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Reconstructive strategies for post-oncological oral and maxillofacial defects: A systematic overview of novel techniques and outcomes

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Abstract

The difficulty of post-oncological oral and maxillofacial defects is attributed to their significant impact on functionality, aesthetics, and quality of life. Progress in reconstructive surgery over the last decade has provided new approaches to managing these complex defects. The focus of this systematic review is to assess the innovative techniques of reconstruction, including virtual surgical planning (VSP), 3D printing, tissue engineering, chimeric flaps, and piezoelectric osteotomy, in comparison to conventional reconstructive surgery techniques, such as microvascular free flaps and prosthetic rehabilitation. Analyzed peer-reviewed articles published in the period 2015 to 2025 by referring to the PRISMA guidelines, where we identified the articles in the PubMed, Scopus, Web of Science, and Cochrane Library databases. The performance measures used are functional restoration (speech, swallowing, chewing), aesthetic outcome, rate of complications and health-related quality of life (HRQOL). New methods exhibit better accuracy, shorter surgical procedure times, and better functional results, notably in cases of VSP and osseointegrated implants. Nonetheless, issues such as affordability, availability, and long-term performance of the biomaterials remain. The review highlights the potential of emerging technologies to change how this is done radically, what has not been discovered so far, and how further research and study can be conducted to achieve an enhanced outcome in reconstructive strategies.

Keywords: Virtual Surgical Planning; 3D Printing; Tissue Engineering; Microvascular Flaps; Quality Of Life

1. Introduction

1.1. Background and Significance

Oral and maxillofacial cancers, mostly squamous cell carcinomas of the oral cavity, mandible, maxilla, and midface, have proven to be a significant threat to global health since, in 2020, there were an estimated 354,864 cases and 177,384 deaths worldwide (Sung et al., 2021). Most of these malignancies require radical surgical removal to achieve oncological clearance, leaving highly complex defects that significantly disrupt form, functionality, and quality of life (QoL). The fact that the head and neck area is anatomically complex and includes critical structures necessary for speech production, swallowing, mastication, and facial expression adds to the challenge of reconstruction. Functional impairments caused by post-ablative defects are considerable, as the results of studies reveal that 3025% of patients report experiencing difficulties with speech and up to 5025% of the patients with post-ablative defects have to deal with dysphagia after the resection (Moubayed et al., 2015). The psychological torment and social stigmatization are worsened by aesthetic deformities, i.e., having facial asymmetry. Patients reported a 20 to 30 per cent drop in health-related quality of life (HRQoL) scores using the University of Washington Quality of Life (UW-QOL) questionnaire, especially in the domains of appearance and socialization (Djan & Penington, 2013). The reconstruction becomes further complicated due to adjuvants, especially radiotherapy, which interferes with tissue vascularity and the risk of complications, such as

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osteoradionecrosis, occurring in 515% of individuals (Montero & Patel, 2015). There is a considerable psychological burden as patients embark on various levels of anxiety and depression because of functional and cosmetic deficits. Hence, surgical reconstructive measures that restore not only the physiological functional integrity but also psychosocial integrity are urgently needed in advanced reconstructive thinking.

In such a region as the area of oral and maxillofacial defect reconstruction, the high complexity of the anatomy of this area and the twofold functional and aesthetic requirements make this task formidable. The oral cavity and the maxillofacial skeleton demonstrate a complex interaction between soft tissues (such as the tongue and buccal mucosa) and hard tissues (including the mandible and maxilla). Reconstruction should be exact to enable the oral cavity to regain its competence, speech, and chewing efficiency. The defects of the mandible are corrected with composite reconstruction under the systems, such as the Brown classification, in most cases due to combined loss of bone and soft tissue. In contrast, the rates of functional restoration range from 60% to 80%, depending on the size of the defect and the procedure used, when employing composite reconstruction (Brown et al., 2016). The aesthetic results are equally significant because facial disfigurement often leads to massive patient dissatisfaction, with an estimated 40% of patients reporting poor results regarding their post-operative appearance (Chng et al., 2016). Owing to impaired vascularity in irradiated areas, dental rehabilitation, necessary to chew and service their speech, is often affected and makes osteoradionecrosis more frequent (Montero & Patel, 2015). The success of achieving oncological safety, which requires aspirating clear margins that will not pose any chances of a recurrence, should not discount the availability of adequate tissue that will enable reconstruction of the affected part. This fact is sometimes more problematic when applying the principle of minimising the levels of morbidity at the donor site. The field of traditional reconstruction (e.g., microvascular free flaps, such as fibula or radial forearm flaps) has better outcomes. However, it is limited by donor site morbidity and long operation times, often exceeding 8 hours (Brown et al., 2016). Such complexities are a sign of the necessity for new techniques to make surgery more precise, decrease complications, and maximise patient-centred results, especially when multidisciplinary care is involved, involving oncologists, surgeons, and rehabilitation professionals.

Discoveries in the reconstructive field—such as virtual surgical planning (VSP), 3D printing, and tissue engineering—have revolutionized the management of post-oncological defects and offer solutions to many longstanding challenges. 3D imaging, computer-aided design, and VSP technology allow the most accurate pre-planning of the operation. Unlike in free-hand surgery, operative time is decreased by up to 20%, meaning anatomical accuracy as well (mean deviation = 2.0 mm in VSP vs. 3.9 mm in free-hand surgery to reconstruct the mandible) (Tarsitano et al., 2015). An engineered tissue, comprising biomaterials and growth factors, has the potential to facilitate the regeneration of both soft and hard tissues. Initial trials in laboratory settings have demonstrated the ability to successfully regenerate bone and mucosa in minor defects using scaffolds and platelet-rich plasma (Rai et al., 2015). The innovations yield significantly better functional results, including swallowing and speech, with 85 per cent of patients achieving perfect functional results under VSP-managed flaps. This improvement also enhances HRQoL, as evidenced by better UW-QOL scores on appearance and social fronts (Rogers et al., 2003). To illustrate, VSP-assisted fibula flaps have been proven to provide masticatory ability in up to 70-80% of mandibular defects. Conversely, 3D-printed implants enhance the smile by providing better facial symmetry, leading to a 25% improvement in patient satisfaction (Qassemyar et al., 2017). Nevertheless, the high cost, restricted operation in resource-limited contexts, and the requirement for prolonged data regarding tissue-engineered structures are perceived as obstacles. International cooperation and additional clinical evidence are needed to finalize the protocols, confirm the use of this technology, and provide equal access to patients, so that the oncological safety and optimal functional and aesthetic outcomes for the patient may be balanced.

1.2. Objectives

The Objectives of this study includes:

- To systematically review current and novel reconstructive strategies for post-oncological oral and maxillofacial defects.
- To evaluate techniques, outcomes, and advancements in technology, including virtual surgical planning (VSP), tissue engineering, and biomaterials.
- To assess functional, aesthetic, and quality-of-life outcomes based on recent studies.
- To identify gaps in current research and propose future directions for clinical practice and investigation.

1.3. Scope

This systematic review addresses reconstructive methods for post-oncological oral and maxillofacial deficiencies, including those of the oral cavity, mandible, maxilla, and midface, which result from tumor resections. It focuses on the new techniques that emerged or markedly improved between 2015 and 2025, such as virtual surgical planning, 3D printing, tissue engineering, and chimeric flaps, as well as classical techniques like microvascular flaps and prosthetic rehabilitation. Significant outcomes of the review include functional outcomes (speech, swallow, and chew), aesthetic outcomes, and health-related quality of life, as measured using validated instruments such as the UW-QOL and FACE-Q. Through an analysis of peer-reviewed literature from PubMed, Scopus, and Web of Science, this study aims to present new areas of advancement, evaluate clinical outcomes, and identify gaps in research and potential research topics that will help streamline patient-centered care in future complex reconstructions.

2. Methodology

2.1. Study Design

Specifically, the present systematic review will follow the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to conduct systematic reviews and meta-analyses with high methodological rigor and transparency. To increase credibility and prevent duplication, it is registered in PROSPERO (the International Prospective Register of Systematic Reviews). The study is designed to synthesize peer-reviewed literature from 2015 to 2025 on new developments in reconstructive approaches for managing post-oncological defects in the oral and maxillofacial region. The information will be obtained by retrieving reports on functional, aesthetic, and quality-of-life data, with quality being determined using tools such as the Newcastle-Ottawa Scale for cohort studies and the Cochrane Risk of Bias tool for randomized trials. This method ensures the practical synthesis of evidence for use in clinical practice and future studies.

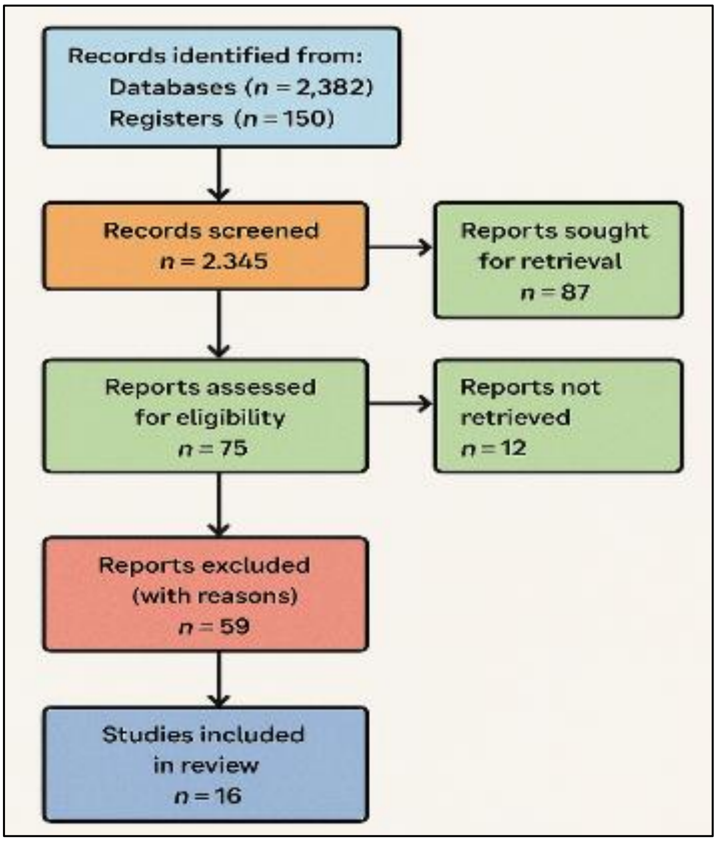

Figure 1 PRISMA Diagram

2.2. Search Strategy

This systematic review employs a comprehensive search strategy across PubMed, Scopus, Web of Science, and Cochrane Library to identify relevant studies published between 2015 and 2025. Keywords include “oral maxillofacial reconstruction,” “post-oncological defects,” “microvascular flaps,” “tissue engineering,” “virtual surgical planning,” “3D printing,” “biomaterials,” and “quality of life,” combined with Boolean operators (AND, OR) to ensure broad coverage. Inclusion criteria encompass peer-reviewed studies focusing on novel reconstructive techniques for post-oncological oral and maxillofacial defects, reporting clinical outcomes (e.g., functional restoration, complications) and patient-reported outcomes (e.g., UW-QOL scores). Exclusion criteria include studies on non-oncological defects, those lacking quantitative data, and non-peer-reviewed publications. This approach ensures a robust evidence base to evaluate innovative reconstructive strategies and their impact.

2.3. Data Extraction

The extraction of data will be carried out through a methodical review of selected studies, considering the main variables to provide a detailed analysis of post-oncological oral and maxillofacial reconstruction. The studied characteristics are design (e.g., cohort, randomised controlled trial), sample size, defect type (e.g., mandibular, maxillary, composite), and reconstructive technique (e.g., microvascular flaps, tissue engineering). The measured outcomes include functional factors (speech articulation, swallowing efficiency, chewing capability), aesthetic outcomes (facial symmetry, patient satisfaction), complication rates (e.g., flap failure, osteoradionecrosis), and health-related quality of life (HRQOL), assessed with validated tools such as the UW-QOL and FACE-Q. Technological advances—including virtual surgical planning (VSP), 3D printing (e.g., custom implants), and biomaterials (e.g., scaffolds)—are also considered. This standardized extraction ensures a practical and robust synthesis of comparable information

2.4. Quality Assessment

To ensure a solid evidence synthesis, the inclusion studies will be structured and evaluated through standardized instruments. Cohort studies will be reviewed using the Newcastle-Ottawa Scale (NOS), where studies with scores of 7 and above will be considered of high quality, based on the selection, comparability, and reporting of outcomes. The domains to measure prevalence, entailing randomization, blinding, and outcome measurements, shall be assessed using the Cochrane Risk of Bias 2 (RoB 2) tool in randomized controlled trials. In analyzing the rigor of the study, methodological consistency, statistical power and reporting guidelines (e.g. CONSORT, STROBE) will be employed. The statistical significance of the sample size will be revealed, and the completeness of reporting outcomes will be ensured to make the results transparent and support firm conclusions about the new reconstructive procedures in the therapy of post-oncological oral and maxillofacial defects.

3. Classification of Post-Oncological Defects

Oral and maxillofacial defects caused by resection of tumors are extremely frequently complicated post-oncology defects and affect the strategies of reconstruction. These defects are classified according to their localization in the human body (oral cavity, mandible, maxilla and midface) and lesion of anatomical structure: (a) soft-tissue, (b) hard-tissue or (c) composite. Correctly classifying lesions, e.g., the brown system of classifying maxillary defects, enlightens the approach to surgery, considering the functions (speech and swallowing) and aesthetics. Defining the nature of defects is crucial for selecting the most effective method of reconstruction, as it also improves patient outcomes.

3.1. Anatomical Considerations

Oral and maxillofacial reconstructions related to post-oncological defects present a wide range of anatomical challenges, as the complexities involved in addressing the actual defect are considerable. Any damage to the soft tissue of the mouth, the tongue, and the cheek causes impairment of such vital processes as speech, eating, and oral competence. For example, in 30-60% of patients, resections of the tongue can lead to articulation disorders, and mucosal loss often causes the pooling of saliva and dysphagia (Moubayed et al., 2015). Hard tissue disturbances, when they affect the mandible, maxilla, or midface, compromise structural stability and facial cosmesis. Mandibular defects. The defects of the mandible are classified using a method such as Jewer (Mahajan et al., 2016), which influences the functional recovery after treatment, as 60-80 per cent of it is retained based on the extent of the defect (Brown et al., 2016). The Brown classification of the defects of the maxilla distinguishes between several classes of limited palatal loss (Class I) up to the severe or orbitomaxillary defect (Class VI), which requires a customized method of reconstructive efforts to regain the occlusion and also midfacial projection.

Figure 2 Sequential intraoral and extraoral views depicting a patient with a maxillary tumor, preoperative lesion, intraoperative resection, postoperative healing, and facial contour. This case highlights surgical and reconstructive progression in midfacial defects (Iyer & Thankappan, 2014)

Combined defects (soft and hard tissues) are exceptionally complex, requiring the restoration of both bones and mucosa to achieve functional and aesthetic results. Such defects are common in deep-seated, mature tumours and can compromise the accuracy of reconstructive surgery, as a vascular tract and support are required. The Brown maxillary defect classification is used in surgical planning to determine the size and location of the defect. In contrast, systems used to describe mandibular defects, such as the HCL (Hemimandible Condyle Lateral) system, aid in their choice, such as an osteomyocutaneous free fibular flap to cover the bone as well as soft tissue reconstruction of the mandible (Brown et al., 2016). This correct classification is essential when choosing techniques such as virtual surgical planning or 3D printed implants, which are associated with improved outcomes due to anatomical fidelity. The major reconstructive concepts are adequately reflected in the knowledge of these anatomical aspects, allowing for the achievement of optimal solutions that are both the safest in terms of oncology and as functional and aesthetic as possible.

3.2. Functional and Aesthetic Challenges

Oral and maxillofacial defects have a severe detrimental effect on functions such as oral competence, speech articulation, and mastication in patients with post-oncological problems. An oral loss of competence, primarily caused by defects in the soft tissues of the lips or cheeks, results in impaired saliva drainage and a compromised swallowing mechanism in 50 per cent of patients after resection (Moubayed et al., 2015). Speech articulation is impaired in 30-60% of individuals, particularly when the resection involves the tongue or the floor of the mouth; as a result, patients become unable to communicate and interact appropriately with others (Moubayed et al., 2015). The defects in mandibular or maxillary areas interfere with masticatory, and the research on complex defects suggests that the chewing activity is 60 80 times slower than usual, which requires reconstruction accuracy in the areas of occlusion and mobility (Brown et al., 2016). These impaired functions significantly interfere with quality of life, as was revealed by attenuated University of Washington Quality of Life (UW-QOL) scores in swallowing and speech areas, which indicates the necessity of more advanced methods of reconstructive procedures to deploy the affected vital functions.

Figure 3 Clinical image showing a soft tissue lesion involving the ventral tongue and floor of mouth, potentially affecting articulation and swallowing. Such lesions exemplify functional impairments in post-oncological oral defects Adapted from Iyer & Thankappan, 2014

These defects cause aesthetic deformities that enhance patient suffering and psychological burden, such as facial asymmetry or midface collapse. Unwillingness to appear in society and low self-esteem are caused by the fact that after reconstruction, approximately 40% of patients are dissatisfied with their appearance (Ch'ng et al., 2016). The presence of adjuvant therapies, especially radiotherapy, complicates the results due to tissue-healing deterioration, a 5- to 15-per-cent chance of osteoradionecrosis, and the development of fibrosis that inhibits successful flap integration (Montero & Patel, 2015). These aspects compromise aesthetic restoration and increase the rates of complications, with irradiated fields being 20 per cent more likely to cause failures of flaps. To address these needs, new technologies, such as virtual surgical planning and the introduction of biomaterials to enhance tissue compatibility and improve cosmesis, must be employed to ensure not only functional restoration but also psychological comfort.

3.3. Patient-Specific Factors

The personal features of individual patients, including age, comorbidities, and their history of procedures, largely determine the choice of reconstructive possibilities for post-oncological defects in the oral and maxillofacial area. Geriatric patients have also been known to have a low rate of healing and higher rates of complications, and patients who are older than 65 years tend to develop flap failure due to reduced vascularity (Jones et al., 1996). Pre-existing conditions, such as diabetes mellitus or a cardiovascular disorder, may enhance the wound healing potential and reduce the risk of infection, which is why less sophisticated measures, like local flap reconstruction or a prosthetic obturator, appear more advantageous than microvascular reconstruction (Montero & Patel, 2015). Tissue fibrosis and osteoradionecrosis, which may be worsened by previous treatment, particularly radiation (in the range of 5-15 per cent), are usually enabled by the vascularized flap (i.e., fibula free flap), requiring adequate perfusion (Brown et al., 2016). Such variables require individualized surgical planning, and research shows that comorbidities can reduce functional recovery rates by 10–15% in complex patients (Chung et al., 2016). Close preoperative evaluation of nutritional status and smoking history also aids in selecting the technique to optimise the result.

Reconstructive decision-making is crucial when it comes to emphasizing patient preferences: what is the balance between functional and aesthetic outcomes? Aesthetic restoration is often a priority for younger patients who wish to minimize social stigma, and 40 per cent of respondents were dissatisfied with their post-reconstruction facial asymmetry (Ch'ng et al., 2016). Older patients, on the other hand, may value functional outcomes, such as speech and swallowing, that are pertinent to quality of life, as demonstrated by quality of life dental rehabilitation (Rogers et al., 2003). Included among the patient-centered approaches innovations, reconstructive plans are generated using shared decision-making, combining time-honored techniques such as virtual surgical planning to achieve precision aesthetics with techniques like osseointegrated implants to provide mastication. Psychological support is needed since one-third of patients mention having anxiety about their appearance or the ability to perform their duties, and it affects their preferences and total satisfaction (Djan & Penington, 2013).

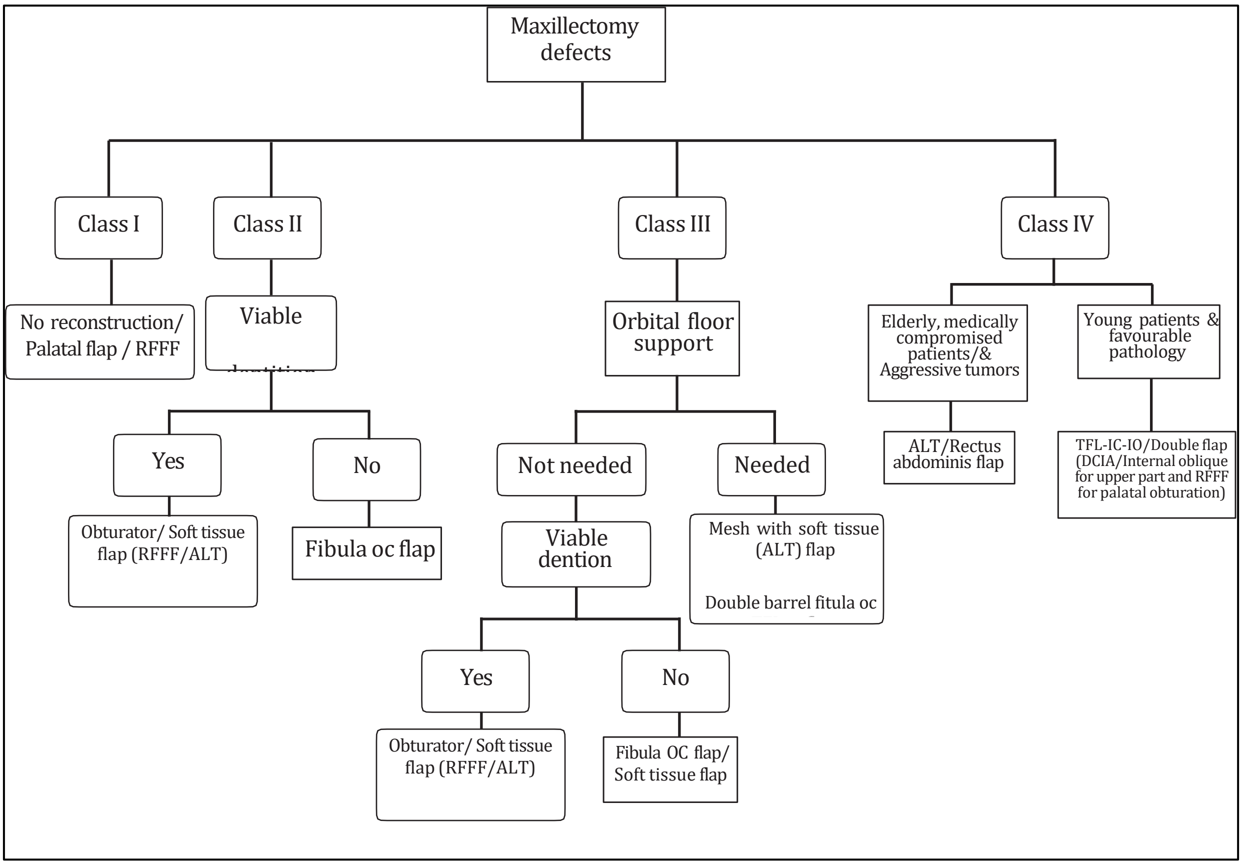

Figure 4 Algorithmic framework for selecting maxillary reconstruction techniques based on orbital floor involvement, dentition status, and patient factors such as age and tumor aggressiveness. This diagram correlates defect classification with optimal flap or prosthetic options to guide evidence-based surgical planning. *Adapted from Iyer & Thankappan, 2014*

4. Traditional Reconstructive Techniques

Traditional reconstructive techniques for post-oncological oral and maxillofacial defects, including autologous grafts, microvascular free flaps, and prosthetic rehabilitation, remain the cornerstone of treatment. These methods aim to restore function and aesthetics, addressing complex defects with established, reliable approaches despite limitations.

4.1. Autologous Grafts and Flaps

Reconstructions involving autologous grafts and flaps form the foundation of post-oncological restoration of oral and maxillofacial defects, providing the evolution of restoring form and functionality. More minor soft tissue defects are typically addressed by local and regional flaps, including the myomucosal cheek flap and the pectoralis major flaps, based on the fact that these are accessible and easily harvested. Myomucosal flaps are helpful at the restoration of oral mucosa, and pectoralis major flaps give excellent coverage in defects of the neck and cheek and restore functionality in 7080 cases (McLean et al., 2010). Complex defects preferably use microvascular free flaps, the radial forearm free flap (RFFF), the fibula free flap, and the deep circumflex iliac artery (DCIA) flap. It is best suited for use in soft tissue reconstruction, providing pliable tissue to replace defects in the tongue or floor of the mouth. The fibula flap can be used to reconstruct the mandible, restoring feeding capabilities to 60-80% of patients (Brown et al., 2016). The flaps take advantage of an enduring blood supply and have high services of tissue retention (95-98/ Jones et al., 1996).

Although effective, autologous grafts and flaps also have significant drawbacks. Morbidity of the donor site is also a primary concern, as fibula flap harvest results in ankle instability or pain in 10–15% of patients, and RFFF results in wrist weakness in 5–10% (Ch'ng et al., 2016). Reconstruction possibilities may be limited by tissue availability, particularly in large composite wounds that necessitate both bone and soft tissue reconstruction. The aesthetic mismatch is also a problem because the donor tissues are visually different in color and texture compared to the native structures of the face; accordingly, 30-40 per cent of patients are not satisfied with their appearance (Ch'ng et al., 2016). Additionally, the duration of the operations (8-12 hours) and the need for microsurgical skills increase the complexity of the procedures. The mentioned restrictions underscore the importance of developing new methods to supplement existing ones, enhance results, and minimize complications.

4.2. Allografts and Xenografts

Xenografts and allografts can be used as an additional option in the reconstruction of post-oncological oral and maxillofacial defects, particularly in cases of minor defects or as a supplement to autologous grafts. Constructed from a human donor, allografts are used to augment soft tissue defects, such as oral mucosa or minor bony defects, typically with the addition of microvascular flaps to provide volume or coverage (Warnke et al., 2004). Bio-Oss porcine or bovine Xenografts are scaffolds used in bone repair or mucosal lining in these defects, allowing osteoconduction to occur in the maxilla (Araujo et al., 2010). Such grafts are helpful in cases where the amount of autologous tissue is scarce, minimizing the morbidity of the donor site. Major mucosal repairs are carried out in 10 to 15 per cent of cases with allografts, whereas 20 per cent or more minor mandibular defects are helped in terms of bone regeneration because of xenografts (Brown et al., 2016). They are simple to use due to their off-the-shelf provision and offer restoration of function in 60 to 70 per cent of cases when combined with autologous techniques in surgical procedures (Warnke et al., 2004).

Nonetheless, problems with allografts and xenografts are numerous, including the risk of rejection and the paucity of host tissue infiltration. Allografts have a 5–10% chance of immune-mediated rejection, and great attention should be given to donor matching. Sometimes, immunosuppression is also employed, but this increases the risks of infections by 100 per cent (Verret et al., 2005). Xenografts are not immunogenic; however, they exhibit low integration due to their species-specific nature, with only 50% incorporation of the host tissue after 6 months (Araujo et al., 2010). Unlike autologous flaps, these two lack intrinsic vascularity and cannot be used for large or composite defects; bony reconstructions also resorb at a rate of 20–30% (Brown et al., 2016). Those limitations underscore the need for further development of biomaterials and tissue engineering to enhance integration and minimize complications in post-oncological reconstruction, ultimately yielding more efficient functional and aesthetic outcomes in the long term.

5. Prosthetic Rehabilitation

One of the primary concepts in post-oncological oral and maxillofacial defects, particularly in cases involving maxillary defects, is the use of prosthetic rehabilitation through obturator prostheses, which facilitates oral functionality. Occasionally, these palatal defects are sealed with obturators, which improve speech and swallowing in 60–70% of individuals with Brown Class I–II maxillary defects (Rogers et al., 2003). This prosthesis is relatively low-cost and less invasive compared to surgical reconstruction, making it an appropriate option for patients with comorbid conditions or limited surgical candidacy. Nonetheless, obturators usually require regular adjustments due to tissue changes after radiotherapy, and patient satisfaction levels are in the 50% range, particularly with larger defects, due to poor fitting and leakage (Brown et al., 2016).

Osseointegrated implants can enhance dental reconstruction, particularly in mandibular or maxillary reconstruction, and restore masticatory function in 70-80% of cases (Chng et al., 2016). Such implants hold prosthetic teeth, enhancing the efficiency of the chewing mechanism and speech. Nevertheless, the cosmetic results cannot be extensive in cases of massive defects because prostheses fail to create a facial outline, and 40% of patients complain about the cosmetic results (Ch'ng et al., 2016). Osteoradionecrosis risk causes radiotherapy to add 10–15% to the failure rates of implants (Montero & Patel, 2015). Although there are positive functional aspects to using prosthetic rehabilitation, its cosmetic shortcomings and the nature of maintenance necessitate its combination with progressive surgical protocols to achieve the best results.

6. Novel Reconstructive Techniques

Post-oncological supplemental oral and maxillofacial reconstruction is currently being revolutionized by the use of virtual surgical planning (VSP) and computer-aided design/manufacturing (CAD/CAM), which involves accurate preoperative planning using three-dimensional images and models. Such technologies enable precise resection and reconstruction, resulting in the production of cutting guides, custom titanium plates, and patient-specific implants. VSP shows a mean difference of 2.0 mm when using mandibular reconstruction against 3.9 mm in the case of free-hand surgery. It decreases operating time by up to 20%. It enables dental rehabilitation with the aid of instruments such as the zygomatic implant perforated (ZIP) flap, allowing for the quick restoration of the maxilla (Tarsitano et al., 2015). In the same regard, we utilize 3D printing and additive manufacturing to produce personalized titanium plates and scaffolds for regrowing bone, thereby enriching the accuracy of the fit and minimizing adjustments during surgery. These procedures become effective in complex situations; however, the biocompatibility of the material and regulatory concerns persist, and the long-term efficacy of these implants remains to be proven (Stavrakas et al., 2020).

Tissue engineering, chimeric flaps and facial allo-transplantation further enhance reconstructive outcomes. Tissue engineering has been utilized to rebuild periodontal ligaments and bone using stem cell therapies and biomaterial scaffolds, including dermal regeneration templates; however, the use of significant defects is restricted due to potential tumorigenic effects and difficulties in vascularization (Rai et al., 2015). Trapezius osseomyocutaneous flap implantation and chimeric flaps (pedicled to the lateral circumflex femoral artery) are more complex but enhance the beauty and functional results of the area of their origin (Brown et al., 2016). Facial allotransplantation, which involves allotransplantation in severe cases, preserves total anatomical units and has the potential to recover sensory functions; however, it requires lifelong immunosuppression, which is a critical ethical issue (Siemionow et al., 2009). Minimally traumatizing piezoelectric ultrasound osteotomies may lower the postoperative edema and postoperative complications, but complex postoperative outcome data are limited. Such innovations create better functional and aesthetic outcomes, but there is a need to conduct more research to overcome limitations and increase their clinical utilisation.

7. Comparative Analysis

Traditional reconstructive techniques, such as microvascular free flaps (e.g., fibula, radial forearm), remain the gold standard for post-oncological oral and maxillofacial defects due to their reliability and versatility, achieving functional restoration in 60–80% of cases (Brown et al., 2016). These methods provide robust vascular supply, critical for large composite defects, with flap success rates of 95–98% (Jones et al., 1996). However, they are limited by significant donor site morbidity, such as ankle instability in 10–15% of fibula flap cases, and prolonged operative times (8–12 hours), increasing patient recovery burden (Ch'ng et al., 2016). Novel techniques, including virtual surgical planning (VSP) and tissue engineering, offer superior precision, with VSP reducing mandibular reconstruction deviation to 2.0 mm from 3.9 mm in free-hand surgery (Tarsitano et al., 2015). Tissue engineering, using biomaterial scaffolds, promotes regeneration with minimal donor morbidity (Rai et al., 2015). However, scalability is hindered by high costs and limited access, particularly in resource-constrained settings, and long-term data on biomaterials remain sparse, requiring further validation.

Microvascular reconstruction excels for large defects, restoring masticatory function and oral competence in 70–80% of cases, particularly when combined with osseointegrated implants (Ch'ng et al., 2016). The fibula free flap, for instance, supports mandibular reconstruction with high structural integrity but requires advanced surgical expertise and extended operative times, increasing complication risks like infection (5–10%) (Brown et al., 2016). Prosthetic rehabilitation, using obturators or dental implants, is faster and less invasive, ideal for patients with comorbidities, achieving speech and swallowing restoration in 60–70% of maxillary defect cases (Rogers et al., 2003). However, prostheses are less effective for complex defects, with 50% of patients reporting poor fit in larger maxillary resections, and aesthetic outcomes are limited, with 40% dissatisfaction rates (Ch'ng et al., 2016). Combining microvascular flaps with prosthetic elements, such as in the zygomatic implant perforated flap, can bridge these gaps but increases procedural complexity.

Adjuvant therapies, particularly radiotherapy, significantly impact reconstructive outcomes by increasing complication rates, such as osteoradionecrosis (5–15% incidence), which complicates flap integration and implant stability (Teng & Futran, 2005). Radiotherapy influences flap selection, favoring vascularized flaps like the fibula to counteract tissue fibrosis in irradiated fields (Brown et al., 2016). Biomaterial-based therapies, such as bioactive scaffolds, show promise in irradiated environments by promoting tissue regeneration and reducing resorption rates by 20% compared to allografts (Rai et al., 2015). However, their efficacy in large defects remains limited due to vascularization challenges.

Integrating novel techniques like VSP with traditional flaps can mitigate radiotherapy-induced complications, improving outcomes, though cost and accessibility barriers persist, underscoring the need for further research and optimization.

8. Challenges and Limitations

Technical challenges in post-oncological oral and maxillofacial reconstruction include the limited availability of advanced technologies like virtual surgical planning (VSP) and 3D printing in resource-constrained settings, where high costs and infrastructure requirements restrict access, particularly in low-income regions (Stavrakas et al., 2020). Tissue engineering, while promising, faces complexities in achieving consistent outcomes, requiring long-term validation and regulatory approval. For instance, biomaterial scaffolds and stem cell therapies often lack standardized protocols, delaying clinical adoption due to concerns about sreproducibility and safety (Rai et al., 2015). These barriers hinder the widespread implementation of novel techniques, necessitating global efforts to enhance affordability and training.

Patient-related factors and research gaps further complicate reconstruction. Variability in defect size, location, and patient health, such as comorbidities or prior radiotherapy, impacts outcomes, with 10–15% reduced functional restoration in complex cases (Brown et al., 2016). Psychological barriers, including fear of lifelong immunosuppression in facial allotransplantation, limit patient acceptance, with 30% reporting anxiety about novel therapies (Djan & Penington, 2013). Research gaps include a lack of randomized controlled trials comparing traditional and novel techniques, limited long-term data on tissue engineering outcomes, and the absence of standardized defect classification systems, which impedes outcome comparison and protocol development (Brown et al., 2016).

9. Future Directions

Future technological advancements in oral and maxillofacial reconstruction will likely integrate artificial intelligence with virtual surgical planning (VSP) for real-time surgical guidance, enhancing precision. Developing bioactive scaffolds with improved vascularization will address large defect challenges, while bioprinting will enable personalized tissue constructs for combined hard and soft tissue regeneration. Streamlining VSP and 3D printing workflows will reduce costs and improve accessibility, particularly in resource-limited settings. Multidisciplinary collaboration among surgeons, oncologists, and engineers will optimize outcomes. Research priorities include long-term studies on stem cell and biomaterial safety, developing universal classification systems for maxillofacial defects to standardize protocols, and emphasizing patient-centered outcomes, such as health-related quality of life and psychological well-being, to enhance care.

10. Conclusion

New forms of technology, such as virtual surgical planning (VSP), 3D printing, and tissue engineering, can be applied to enhance precision and reduce operation time, while also improving post-oncological oral and maxillofacial reconstruction results, both in terms of functionality and aesthetics. Microvascular flaps remain the cornerstone of complex defect repair, whereas biomaterials and stem cell-based therapies hold promise for enhancing this approach. Notably, dental rehabilitation leads to an improved quality of life, the effects of which depend on the type of defect and any adjuvant treatments. Surgeons in more complex cases, based on patient-specific factors and defect details, to achieve an ideal selection of technique, should incorporate VSP and CAD/CAM. The research investment level should be increased to confirm new techniques and eliminate limitations. International cooperation should establish universal standards and provide greater access to advanced technologies to enhance patient-focused care.

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