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Free Flap Reconstruction In The Mandible: A Comprehensive Review

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Abstract

Reconstruction of mandibular defects remains one of the most challenging aspects of maxillofacial surgery. The introduction of microvascular free tissue transfer has transformed reconstructive outcomes, enabling restoration of both form and function with high success rates. Among the various donor options, the fibula, iliac crest, scapular, and radial forearm free flaps remain the primary workhorses in mandibular reconstruction. The evolution of digital technologies such as computer-aided design and manufacturing (CAD/CAM), three-dimensional (3D) printing, and virtual surgical planning (VSP) has further refined precision and predictability. This comprehensive review provides an in-depth overview of the principles, techniques, flap selection, functional outcomes, complications, and recent technological advancements in free flap reconstruction of the mandible. The fibula flap remains the gold standard due to its versatility, reliability, and ability to support dental rehabilitation. Future directions include bioprinting and tissue-engineered vascularized constructs to further enhance reconstructive outcomes.

Keywords: Mandibular reconstruction, free flap, fibula flap, microvascular surgery, CAD/CAM, 3D printing, mandibular defects.

1. Introduction

The mandible plays a vital role in facial esthetics, mastication, deglutition, speech, and airway stability. Mandibular defects may arise from trauma, tumor resection, osteoradionecrosis, or infection, often leading to severe functional and psychosocial morbidity[1-3]. The primary objective of mandibular reconstruction is to restore mandibular continuity, occlusion, facial contour, and oral competence while minimizing donor site morbidity[4].

Over the past four decades, the evolution from non-vascularized bone grafts to microvascular free tissue transfer has revolutionized maxillofacial reconstruction[5]. The introduction of the **fibula osteocutaneous flap** by Hidalgo in 1989 marked a turning point[6]. This technique allows simultaneous transfer of bone and soft tissue, maintaining viability through a consistent vascular pedicle, and facilitating immediate or delayed dental implant placement[7-8].

Today, free flap reconstruction of the mandible has achieved success rates exceeding 95%, with marked improvements in functional outcomes[9]. Advancements such as CAD/CAM-assisted planning and 3D printing have further enhanced reconstructive precision and aesthetic harmony[10-12].

This review provides a detailed analysis of the principles, techniques, outcomes, and innovations in mandibular reconstruction using free flaps, emphasizing current trends and future prospects.

2. Principles of Mandibular Reconstruction

Mandibular reconstruction follows three guiding principles: **anatomical restoration**, **functional rehabilitation**, and **aesthetic integration**. The ideal reconstructive method must provide sufficient bone for mandibular contour, adequate soft-tissue coverage, and potential for dental rehabilitation[13].

Reconstruction can be performed using:

- **Non-vascularized bone grafts:** suitable only for small defects (<6 cm).
- **Pedicled regional flaps:** such as pectoralis major myocutaneous flap, limited by arc of rotation.
- **Free vascularized flaps:** the current gold standard for large segmental defects[14,15].

3. Types of Free Flaps Used in Mandibular Reconstruction

3.1 Fibula Free Flap

The **fibula osteocutaneous flap** is the workhorse for mandibular reconstruction due to its long bicortical bone (up to 25 cm), consistent vascular anatomy, and ability to undergo multiple osteotomies[16,17]. The peroneal artery and its venae comitantes provide a reliable vascular supply. Advantages include:

- Adequate bone stock for dental implants.
- Simultaneous two-team approach (harvest and resection).
- Low donor-site morbidity.

Functional and esthetic outcomes are superior, with flap survival rates exceeding 95%[18,19].

3.2 Iliac Crest Free Flap

The **deep circumflex iliac artery (DCIA) flap** provides excellent bone height, making it ideal for anterior mandibular reconstruction where vertical dimension is critical[20]. It offers good contour and allows placement of osseointegrated implants. However, donor site complications such as gait disturbance and hernia formation limit its use[21].

3.3 Scapular Free Flap

The **scapular osteocutaneous flap** offers variable bone and soft-tissue components with a long pedicle based on the circumflex scapular artery[22]. It is preferred for composite defects requiring extensive soft tissue coverage. The patient can be positioned laterally, enabling a two-team approach[23].

3.4 Radial Forearm Osteocutaneous Flap

Although providing only limited bone (up to 10 cm), the **radial forearm osteocutaneous flap** is useful for small mandibular or alveolar defects[24]. The thin, pliable skin paddle allows intraoral lining. However, donor site morbidity such as radius fracture restricts its wider application[25].

4. Functional and Aesthetic Outcomes

Successful mandibular reconstruction restores mastication, speech, and facial symmetry. Multiple studies report that **85–90%** of patients achieve satisfactory functional outcomes following fibula reconstruction[26,27]. Rehabilitation with **osseointegrated implants** has further enhanced oral function[28,29].

Aesthetic outcomes are equally significant. Restoration of the mandibular contour and chin projection is critical for facial harmony. The use of **pre-bent titanium plates**, **3D-printed cutting guides**, and **virtual templates** ensures superior aesthetic outcomes[30,31].

5. Technological Advancements

5.1 Virtual Surgical Planning (VSP)

VSP involves preoperative 3D simulation of resection and reconstruction, allowing precise osteotomies and better occlusal alignment[32,33]. Studies demonstrate significant reductions in ischemia time, operative duration, and intraoperative adjustments[34].

5.2 Computer-Aided Design/Manufacturing (CAD/CAM)

CAD/CAM enables creation of **customized reconstruction plates** and **osteotomy guides**. These innovations have improved accuracy and minimized errors[35,36]. In addition, **CAD/CAM-fabricated fibula segments** ensure near-perfect mandibular contour.

5.3 3D Printing and Bioprinting

3D printing has revolutionized preoperative planning by producing anatomical models for surgical rehearsal[37]. Recent developments in **bioprinting** aim to fabricate vascularized bone constructs for future clinical use[38,39].

5.4 Augmented Reality and Intraoperative Navigation

Emerging technologies such as **augmented reality (AR)** and **intraoperative navigation systems** enhance spatial orientation during reconstruction, providing real-time guidance for accurate bone positioning[40].

6. Complications

Common complications include venous thrombosis, partial flap loss, infection, and wound dehiscence. Donor site complications vary by flap type:

- Fibula: transient gait disturbance (5–10%).
- Iliac crest: hernia formation (<5%).
- Radial forearm: radius fracture (up to 3%).
- Scapula: minimal morbidity.

Meticulous microvascular technique and postoperative monitoring are critical for preventing flap loss.

7. Future Directions

The future of mandibular reconstruction lies in **bioengineered vascularized bone constructs** and **tissue engineering**. Advances in stem cell biology and scaffold technology are enabling in vitro generation of vascularized bone tissues. **3D bioprinting** combining osteogenic cells, growth factors, and biomimetic scaffolds has shown promising experimental results. The integration of **AI-driven surgical planning** may soon allow fully customized, patient-specific reconstructions.

8. Conclusion

Free flap reconstruction represents the gold standard in mandibular defect rehabilitation. Among available techniques, the fibula flap remains the most versatile due to its length, vascular reliability, and implant compatibility. Technological innovations such as CAD/CAM, 3D printing, and virtual planning have dramatically enhanced precision and outcomes. The next generation of reconstructive surgery will likely integrate bioengineered tissue, AI-based simulation, and regenerative strategies to achieve true biological and aesthetic restoration.

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