of surgical and prothetic reconstruction, examines the different techniques currently in use for mandibular and maxillary reconstruction as related to a range of etiologies, including the different bone donor sites, the alternative to free flaps, as welll the contribution of computer-assisted surgey. Osseouss free flaps allows relable and satisfying outcomes. Locoregional flap, distraction osteogenesis, induced membrane techniques are other potential options in less favorable cases. The introduction of microvascular surgery, the description and undestanding of the different soft tissue and composite tissues available for reconstruction along with technologic development in osseointegration and virtual surgical planning have transformed the lives of patients treated surgically for oral tumors.

**Keywords**: maxillary, mandibular reconstruction, bone tissue engineering, free flap, microvascular

## INTRODUCTION

The upper and lower jaws play an essential role in mastication, articulation and physiognomic function. The mandible provides support for tongue position and elevation of the larynx during swallowing while maxilla provides support fot he nasal structures as well as an opposing structure to the mandible during mastication. The evolution of mandibular and maxillary reconstruction dates back to the 19th century. Before introduction of free tissue transfer, a variety of local flaps, regional flaps and prothetics were introduced, each was met with eventual failure. Since the introduction of free tissue transfer, mandibular and maxillary reconstruction has become an art it is a science (1).

The head and neck region is one of the most commonly affected areas in gunshot injuries. More than 50% of attempted suicides, 14% of asssault and 12% of accidental injuries occur in the head and neck region (2,3).

Mandible defects occur as a rezult of trauma, infection and surgical removal of malignes tumors. The mandible, the only moveable bone of the skull, is u-shaped bone attached to the skul with muscles at the temporomandibular joint. It plays vital roles in speech, mastication and facial appearance (4,5). Mandible reconstruction is still a major surgical challenge with the current gold standard being vascularised bone flap which requires the creation of another surgical site from a different area of the body to facilitate the reconstruction of the defect with its concomitant morbidity. Consequently, aloplastic manidible reconstruction using biomaterials alone has been investigated extensively as a viable since it eliminates the need for elaborate procedures. In addition, the method is patient-specific, economical and there is no need for prolonged rehabilitation (5,6).

For reconstruction of mandible and maxilla the first major paradigm occured with the development of reliable free tissue transfer option along with advances in hardware devices. Before these advances technique involving nonvascularized bone grafts and alloplastic materials was not realiable successful for primary reconstruction, especially in the typical defects that were caused by tumor-ablative surgery. Altough current options have proved to be reliably successful for single-stage primary reconstruction in the mandible and maxilla, these procedures remain highly complex and challenging and donor sites are stilll required. In addition, it is difficult to restore the three-dimensional structure precisely in many defects with bone from distant sites because of differences between the size and shape of the bone graft and the defect configuration (1).

**THE PAST**

In the post-war era the lessons learned by Gillies and others began to be applied to oral cavity reconstruction with the introduction of local and loco-regional flaps such as the forehead flap, deltopectoral flap and numerous, staged or delayed options for head and neckreconstruction At the same time, the development of an undestanding of the growth and spread of oral cancer patterns of spread to the regional lymph nodes resulted in much lower rates of mandibular resection (except when the mandible was involved) and dramatic improvements for patients in terms of deformity and function (7,8).

The first transformative change in oral cavity reconstruction occured with the description of the pectoralis major myocutanteous flap by Ariyan in 1979. This myoctaneous flap could be rotated to reconstruct both the oral cavity and external skin defects and some authors attempted composite mandibular reconstruction by harvesting the underlying ribs vascularized thorough facial ans periosteal attachments (9).

Reconstruction of the mandible was not really an option in the early days of oral cavity blative surgery. As the functional and aesthetic consequence of the absence of mandibular reconstruction became apparent, a variety of techniques were developed to reconstruct the mandible with a wide array of bone replacement. Based on the experience in extremity surgery with non-vascularized bone grafting, numerous reconstructive surgeons attempted mandibular reconstruction utilizing non-vascularized grafts from the iliac crest. These grafts had variable sucess rates but almost always failed in defects greater than 6 cm. Attempts was also made using non-vascularized ribs with similar results in terms of graft exposure or failure. In the 1970's a number of authors described the use of alloplasts in the form of stainless steel plates, acrylic or bioresorbable trays (10). These plates worked well in lateral defects but would universally extrude if placed centrally. In addtion, in patients with functional dentition, plate fracture where the rigid reconstructioncrossed the native mandible was extremely common. As the experience evolved and failure of non-vascularized grafts became clear, many recontructive surgeons pivoted to delayed recontructive surgeons pivoted to delayed reconstruction. This approach offered the potential of placing bone graft in a better vascularized wound with much less oral contamination. Techniques incorporating reconstructive plates and trays were developed with cortico-cancellous or cancellous grafts. These procedures unfortunately also produced variable and unpredictictable results.

The description of vascularized bone transfers and particularly the work of Taylor et al on the deep circumflex iliac artery flap incorporating the iliac crest in 1982 heralded the modern era of mandibular reconstruction (11). The subsequent description of the osseocutaneous forearm flap, the fibular osseocutaneous flap and the scapular system of flaps including the lateral border of the scapula in the 1980's and 1990's provided surgeons with a many options of reconstructive for the mandible (11).

Historically maxillary reconstruction for oral cavity tumors has been achieved through the use of dental prosthetics and maxillary obturation. These techniques developed by dentists and maxillofacial prosthodontist are stilll used today and continue to produce excellent results. At the maxillaire level, the results of prosthetic reconstruction are dependent on the extent of the defect. Patients with small defects of the maxilaire infrastructure of the maxilair have excellent results with maxillary obturation while patients with defects that cross the midlineb or have vertical resections to include the suprastructure of the maxilla or the orbit do less well with prosthetic reconstruction (8).

Initial attempts at maxilla reconstruction utilized local and regional flaps, usually the temporalis muscle and produced good results for lateral and posterior defects. With the introduction of free tissue transfer, numerous authors attempted maxillary reconstruction with either cutaneous or myocutaneous flaps.

While these approaches could adequately close maxillary defects, they made it impossible to dentally rehabilitate patients, as soft tisuue flaps would become trampoline like, making it impossible to retain dental prosthese. In addition, for patients in neeed of bone reconstruction, the soft tissue reconstructions could not maintain critical elements facial contour and resulted in late secondary contour deformities of the mid-face (8).

Brown's description of the use of the DCIA flap with muscle for maxillary reconstruction in 1996, significantly advanced the reconstructive opportunities for patients with extensive defects of the maxilla (12). Patients could undergo reconstruction including primary or secondary osseointegrated implant placement and have restoration of normal contour and functional of face. In the early days of oral reconstruction little attention was paid to dental rehabilitation except in maxillary defects where obturatores had been used. Initial attempts at dental rehabilitation of mandibular defects was developed by maxillofacial prosthodontists through the use of dentures with claps that would retain the devices. To be effective these denture needed a stable bone infrastructure without a great deal of mobile intervening soft tissue. Abutting teeth needed to be stable with root forms that would allow long-term roatation forces asscoiated with denture loading and mastication. Branemark's description of osseointegration in 1983 and the subnsquent development of osseointegrated implants for functional dental rehabilitation and tooth replacement created the opportunity for patients with mandible and maxillaire reconstructeds to undergo comprehensive and functional dental rehabilitation with either fixed or removable dentures that were stable and functional (15).

## PRESENT

Current approach to mandibular reconstruction have moved away from alloplasts in to free vascularized bone transfer. In selected patients with poor performance status or advanced tumors reconstruction plates may be considered for defects posterior of the mental foramen (8).

The workhorse flap for mandibular reconstruction is the osseocutaneous fibular transfer. This flap offers a long lengh of bone with a reliable and predictable blood suply incorporating a thin and pliable skin flap based on perforators from the peroneal artery and its venae commitantes. Disadvantages of this flap are mostly limited to the donor site problems issues in older patients. Clearly patients with vascular issues in the lower extremity either arterial or venous are not good candidates for fibular transfer. Modern use of thsi flap includes the use of virtual surgical planning with pre-bent reconstruction plates and cutting guides to simplify and make more predictable the aesthetic and functional results for secondary implant placement and dental rehabilitation (16,17).

A number of centres have begun using the angular tip of scapula based on the angular branch of the thoracodorsal artery for lateral and parasympyseal mandibular reconstruction (18). This flap can be harvested as a chimeta with either muscle or a perforator based cutaneous flap (thoracodorsal artery perforator flap). This flap can provide tip to 10 cm of bone and is suited for vertical ramus reconstruction with the cartilaginous scapular tip used to recreate the joint or more commonly for defects of the mandibular body and parasymphysis. This flap has the vertical height and breadth to undergo secondary implant placement. It is ideally suited for small defects of the mandible and major ablative defects in the older patients where the fibula may not concerns regarding the potential gait disturbance associated with fibular transfer in the elderly (8).

State of the management of maxillary defects includes the use of an appropriate classification system for defects and a management approach based on expected function, co-morbidity and patient preference.

Okay et al in 2001 classified palato-maxillary defects into 3 major classes and 2 sub classes. The aim was to organize and define the complex nature of the restorative decision making process (19). The classification is as follows:

**Class 1a:-** Defects that involve the hard palate but not the tooth bearing alveolus.
**Class 1b:-** Defects that involve any part of the maxillary alveolus and dentition posterior to the canines or involving the pre-maxilla.
**Class 2:-** Defects that involve any portion of the tooth bearing maxillary alveolus but include only one canine. The anterior margin of these defects lies within the pre-maxilla.
**Class 3:-** Defects that involve any portion of the tooth bearing area and includes both canines, total palatectomy defects and anterior transverse palatectomy that involved more than half of the palatal surface.

**Subclasses f and z:-** Subclass f includes defects that involve inferior orbital rim, whereas, Subclass z has defects that involve the body of the zygomatic bone.

Durrani et al in 2013, proposed a classification of maxillary defects based on their research and surgical experience (20). Their aim was to develop a simple, comprehensive and easy to use classification which should also act as a guide for the clinician regarding reconstructive and rehabilitation options. Their classification is as follows:
1. **Alveolectomy:-** These defects involve the alveolar bone alone.
2. **Sub-total Maxillectomy:-** These defects cause oro-nasal or oro-antral fistula but do not disturb the orbital wall of maxilla.
3. **Total Maxillectomy:-** These defects are characterized by absence of complete maxilla including orbital floor but the orbital contents remain intact.
4. **Radical Maxillectomy:-** These defects are characterized by absence of orbital contents along with the maxilla.
5. **Composite Maxillectomy:-** These defects involve resection of facial skin, soft palate, and any other part of the oral cavity.

All these defects can be further classified into Unilateral and Bilateral defects.

Classification of mandibular defects by Urken et al in 1991 is based on functional considerations caused by detachment of different muscle groups and difficulties with cosmetic restoration (21). The classification is as follows:
**C**– Condyle.
**R**– Ramus.
**B**– Body.
**S**– Total symphysis.
**SH**– Hemisymphysis.

Brown et al in 2016 defined four classes of segmental mandibulectomy (class I as lateral, class II as hemimandibulectomy, class III as anterior, class IV as extensive, c when condylectomy is required). This classification is intended to be simpler and more detailed (size and location of the defect, functional morbidity) to define the most adapted free flap type (22). Finally, lateral and anterior defects are the two main types of these classifications playing a major role for the functional outcomes: lateral resections are better tolerated than resections involving the anterior symphyseal region which present greater functional (eg, swallowing, mastication, phonation, and breathing) and esthetic morbidity (22).

Many defects particularly small central or lateral infrastructure defects are easly managed with prosthetics. In defects where a prosthesis will not achieve the reconstructive goals, the use of a myo-osseous free tissue transfer or an osseocutaneous transfer is an excellent option. As initialy described by Brown in 1996 the deep circumflex iliac artery flap incorporating a muscle flap of the inferior oblique represent the standard for maxillary reconstruction (12). This flap provides the reconstructive surgeon with ability to recreate both the vertical and horizontal bone elements of the maxillary defect with a muscle based transverse element that can either fill dead-space or be used as a platform for a re-mucosalized surface. This angular tip of scapular flap incorporating the teres major or serratus anterior mascles can be placed in vertical orietation for extended defects used to reconstruct the palate. When placed vertically the flap can be osteotomized to optimize bone alignement for secondary implant placement. For infracture defects the flap can be oriented horizontally to recreate the palate. The unique advantage of this flap is the vascular pedicle. (8,23).

The osseocutaneous fibular flap has ben used extensively for maxillary defects. In the maxillectomy with vertical defects including the orbit and orbital floor the insertion can be three dimensionally geometric complex. (8,23).

The use of virtual surgical planning, prefabricated palts and cutting can both expedite reconstruction and procedure predictable results in maxillary reconstruction (8,19). Resection of varying portions of the maxilla with the overlying soft tissue, skin, periorbital, and intraoral structures creates patterns of specific defects (24).

## THE FUTURE

The concept of prefabrication or the autologous construction of composite structures such as bone and mucosa will be of increasing importance in the future. Ronner and colleagues have pioneered techniques to prefabricate fibular transfer with incorporated ossteointegrated implants and mucosa fot two stage reconstruction of mandibular and maxilary defects. These technoques which include virtual surgical planning for primary creation of a comprehensive dental reconstruction will be expanded in their application for secondary reconstrction and for management of begin odontogenic tumors (25, 26).

Virtual surgical planning (VSP) is now routinely in oromandibular reconstruction. The ability to create surgical models, digital treatment plans, customized prefabricated plates and cutting guides has expedited the surgical process by reducind the technical expertise required and the time to perform these procedures. The precision of VSP has certainly constructs that are the correct shape and in the right position. The rapid development in 3D printing combined with the rapid development of the software elements to perform VSP will likely allow the use of this technology more broadly in the head and neck regions. The introduction of artificial intelligence and deep learning already developed and radiation treatment palnning will likely afford more rapid development of surgical treatment plans including three-dimensional visualization of resection plans and expedited VSP with the potential to improve the quality of surgical management of oral cancer (8).

The introduction of vascularized composite allografts in the management of severe traumatic or congenital facial deformities has garnered a great deal of attention from head and neck reconstructive community. The ability to restore functional structures such as the tongue, palate or mandible in primary or secondary reconstructive settings wolud be a major step forward and a paradigm shift in the functional and esthetic results possible in the surgical management of malignancy (27).

In extensive bone defects Giannoudis et al in 2019 diagrammatically described the well-known “diamond concept” for BTE that is based on five entities including an osteoconductive support or “scaffold” playing the role of extracellular matrix, this matrix's mechanical stability, osteogenic cells that are capable of differentiation, osteoinductive regulation factors, and vascular supply providing nutrition and oxygen input (28). The advantage of BTE is defining a reproducible procedure that is technically simple, adaptable to bone defects and each type of patient (comorbidity, infection, and postoperative radiotherapy) using biomaterials to prevent the morbidity associated with autologous bone harvesting.

The scaffold is a porous 3D support that plays the role of an extracellular matrix that should serve as a guide to bone growth stemming from the host tissue. It should be suitable for the local mechanical properties, be the vector for osteogenic cells, and allow cellular exchanges and vascular colonization. The desirable properties of the “perfect” scaffold must include no immune response, consolidation with the host tissue and new bone formation. In addition, biodegradation and the newly formed bone should also occur concurrently at a matching rate (29). CaP ceramics can be made of hydroxyapatite (HA), beta-tricalcium phosphate (βTCP), or both (biphasic calcium phosphate, BCP). Close to the inorganic fraction of bone, they are particularly interesting for their biocompatibility, osteoconduction, and bioactivity. They also have the advantage of good mechanical resistance. HA has a long bioresorption time but provides mechanical resistance to the scaffold. βTCP degrades more rapidly and improves bioresorption and biocompatibility but at the expense of mechanical properties. As a result, combining the two (BCP) makes it possible to accumulate the qualities of each of the biomaterials and obtain a balance between mechanical properties and their bioresorption qualities (30).

Polymer bone substitutes can be either natural or synthetic. Natural polymers such as collagen have excellent osteoconduction but low biocompatibility and mechanical properties. Consequently, synthetic polymers aremorewidely used. Polylactic acid (PLA), polyglycolic acid (PGA), poly(lactic-co-glycolic acid) (PLGA), which associates PGA and PLA, and polycaprolactones present excellent biocompatibility at a low price. However, the risk of an inflammatory reaction related to long bioresorption, limited bioactivity, and low mechanical resistance are the main weak points of these scaffolds, severely limiting their compatibility for mandibular reconstruction and their use for clinical settings (29).

## REFERENCES

1. Eric M. Gender. Reconstruction of the mandible and the maxilla. The evolution of surgical technique. Arch Facial Plast Surg 2010; 12(2):87-90.
2. Cunningham LL, Haug RH, Ford J. Firearm injuries to the maxillofacial region: an overview of current thiughts regarding demographics, pathophysiology and management. J Oral Maxillofac Surg 2003; 61:932-942.
3. Avinash S, Bidra BDS, Ashok N, Veeranki BDS. Surgical and prosthodontic reconstruction of a gunshot injury of the mandible using dental implants and an acrylic resin fixed prosthesis: A clinical report. The Journal of Prosthetic Dentistry 2010; 104:142-148.
4. Chanchareonsook N, Junker R, Jongpaiboonkit L, Jansen JA. Tissue-engineered mandibular bone reconstruction for continuity defects: a systematic approach to the literature. Tissue Eng B Rev 2013;20(2):147-162.
5. Somasundaram Prasadh, Santhosh Suresh, Kang Lun Hong, Aishwarya Bhargav, Vinicius Rosa, Raymond Chung Wen Wong. Journal of the Mechanical Behavior of Biomedical Materials 2020; 1-7.
6. Prasadh S, Wong RCW.Unraveling the mechanical strength of biomaterials used as a bone scaffold in oral maxillofacial defects. Oral Science International 2018; 15(2):48-55.
7. Gilies HD. Plastic Surgery of the Face Based on Selected Cases of War Injuries of the Face Including Burns, with Original ilustration. Wentworth Press 2016.
8. Ralph W Gilbert. Reconstruction of the oral cavity: past, presnt and future. Oral Oncology 2020; 108:1-5.
9. Ariyan S. The pectoralis major myocutaneous flap. A versatile flap for reconstruction in the head and neck. Plast Reconstruct Surg 1979; 63(1):73-81
10. Gullane PJ. Primary mandibular reconstruction: analysis of 64 cases and evaluation of interface radiation dosimetry on bridging paltes. Laryngoscope 1991; 101:1-24
11. Taylor GI. Reconstruction of the mandible with free composite ilioac bone grafts. Ann Plast Surg 1982; 9(5):361-376
12. Brown JS. Deep circumflex iliac artery free flap with internal oblique muscle as a new method of imeediate reconstruction of maxilectomy defects. Head and Neck 1996; 18(5):412-421.
13. Futran ND, Wadsworth JT, Villaret D, Farwell DG. Midface reconstruction with the fibula free flap. Arch Otolaryngol Head and Neck Surg 2002; 128(2):161-166.
14. Clark JR, Vesely M, Gilbert R. Scapular angle osteomyogenous flap in post-maxillectomy reconstruction:defect, reconstruction, shoulder function and harvest technique. Head Neck J Sci Specialt Head Neck 2008; 30(1):10-20.
15. Branemark PL. Osseointegration and its experimental background. J Prosthet Dent 1983; 50(3):399-410.
16. Hanasono MM, Skoracki RJ. Computer-assisted design and rapid prototype modeling in micorvascular mandible reconstruction. The laryngoscope 2013; 123(3):597-604.
17. R.I. Malancea, E.R. Gavriliuc, B. Veliceasa, B. Puha, D. Popescu, O. Alexa. Methodology of three-dimensional printing in acetabular fractures. Materiale Plastice 2017; 54(3):513-516.
18. Yoo J, Dowthwaite SA, Fung K, Franklin J, Nichols A. A new angle to mandibular reconstruction:

the scapular tip free flap. Head annd Neck 2013; 35(7):980-987.
19. Okay DJ, Genden E, Buchbinder D, Urken M. Prosthetic Guidelines for surgical reconstruction of the maxilla: a classification system of defects. J Prosthet Dent 2001; 86:352-63.
20. Durrani Z, Hussain SG, Alam S A. A Study of Classification Systems for Maxillectomy Defects. JPPA 2013; 01(02): 117-124.
21. Urken, ML, Weinberg, H, Vickery, C, Buchbinder, D, Lawson, W, and Biller, HF. Oromandibular reconstruction using microvascular composite free flaps. Report of 71 cases and a new classification scheme for bony, soft-tissue, and neurologic defects. Arch Otolaryngol Head Neck Surg. 1991; 117:733–744.
22. Brown JS, Barry C, Ho M, Shaw R. A new classification for mandibular defects after oncological resection. Lancet Oncol. 2016;17(1)-23.
23. Arnaud Pare, Pierre Weiss, Adeline Bossard, Olivier Gauthier, Boris Laure, Pierre Corre. Reconstruction of segmental mandibular defects: current procedures ans perspectives. Laryngoscope Investigative Otolaryngology 2019; 4:587-596.
24. De Santis G, Cordeiro PG, Chiriani P. Classification System for Maxillectomy Defects. In: De Santis G., Cordeiro P., Chiarini L. (eds) Atlas of Mandibular and Maxillary Reconstruction with the Fibula Flap. 2019, Springer.
25. Jaquiery C, Rohnen D, Kunz C, Bucher P, Peters F, Schenk RK et al. Reconstruction of maxillary and osseointegrated dental implants- a prospective study. Clin Oral Implants Res 2004; 15(5):598-606.
26. Rohnen D, Bucher P, Kunz B, Prein J, Schenk RK. Treatment of severe atrophy of the maxilla with the prefabricated free vascularized fibula flap. Clin Oral Implant Res 2002; 13(1):44-52.
27. Rifkin WJ, David JA, Plana NM, Kantar RS, Diaz-Siso JR, Gelb BE et al. Achievements and challenges in facial trasplantation. Ann Surg 2018; 268(2):260-270.
28. Giannoudis PV, Einhorn TA, Marsh D. Fracture healing: the diamond concept. Injury. 2007;38(Suppl 4):S3-S6.
29. Konopnicki S, Troulis MJ. Mandibular tissue engineering: past, present, future. J Oral Maxillofac Surg. 2015;73(12):S136-S146.
30. Turnbull G, Clarke J, Picard F, et al. 3D bioactive composite scaffolds for bone tissue engineering. Bioact Mater. 2018;3(3):278-314.