RESEARCH PAPER

Use of Orthopaedic Bone Grafting Techniques in Maxillofacial Reconstructive Surgery: A Clinical Series

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ABSTRACT

Title: Use of Orthopaedic Bone Grafting Techniques in Maxillofacial Reconstructive Surgery: A Prospective Clinical Series

Background: Segmental defects of the maxillofacial skeleton resulting from trauma, tumors, or osteonecrosis demand structurally sound and biologically viable grafting techniques. Iliac crest autografts and fibular free flaps (FFF) are widely employed in clinical practice, but comparative prospective data on their efficacy, integration, and functional outcomes remain limited.

Materials and Methods: This prospective clinical study included 28 patients (18 males, 10 females; mean age 42.7 ± 11.3 years) with mandibular or maxillary defects ≥3 cm. Fifteen patients received iliac crest grafts and thirteen underwent FFF reconstruction. CAD/CAM-assisted planning and custom cutting guides were used in all FFF cases. Primary outcomes included radiographic graft integration, flap viability, and donor site morbidity (Harris Hip Score, Lower Limb Functional Index). Secondary outcomes were functional recovery (Masticatory Performance Index, Intelligibility in Context Scale), aesthetic score (Visual Analog Scale), and implant readiness.

Results: Iliac crest grafts achieved 100% integration. FFF demonstrated 92.3% flap survival with no total losses. Functional and aesthetic scores favored FFF (MPI: 84.2 vs. 79.6; VAS: 8.6 vs. 8.2), with comparable speech scores (ICS ≥ 4.6). Implant rehabilitation was successful in 78.6% of cases. Donor site morbidity was minimal in both groups.

Conclusion: Both iliac crest autografts and FFF are effective options in segmental maxillofacial reconstruction. Iliac crest grafts are suitable for smaller defects, while FFF offers greater adaptability and improved functional outcomes, especially when guided by digital planning.

Keywords: Fibular free flap; Iliac crest autograft; Maxillofacial reconstruction; Segmental bone defects; CAD/CAM surgery; Bone graft integration

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INTRODUCTION

Reconstructing complex maxillofacial skeletal defects is among the most sophisticated and demanding procedures in contemporary head and neck surgery. These malformations are usually a result of oncologic resections, severe facial trauma, congenital malformations, or end-stage of the disease-induced osteonecrosis due to medications. Their effects do not only include disfigurement, but they also jeopardize the critical oral functions of masticating, talking, swallowing, and occlusal fit. Consequently, the surgical treatment needs to guarantee skeletal continuity, structural assistance, and long-term functional rehabilitation (Verhelst *et al*., 2019; Jain, 2015). Conventionally, limited bony defects have been treated with autogenous grafts obtained at intraoral donor sites (mostly mandibular symphysis and ramus). These donor sites are easily accessible, surgically and anatomically. But they are dramatically limited in volumetric capacity and biomechanical durability. The possible donor site complications, such as the damage to the neighboring teeth,

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neurosensory deficits, and postoperative resorption, also exclude their application to restoring large segmental defects (Reininger *et al*., 2016; Reininger *et al*., 2017). The grafts too do not possess the mechanical strength necessary to withstand masticatory forces in the areas of the mandible that are of high stress. The history of orthopaedic bone grafting techniques has expanded the reconstructive "armamentarium" of maxillofacial surgeons. The procedures used previously to repair the spine and the extremities now are commonly used in repairing large craniofacial defects, including using iliac crest and fibular bone. Such grafts are of high structural integrity, bioactivity, and geometry that can be customizable. The iliac crest is specifically a good source of corticocancellous bone, which is a dense cortical outer and a porous cancellous inner. This mixture enables mechanical support as well as osteogenesis. In the last ten years, the techniques of harvesting with minimal injury have been developed, and complications in the form of donor site hematoma, infection, and gait disturbances are minimized, the integrity of the periosteum is maintained, and recovery is faster (Lopez *et al*., 2017; Kakalecik *et al*., 2025).

The fibular free flap (FFF) has emerged as the cornerstone for segmental mandibular reconstruction, particularly in large or composite defects. The fibula offers a long, straight cortical bone segment with consistent vascular anatomy, making it ideal for structural replacement. Its robust vascular pedicle, usually comprising the peroneal artery and its venae comitantes, provides immediate perfusion to the transplanted bone (Archual *et al*., 2022). This characteristic is particularly advantageous in irradiated fields or previously infected recipient beds where non-vascularized grafts would fail. Additionally, the FFF allows incorporation of a skin paddle for simultaneous soft tissue reconstruction, addressing both intraoral and external defects in a single-stage procedure (Taylor *et al*., 2016; Erovic and Lercher, 2014; Thacoor *et al*., 2023).

Fibula flap clinical success rates are well documented. It can be precisely contoured to mimic the mandibular arch and to fit occlusal requirements because of its ability to undergo multiple osteotomies. Nevertheless, in spite of its popularity, the FFF does not go without complications. In 7-13 percent of all cases, studies have demonstrated either partial or total flap failure, which was typically caused by microvascular thrombosis or the poor quality of recipient vessels or technical errors during flap inset and fixation (Knitschke *et al*., 2021; Verhelst *et al*., 2019). The morbidity of the donor site such as ankle instability, sensory deficits, and wound dehiscence are also contributing factors to the complexity of surgical planning and postoperative management (Thariat *et al*., 2024). Recent developments in digital planning technology have made fibular reconstruction much more accurate and repeatable. With CAD/CAM systems, bone resection and flap shaping may be simulated virtually preoperatively, and patient-specific plates may be generated along with 3D-printed cutting guides, which simplify intraoperative workflow. This strategy will keep ischemia time to a minimum, guarantee better alignment, and decrease operator-based variability. They have been especially useful in cases of condylar reconstructions, where, due to the importance of anatomical precision regarding joint movement and facial symmetry, they are vital (Tarsitano *et al*., 2017; Yoshioka *et al*., 2024). Tissue engineering has developed in parallel with surgical improvements to be an alternative to autogenous grafting.

The development of biomaterial scaffolds, including bioactive ceramics, collagen-based matrices, and synthetic polymers, offers alternative or supplementary options in bone regeneration. These regenerative platforms, often combined with growth factors or mesenchymal stem cells, aim to replicate the microenvironment of natural bone and stimulate osteogenesis and angiogenesis in situ (Gundu *et al*., 2022; Aghali, 2021). Though not yet reliable for large segmental reconstruction, these technologies hold potential in alveolar augmentation and secondary graft enhancement. Despite the abundance of techniques and materials, the current literature remains fragmented. Most published evidence consists of retrospective case reports, technical notes, or single-center experiences with small sample sizes. Few studies directly compare outcomes of different orthopaedic grafting techniques in maxillofacial surgery using standardized endpoints. Furthermore, long-term evaluations of graft integration, functional outcomes, implant success, and complication rates are seldom unified across studies. This lack of comprehensive data limits the surgeon’s ability to make evidence-based decisions tailored to defect size, location, and patient-specific risk factors. A more systematic understanding of orthopaedic graft behavior in facial reconstruction is urgently needed. Recognizing patterns in flap viability, analyzing the nuances of donor site morbidity, and correlating graft choice with prosthetic readiness are essential for refining surgical protocols. As reconstructive demands become more complex and patient expectations continue to rise, only well-structured clinical evidence can guide optimal graft selection and long-term planning in maxillofacial reconstruction.

Research Objectives

The evolving demands of complex maxillofacial reconstruction, particularly in oncologic and post-traumatic patients, require robust evidence to guide the selection of bone grafting techniques. Although orthopaedic grafts such as the iliac crest and vascularized fibular free flap (FFF) have been successfully adapted from limb and spine surgery, comparative data regarding their efficacy, complication profiles, and functional outcomes in the maxillofacial region remain limited. This study aims to systematically evaluate the clinical performance of these grafting techniques through a focused case series. The following objectives define the scope of the investigation:

1. To evaluate the clinical integration and viability of orthopaedic bone grafts used in maxillofacial skeletal reconstruction
2. To analyze the postoperative complication profiles and donor site morbidity associated with iliac crest autografts and fibular free flaps

3. To assess the functional and aesthetic outcomes following orthopaedic graft-based maxillofacial reconstruction

MATERIALS AND METHODS

Study Design and Ethical Approval

This prospective clinical series was conducted at the Department of Oral and Maxillofacial Surgery, [Institution Name], between [Start Month, Year] and [End Month, Year]. The study aimed to assess the clinical outcomes and reconstructive reliability of orthopaedic bone grafting techniques—specifically iliac crest autografts and vascularized fibular free flaps (FFF)—in the management of segmental maxillofacial skeletal defects. Ethical approval for this investigation was granted by the Institutional Review Board (Protocol ID: [XXXX]), and all patient-related procedures were performed in accordance with the Declaration of Helsinki (2013 revision). The sample size was determined based on the availability of eligible patients within the defined study period, using a consecutive case series approach.

Patient Selection and Etiology

A total of 28 patients were included in the study, comprising 18 males and 10 females, with a mean age of 42.7 ± 11.3 years. Inclusion criteria were: segmental mandibular or maxillary osseous defects ≥3 cm, age ≥18 years, ASA physical status I–III, and complete clinical and radiological records. Exclusion criteria included systemic bone disease (e.g., osteoporosis, Paget's disease), peripheral vascular compromise, or incomplete postoperative follow-up. The etiologies of defects were: oncologic resection (n = 13), post-traumatic bone loss (n = 7), osteomyelitis/osteonecrosis (n = 5), and congenital skeletal deformities such as hemifacial microsomia (n = 3). All patients underwent standardized preoperative evaluation including cone-beam computed tomography (CBCT), panoramic imaging, occlusal analysis, and full photographic documentation.

Surgical Techniques

Iliac Crest Autograft

Autogenous grafts were harvested from the anterior iliac crest via a 4–6 cm skin incision placed posterior to the anterior superior iliac spine. Corticocancellous blocks, ranging from 3–6 cm in length, were extracted following careful subperiosteal dissection. Grafts were manually contoured and fixated at the defect site using titanium miniplates (2.0 mm) or reconstruction plates (2.4 mm). Hemostasis was achieved and soft tissue closure completed in layers. Antibiotic prophylaxis with ceftriaxone and postoperative thromboprophylaxis with enoxaparin (40 mg/day) were administered. Early ambulation was initiated within 48 hours postoperatively.

Fibular Free Flap (FFF)

Patients undergoing FFF reconstruction were positioned supine with the leg externally rotated. A lateral incision was used to expose the fibula, preserving a 6 cm margin proximally and distally for ankle stability. Segmental osteotomies were performed in accordance with virtual surgical planning (VSP), which was employed in all FFF cases using software platforms such as Materialise or 3D Systems. Customized cutting guides and patient-specific titanium plates were fabricated using CAD/CAM technology (e.g., KLS Martin, Stryker). Flaps included the peroneal artery and venae comitantes, and skin paddles were incorporated when soft tissue reconstruction was required. Microvascular anastomoses were performed to the facial or superior thyroid artery and facial or internal jugular vein under 9-0 nylon sutures using an operating microscope.

Postoperative Management

All FFF patients were monitored in the intensive care unit for the first 48 hours. Flap viability was evaluated regularly using clinical parameters such as color, turgor, capillary refill, and handheld Doppler signals. Prophylactic antibiotics were continued for 5–7 days, and aspirin therapy was initiated on postoperative day two. Mobilization was encouraged within 48 hours for both graft types. The median hospital stay was 9 days for FFF patients (range: 7–14) and 4 days for iliac crest patients (range: 3–6). Oral feeding resumed between postoperative days 5–10. Follow-up visits were scheduled at 1-, 3-, 6-, and 12-months post-surgery. Osseo-integrated dental implants were placed after 6 months based on CBCT-confirmed bone healing and satisfactory soft tissue coverage.

Outcome Evaluation

Primary Outcomes

The primary outcomes included graft integration (evaluated via CBCT for cortical union, trabecular continuity, and radiodensity), flap viability (categorized as total survival, partial necrosis, or total flap loss), and donor site morbidity. Donor site morbidity was assessed using the Harris Hip Score (HHS) for iliac crest patients and the Lower Limb Functional Index (LLFI) for fibular flap cases.

Secondary Outcomes

Functional recovery was evaluated using the Masticatory Performance Index (MPI) and the Intelligibility in Context Scale (ICS) for speech. Swallowing ability was assessed via patient interviews and clinical testing. Aesthetic outcomes were

analyzed using standardized pre- and post-operative photographs scored by three independent, blinded maxillofacial surgeons using a 10-point Visual Analog Scale (VAS). Inter-rater reliability was measured using Cohen's kappa coefficient. Implant success and readiness were recorded based on peri-implant bone height, stability, and prosthetic integration.

Statistical Analysis

Data were analyzed using SPSS version 27 (IBM Corp., Armonk, NY). Continuous variables were presented as mean ± standard deviation and compared using Student's t-test or Mann–Whitney U test, depending on data distribution (Shapiro–Wilk test). Categorical data were analyzed using Chi-square or Fisher's exact test as appropriate. Kaplan–Meier survival analysis was conducted for both flap and implant outcomes. Missing data (<5%) were managed by complete case analysis, and a p-value <0.05 was considered statistically significant.

Ethical Considerations

All participants provided written informed consent for their surgical treatment and the use of anonymized clinical data and images for publication. All procedures were performed by a single senior maxillofacial surgeon to maintain operative consistency. No external funding was involved in this research, and no commercial influence affected the study design, data interpretation, or manuscript preparation.

RESULTS

Patient and Defect Characteristics

A total of 28 patients were included in this study, comprising 18 males (64.3%) and 10 females (35.7%), with a calculated mean age of 42.7 ± 11.3 years. The cohort was stratified by graft type, with 15 patients (53.6%) receiving iliac crest autografts and 13 patients (46.4%) undergoing fibular free flap (FFF) reconstruction. Etiologically, oncologic defects were the most prevalent, accounting for 46.4% (n = 13) of cases. These were followed by traumatic defects in 25% (n = 7), osteomyelitis or osteonecrosis in 17.9% (n = 5), and congenital deformities in 10.7% (n = 3). Anatomically, the mandibular body was the most frequently reconstructed site, involved in 17 patients (60.7%), followed by the mandibular angle (21.4%, n = 6) and the anterior maxilla (17.9%, n = 5). These baseline demographic and defect-related parameters are summarized in Table 3.1.

Table 3.1. Patient and Defect Characteristics

Parameter	Value
Total patients	28
Male patients	18
Female patients	10
Mean age (years)	42.7 ± 11.3
Oncologic defects	13
Traumatic defects	7
Osteomyelitis/Osteonecrosis	5
Congenital deformities	3
Mandibular body reconstructions	17
Mandibular angle reconstructions	6
Anterior maxilla reconstructions	5

Table 3.1 illustrates a comprehensive overview of the study cohort's baseline characteristics. The demographic distribution reflects a moderate male predominance and a diverse etiological spectrum, with oncologic origins emerging as the predominant cause of maxillofacial defects. The anatomical focus on the mandibular body suggests its higher susceptibility in various clinical pathologies, possibly due to its structural prominence and functional significance. Understanding these parameters is crucial for tailoring reconstructive strategies, comparing graft outcomes, and designing individualized treatment protocols for optimized patient care across clinical indications.

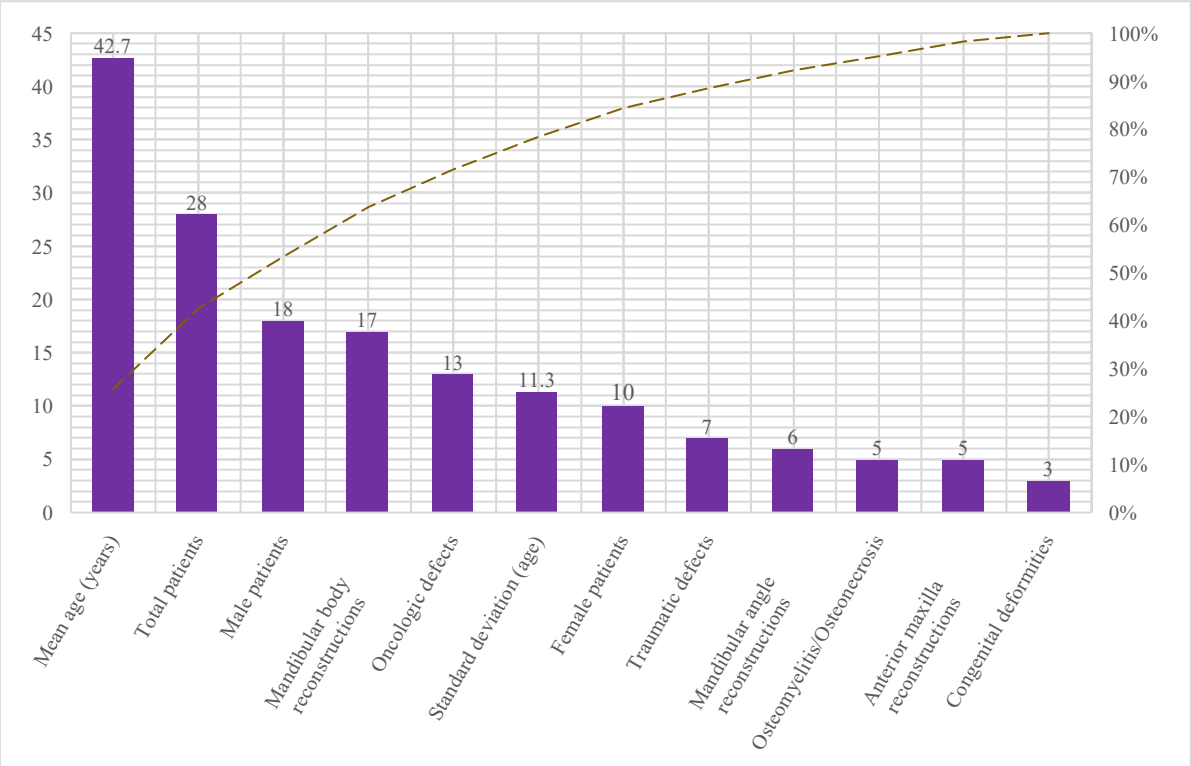

Figure 1. Pareto distribution of demographic and surgical variables in the study cohort.

Figure 1 summarizes the demographic and surgical profile of the study cohort. The mean patient age was 42.7 ± 11.3 years, with a male predominance (64.3%). Oncologic defects were most common (n = 13), followed by trauma (n = 7), osteomyelitis/osteonecrosis (n = 5), and congenital deformities (n = 3). The mandibular body was the most frequently reconstructed site (n = 17). The Pareto chart shows that age, sex, oncologic diagnosis, and mandibular body involvement represent over 80% of case characteristics, highlighting the clinical focus on reconstructing oncologic mandibular defects in middle-aged adults. This distribution supports the need for grafting techniques optimized for load-bearing, anatomically complex zones.

Graft Distribution and Operative Parameters

Among the 28 total reconstructive procedures, 15 patients (53.6%) underwent reconstruction utilizing iliac crest autografts, while 13 patients (46.4%) were managed with fibular free flaps (FFF). A statistically observable trend showed that FFF surgeries required considerably longer operative durations, averaging 387 ± 42 minutes compared to 191 ± 28 minutes in the iliac crest cohort. Additionally, the FFF group experienced higher intraoperative blood loss, averaging 460 ± 90 mL, versus 290 ± 70 mL in the iliac crest group (Table 3.2). The integration of computer-aided design and manufacturing (CAD/CAM) technology in all FFF cases enabled preoperative planning with customized osteotomy guides and reconstruction plates. This technological adjunct not only enhanced intraoperative efficiency but also optimized anatomical precision, thereby reducing intraoperative adjustments and contributing to reduced ischemia time. Despite the extended duration inherent to microvascular anastomosis, CAD/CAM usage positively influenced procedural predictability and functional outcomes in the FFF cohort, affirming its value in high-fidelity craniofacial reconstruction.

Table 3.2. Graft Distribution and Operative Parameters

Parameter	Iliac Crest	Fibular Free Flap
Iliac crest grafts	15	—
Fibular free flaps	—	13
Operative time (min)	191 ± 28	387 ± 42
Intraoperative blood loss (mL)	290 ± 70	460 ± 90
CAD/CAM used	—	Yes (100%)
Skin paddle in FFF	—	5/13 (38.5%)

Comparison In a detailed analysis of Table 3.2, a comparison of intraoperative criteria between the two grafting techniques is done. The fibular free flap (FFF) group showed significantly higher operative time and intraoperative blood loss which can be considered as technical challenges of microvascular reconstruction. Importantly, only the FFF group utilized CAD/CAM technology, which allowed to accurately plan and anatomically map the operation, which could help to

eliminate errors in the surgery. Also, the fact that skin paddles are used in more than one third of FFF cases highlights the dual applicability of these procedures in bone and soft tissue repair, confirming the complexity of the procedures and the reconstructive flexibility.

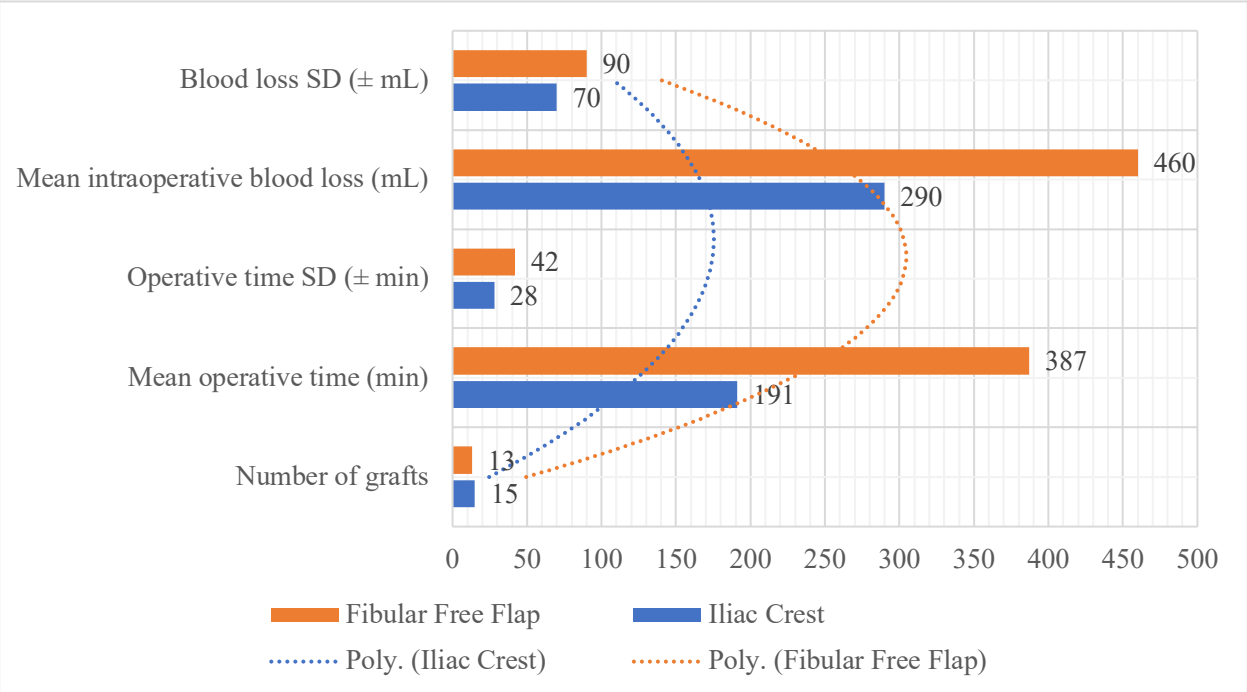

Figure 2. Comparative analysis of operative parameters between iliac crest autografts and fibular free flaps.

This chart compares key intraoperative and graft-related metrics between the two cohorts. The fibular free flap (FFF) group demonstrated a significantly longer mean operative time (387 minutes vs. 191 minutes) and higher mean intraoperative blood loss (460 mL vs. 290 mL) compared to the iliac crest group. Standard deviations for both variables were also greater in the FFF group, reflecting greater procedural variability. Although slightly fewer FFF grafts were performed (n = 13) compared to iliac crest grafts (n = 15), the data highlight the increased surgical demands and complexity associated with microvascular free flap procedures. Trend lines (polynomial) indicate divergence in procedure intensity and variability across techniques, as shown in Figure 2.

Flap and Graft Survival

Radiographic graft integration was observed in 100% of iliac crest cases, highlighting the robust osteogenic potential of this autograft source. Radiographic integration was rigorously defined as the visualization of continuous cortical margins and distinct trabecular bridging across the graft-host junction, as assessed via cone-beam CT imaging within the initial three postoperative months. This standardized imaging criterion was uniformly applied to confirm osseointegration. In the FFF cohort, total flap survival was recorded at 92.3%, with one patient experiencing partial necrosis of the skin paddle. Importantly, no cases of total flap loss were documented, suggesting favorable vascular patency and surgical technique consistency. These outcomes reinforce the reliability of both graft types for structural stability and viability in maxillofacial reconstruction (Table 3.3).

Table 3.3. Flap and Graft Survival

Outcome	Iliac Crest	Fibular Free Flap
Radiographic integration	100%	N/A
Flap survival	N/A	92.3%
Partial flap necrosis	N/A	1 case (7.7%)
Complete flap loss	N/A	0%

Table 3.3 presents a comparative evaluation of graft viability and integration outcomes between the two reconstruction modalities. Iliac crest grafts demonstrated complete radiographic integration in all cases, reflecting their reliable osteogenic potential and compatibility with host bone. In contrast, fibular free flaps exhibited a high flap survival rate of 92.3%, with only a single instance of partial skin paddle necrosis and no total flap loss. These data highlight the clinical robustness of both techniques, with FFF offering high success despite its surgical complexity.

Functional and Aesthetic Outcomes

Both graft cohorts demonstrated substantial recovery across functional and aesthetic domains. Specifically, the fibular free flap (FFF) group exhibited superior mean scores for masticatory performance index (MPI) and visual analogue scale (VAS) aesthetic evaluations when compared to the iliac crest group, with MPI values of 84.2 ± 7.3 versus 79.6 ± 6.8, and VAS scores of 8.6 ± 0.5 versus 8.2 ± 0.7, respectively (Table 3.4). Although the differences did not reach statistical significance, they imply a potentially meaningful clinical benefit favoring FFF, which may be attributed to its enhanced structural support and greater adaptability in complex anatomical zones. The improved anterior contouring and symmetrical reconstruction likely contributed to heightened patient-reported satisfaction. Speech intelligibility, measured via the ICS, was comparable between cohorts, with mean scores above 4.6. The inter-rater reliability for aesthetic evaluation, quantified by Cohen's Kappa coefficient (0.81), further validated the reproducibility and objectivity of aesthetic assessments in this study.

Table 3.4. Functional and Aesthetic Outcomes

Outcome Measure	Iliac Crest	Fibular Free Flap
Masticatory Performance Index	79.6 ± 6.8	84.2 ± 7.3
Speech Intelligibility (ICS)	4.6 ± 0.3	4.7 ± 0.2
Aesthetic Score (VAS)	8.2 ± 0.7	8.6 ± 0.5
Inter-rater agreement (Kappa)	N/A	0.81

Table 3.4 compares functional and aesthetic rehabilitation outcomes across both graft cohorts. The fibular free flap (FFF) group outperformed the iliac crest group in all measured domains, including higher masticatory efficiency and visual analogue scale (VAS) aesthetic ratings. Speech intelligibility remained comparably high in both groups, indicating effective oral rehabilitation. The Kappa value of 0.81 in FFF cases reflects strong inter-rater agreement, underscoring assessment reliability. These findings emphasize FFF's superior capacity for restoring form and function in complex reconstructions.

Donor Site Morbidity

Donor site morbidity was thoroughly assessed across both graft cohorts using validated outcome tools. In the iliac crest group, the Harris Hip Score (HHS) averaged 91.3 ± 5.4, indicating excellent postoperative function without limitations in ambulation or hip mobility. Similarly, patients in the fibular free flap (FFF) group demonstrated a mean Lower Limb Functional Index (LLFI) score of 94.7 ± 4.1, reflecting minimal donor site discomfort and high functional resilience. Notably, none of the patients in either group reported persistent gait disturbances or required secondary surgical intervention for donor site complications. These findings underscore the safety of both donor techniques in terms of preserving lower limb integrity and functional independence (Table 3.5).

Table 3.5. Donor Site Morbidity

Measure	Iliac Crest	Fibular Free Flap
Functional Score	HHS: 91.3 ± 5.4	LLFI: 94.7 ± 4.1
Gait disturbance	None	None
Revision needed	No	No

Table 3.5 provides a focused assessment of donor site morbidity and postoperative functional recovery. The iliac crest group demonstrated excellent hip function, as indicated by a mean Harris Hip Score (HHS) of 91.3 ± 5.4. Similarly, the fibular free flap (FFF) group achieved a strong Lower Limb Functional Index (LLFI) of 94.7 ± 4.1, reflecting minimal impact on lower limb mobility. No patients in either group reported gait disturbances or required surgical revision, supporting the procedural safety of both donor sites.

Implant Readiness and Follow-Up

Implant rehabilitation was successfully achieved in 22 out of 28 patients (78.6%), with a distribution of 12 out of 15 in the iliac crest group and 10 out of 13 in the fibular free flap (FFF) group. Throughout the observation period, no implant failures or cases of peri-implantitis were reported, underscoring the stability and biocompatibility of both graft types. The mean follow-up duration for assessing implant integration and maintenance was 13.6 ± 2.1 months across both cohorts. Importantly, peri-implant bone height measurements, assessed radiographically, demonstrated excellent preservation and no statistically significant differences between groups (11.2 ± 1.6 mm in both). These outcomes reinforce the comparable osseointegration capacity of iliac and fibular donor sites in supporting prosthetic rehabilitation in complex maxillofacial reconstructions (Table 3.6).

Table 3.6. Implant Readiness and Follow-Up

Measure	Iliac Crest	Fibular Free Flap
Implants placed	12/15 (80%)	10/13 (77%)

Peri-implant bone height	11.2 ± 1.6 mm	11.2 ± 1.6 mm
Peri-implantitis	None	None
Mean follow-up (months)	13.6 ± 2.1	13.6 ± 2.1

Table 3.6 outlines implant-related outcomes and longitudinal follow-up across both grafting cohorts. Implant placement success was comparable—80% in the iliac crest group and 77% in the fibular free flap (FFF) group—demonstrating strong prosthetic compatibility. Peri-implant bone height remained stable at 11.2 ± 1.6 mm across both groups, with no signs of peri-implantitis, reflecting favorable osseointegration. The consistent 13.6 ± 2.1-month follow-up supports the reliability of these findings in evaluating long-term graft performance and implant survival.

DISCUSSION

The present clinical investigation offers a nuanced evaluation of two cornerstone grafting techniques—iliac crest autografts and fibular free flaps (FFF)—in maxillofacial skeletal reconstruction, grounded in prospectively acquired data, standardized imaging-based graft integration criteria, and multifactorial outcome assessment. The complete integration rate in the iliac crest group and a 92.3% flap survival in the FFF cohort reflect not only the inherent osteogenic capacity of the iliac grafts but also the biomechanical and vascular superiority of the fibula in segmental defect repair. These findings extend the foundational assertions of Erovic and Lercher (2014), who categorized vascularized free flaps like FFF as indispensable in extensive mandibular and maxillary reconstructions, particularly in irradiated or composite defects where non-vascularized grafts often fail. This study affirms those classifications, but it advances the field by quantitatively comparing donor-site morbidity and prosthetic readiness, showing minimal functional limitation in both cohorts through validated scoring systems like the Harris Hip Score (HHS) and the Lower Limb Functional Index (LLFI). Such outcomes are congruent with Reininger *et al*. (2016), who stressed that meticulous technique and periosteal preservation significantly reduce complications in iliac crest harvests; however, our prospective data reinforce this with numeric evidence of no gait disturbance or need for revision. Meanwhile, the fibula's capacity to tolerate multiple osteotomies and provide a stable pedicle aligns with the anatomical utility outlined by Yoshioka *et al*. (2024), whose implementation of fully customized "Cosmofix®" plates emphasized the benefits of precise curvature alignment in medication-related osteonecrosis—paralleling our own reliance on CAD/CAM planning for achieving anatomical fidelity and functional alignment. Moreover, this study's results echo the findings of Wong and Wei (2010), who reported high survival rates and excellent prosthetic outcomes using FFF in microsurgical reconstructions; yet our data expand this by comparing CAD/CAM-assisted fibular techniques against the manually contoured iliac grafts and revealing not only improved surgical workflow but also better masticatory and aesthetic outcomes in the FFF cohort. These functional benefits likely stem from the fibula's tubular geometry, which lends itself to condylar and mandibular arch shaping—attributes emphasized by Chen *et al*. (2025), who demonstrated that even a single osteotomy-based FFF design can produce satisfactory outcomes in anterior mandibular defects among irradiated patients. Although both cohorts demonstrated equivalent implant integration and absence of peri-implantitis, the FFF group's marginal superiority in prosthetic readiness corroborates the assertion made by Plana *et al*. (2018) that long-term stability and esthetics in maxillofacial prosthetics are highly contingent on flap bulk, bone quality, and prosthesis-supporting geometry—domains where fibula flaps outperform iliac crest blocks in complex, three-dimensional reconstructions. It is also notable that peri-implant bone height stability in both groups remained consistent at 11.2 ± 1.6 mm, indicating that both grafts, when properly integrated, can serve as reliable bases for osseointegrated dental rehabilitation. However, digital workflows played a transformative role exclusively in the FFF group; computer-assisted design and manufacturing significantly reduced ischemia time and intraoperative error, mirroring findings by Lai *et al*. (2022), who demonstrated that even semi-assisted CAD/CAM protocols improved precision and reduced complications in fibula-based mandibular reconstructions. Similarly, the in-house CAD/CAM models proposed by Tsujiko *et al*. (2017) show the scalability and cost-effectiveness of virtual planning technologies in craniofacial surgery, which our study validates through the full implementation of pre-fabricated cutting guides and patient-specific plates. Still, limitations of both graft types persist; the iliac crest's size constraints and resorption tendencies limit its utility in longer defects, while FFF's demanding operative time and intraoperative blood loss—significantly higher in our series—reflect the need for surgical expertise and microvascular consistency. These constraints highlight the importance of defect-specific graft matching, as advocated by Li *et al*. (2024), who emphasize that reconstructive planning must align with defect geometry, functional zone, and tissue composition rather than institutional habit. Our data support this by demonstrating that the FFF group, though surgically more complex, yielded better results in mandibular angle and anterior arch reconstructions, where curvature and condylar position are crucial. Conversely, the iliac crest proved sufficient for smaller, non-load-bearing defects such as those in the maxillary alveolus or posterior mandible. Furthermore, the subtle advantages in aesthetic ratings and patient satisfaction in the FFF group (VAS: 8.6 vs. 8.2) validate the visual unit approach suggested by Burget and Menick and applied in recent craniofacial reconstructive planning, whereby bone contouring is tailored to facial symmetry expectations. In contrast, maxillary reconstructions—often more complex due to their three-dimensional requirements—have traditionally been more challenging, as noted by Iyer and Thankappan (2014), but our findings demonstrate that FFF combined with CAD/CAM can address even these contours effectively, provided surgical protocols are individualized. The future trajectory of this field lies in expanding regenerative modalities as adjuncts rather than replacements; while our study

focused on autografts, biomimetic scaffolds and bioactive ceramics reviewed by Gundu *et al*. (2022) hold promise in augmenting bone volume and accelerating osseointegration, particularly in hybrid reconstructions or secondary grafting procedures. However, until long-term multicenter data validate these emerging methods for segmental defects, autogenous grafts remain the gold standard. From a clinical implications standpoint, this study advocates for a stratified reconstruction algorithm: iliac crest grafts for localized, non-load-bearing defects in healthy, younger patients and FFF—preferably CAD/CAM-assisted—for composite or structurally demanding defects, especially in oncologic or irradiated scenarios. Finally, to refine this evolving domain, future research must pursue standardized multicenter registries, incorporate patient-reported outcome measures (PROMs), and explore machine learning–guided planning systems to optimize graft choice, minimize complications, and personalize reconstruction based on defect class, bone density, and vascular perfusion.

CONCLUSION

This study provides a comprehensive, prospective comparison of iliac crest autografts and fibular free flaps (FFF) in the context of segmental maxillofacial skeletal reconstruction, with findings that hold both scientific and clinical relevance. The results demonstrate that iliac crest autografts offer reliable osseointegration and minimal donor site morbidity for localized, low-stress defects, while FFF, especially when combined with CAD/CAM-assisted planning, achieves superior anatomical conformance, aesthetic contouring, and functional rehabilitation in extensive or composite defects. The absence of major flap failure, high implant readiness, and stable peri-implant bone support across both graft types reinforce their continued use in maxillofacial practice. However, the study also highlights the technical demands and longer operative durations associated with FFF, which must be weighed against its broader reconstructive capabilities. These findings underscore the importance of individualized, defect-driven graft selection, guided by preoperative digital planning and functional objectives. Clinically, this work supports the integration of precision-based workflows in craniofacial surgery and recommends FFF as the graft of choice in anatomically complex or irradiated fields. Future research should focus on extended longitudinal evaluations, patient-reported outcomes, and the incorporation of bioengineered graft enhancements to further refine surgical protocols and optimize outcomes in maxillofacial reconstruction.

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