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Research Article

Non-vascularized fibular autograft is a reliable option for reconstruction after tumor-related metatarsal resections

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ABSTRACT

Objective: This study aimed to evaluate the clinical, radiological, and functional outcomes of metatarsal reconstruction using non-vascularized fibular autografts after resection of benign aggressive and malignant tumors.

Methods: This retrospective review included 12 patients (15 reconstructions; 7 male, 5 female) who underwent metatarsal reconstruction with a non-vascularized fibular autograft between 2006 and 2023. The mean age was 27.6 ± 9.3 years (range, 7-49), and the mean follow-up was 46.3 ± 16.1 months (range, 29-157). Radiographic union at the proximal and distal graft–host junctions, complications classified according to the Henderson system, time to weight-bearing, time to Kirschner wire removal, and functional outcomes (Visual Analog Scale, Musculoskeletal Tumor Society (MSTS), Foot and Ankle Disability Index (FADI), and American Orthopaedic Foot and Ankle Society (AOFAS)) were evaluated.

Results: Radiographic union was achieved in all reconstructions without nonunion or graft failure. Mean union time was 7.1 ± 1.1 weeks (range, 6-9) proximally and 10.1 ± 0.8 weeks (range, 9-11) distally, and weight-bearing was initiated at a mean of 4.7 ± 1.4 weeks (range, 3-8). Intercalary reconstruction yielded significantly higher functional scores than arthrodesis-based reconstruction (FADI, $P = .012$; AOFAS, $P = .022$; MSTS, $P = .005$) and shorter operative duration ($P < .001$). No local recurrence or systemic metastasis was observed during follow-up. Six patients developed soft-tissue complications (Henderson Type 1A/1B), none requiring amputation or revision surgery.

Conclusion: Non-vascularized fibular autograft reconstruction provided consistent union and generally favorable functional outcomes after tumor-related metatarsal resections in this series. Clinically, non-vascularized fibular autografts may represent a reliable, technically simpler alternative to vascularized grafts for metatarsal reconstruction and may reduce operative time and procedural complexity, with a relatively low rate of major complications.

Level of Evidence: Level IV, Therapeutic Study.

Introduction

Neoplastic lesions of the bones of the foot are rare, accounting for approximately 3%-6% of all primary bone tumors, with the majority being benign and a smaller proportion classified as malignant.[1] Despite their low incidence, tumors involving the metatarsal region pose significant surgical challenges due to the limited soft tissue coverage, complex anatomy, and the essential role of this region in weight-bearing and gait.[2,3] Historically, malignant tumors of the foot often resulted in amputation; however, advances in oncologic and reconstructive surgery have shifted treatment strategies toward limb salvage whenever feasible.[3,4]

Wide or marginal resection of benign aggressive and malignant metatarsal tumors frequently results in segmental bone defects that require reconstruction to restore forefoot alignment, pedal arch integrity, and functional ambulation.[4] The forefoot functions as a dynamic load-bearing structure during gait, and the first and fifth metatarsal heads constitute key contact points contributing to the "tripod" configuration that supports balance and propulsion.[5] Accordingly, defects involving the first or fifth metatarsals may have distinct functional implications compared with reconstructions of the central metatarsals. The small size of the metatarsal bones, close proximity of neurovascular structures, and limited options for stable fixation make reconstruction particularly demanding. In this context, the fibula represents a suitable graft source due to its cortical strength, straight geometry, and adaptability to metatarsal dimensions.[6]

Vascularized fibular grafts have been widely used for reconstruction of skeletal defects following tumor resection; however, their application in metatarsal reconstruction remains controversial.[7-9] These procedures require microsurgical expertise, prolonged operative time, and are associated with increased donor-site morbidity. In contrast, non-vascularized fibular autografts offer a technically simpler and more readily available alternative, potentially reducing surgical time, perioperative complexity, and overall morbidity while still providing adequate biological potential for bone healing.[6,10-12]

Although several case reports and small series have described the use of non-vascularized fibular grafts

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for metatarsal reconstruction, the reported outcomes remain heterogeneous, and the optimal indications and reconstructive strategies are not well defined.[10-12] Given the rarity of tumor-related metatarsal resections, further clinical data are required to clarify the role of non-vascularized fibular autografts in this setting.

Therefore, the aim of this study was to evaluate the clinical, radiological, and functional outcomes of metatarsal reconstruction using non-vascularized fibular autografts following resection of benign aggressive and malignant tumors.

Material and methods

The study was conducted at Baltalimanı Bone Diseases Training and Research Hospital and was approved by the local ethics committee under the meeting number 28 and decision number 195, dated October 28, 2024. Informed consent was obtained from all patients before surgery; for patients under the age of 18, consent was obtained from their legal caregivers. The data of 23 patients with primary benign aggressive and malignant bone tumors of the metatarsals of the foot treated in this center between November 2006 and July 2023 were retrospectively reviewed. Two patients with insufficient radiological imaging and 3 patients with a follow-up period of <24 months were excluded. Three patients with giant cell tumors of metatarsal origin treated with curettage and cementation, and 2 patients with metatarsal aneurysmal bone cysts managed with curettage and cementation and 1 patient with chondrosarcoma of the first metatarsal treated with non-biological reconstruction were excluded. Finally, 15 metatarsal reconstructions with non-vascularized fibula of 12 patients were included in the final analysis.

All patients in this series were non-metastatic at the time of initial evaluation. Magnetic resonance imaging (MRI) and computed tomography (CT) were used to assess surgical margins and evaluate both the osseous involvement and extraosseous soft tissue extension of the tumor for preoperative planning (Figure 1). Neoadjuvant chemotherapy was administered to 1 patient diagnosed with Ewing sarcoma before surgical intervention for local control. A patient with Ewing sarcoma and a patient with synovial sarcoma were evaluated for lung and bone metastases using chest CT and positron emission tomography (PET). Local recurrence was assessed with MRI during follow-up. Neoadjuvant radiotherapy was administered to 1 patient with Ewing sarcoma and 1 patient with synovial sarcoma. The patient with Ewing sarcoma received neoadjuvant chemotherapy (Figure 2).

The lesion size, prior chemo/radiotherapy, resection type, harvested graft length, and time to surgery were recorded. The primary outcomes were radiographic union at the proximal and distal graft–host junctions (recorded separately, as defined above) and procedure-related complications, categorized according to the Henderson classification for biological reconstructions.[13] The secondary outcomes included time-dependent clinical milestones and functional results: time to initiation of weight-bearing, time to fixation material removal, and patient-reported/clinician-reported outcomes measured using preoperative and postoperative visual analog scale (VAS) scores and the Musculoskeletal Tumor Society (MSTS), Foot and Ankle Disability Index (FADI), and American Orthopaedic Foot and Ankle Society (AOFAS) scores at the last follow-up.

HIGHLIGHTS

- Non-vascularized fibular autografts achieved radiographic union at both junctions, with a relatively short time to union (mean 7.1 weeks proximally and 10.1 weeks distally).
- The mean time to weight-bearing was 4.7 weeks, without graft failure or nonunion.
- Superior functional recovery was observed in intercalary reconstructions, with statistically better Musculoskeletal Tumor Society, AOFAS, and Foot and Ankle Disability Index scores ($P < .05$)
- Reduced operative time (≈104 minutes vs. typical vascularized procedures) was observed, showing a reverse correlation with functional outcome.

Harvesting of the fibular autograft was performed keeping the periosteum intact and at least 1 cm exceeding the resected segment of the fibula at both ends. The harvested fibular autograft was prepared to match the measured defect length and was typically fashioned equal to or slightly longer (by a few millimeters) than the resected segment to allow a press-fit at the graft–host interface. The double-barrel method was used in relatively larger first metatarsal defects or multi-metatarsal involvement where increased cross-sectional support was desired. The graft was gently impacted into the defect to enhance initial axial and rotational stability prior to intramedullary Kirschner wire (K-wire) fixation. Reconstruction was performed immediately after graft harvest, without delay. The autograft was stabilized with an intramedullary K-wire, and the periosteal extensions were sutured to the recipient periosteum at both ends.

A short-leg splint was applied for 15 days postoperatively to protect the reconstruction and to support K-wire fixation. To minimize the risk of wire migration and rotational instability, the external end of the K-wire was bent to approximately 90° and positioned in a stable orientation. The position of the external wire end and the integrity of fixation were checked clinically at each follow-up.

Patients were followed using a standardized clinical and radiographic protocol. Standard anteroposterior, lateral, and oblique radiographs of the foot were obtained on postoperative day 1, then at 2-week intervals until K-wire removal, and subsequently at 3-month intervals during the first postoperative year and every 6 months thereafter. Radiographs were reviewed to assess graft-host junction healing, alignment, and implant position. Radiographic union was defined as the presence of bridging callus across the graft-host junction on plain radiographs, recorded separately for the proximal and distal junctions.

Progression of weight-bearing was individualized but guided by both clinical tolerance and radiographic evidence of early consolidation. Patients were maintained with restricted weight-bearing initially, and gradual loading was permitted once early bridging callus was observed without pain at the reconstruction site. K-wire removal was planned when radiographs demonstrated consolidation sufficient to maintain stability without fixation and when clinical examination confirmed painless progressive ambulation; removal was performed in the outpatient setting when feasible. Local recurrence surveillance was based on routine clinical evaluation and radiographs, and MRI was obtained when symptoms or imaging findings raised suspicion of recurrence. For malignant diagnoses, systemic surveillance (with chest CT and PET) was continued according to institutional oncology protocols.

Chi-square and Spearman's tests were used to analyze correlations, and the analysis of variance test was used to compare means. The differences were considered significant if $P < .05$. SPSS version 28.0 (SPSS) software was used for the statistical analyses.



Figure 1. Preoperative magnetic resonance imaging and intraoperative images of an aneurysmal bone cyst in the third metatarsal of a 6-year-old male patient. Resection and reconstruction were performed using a non-vascularized fibular autograft. Follow-up radiographs at 5 years showed intact joint lines and excellent function (Musculoskeletal Tumor Society score: 30).

Results

A total of 15 metatarsal reconstructions were performed on 12 patients (7 male/5 female) with metatarsal pathology. The mean age was 27.6 ± 9.3 years (7-49), indicating a predominantly young adult population. The mean follow-up period was 46.3 ± 16.1 months (29-157) with a median follow-up of 35 months (Table 1).

The underlying pathologies requiring reconstruction demonstrated considerable diversity across both benign aggressive and malignant conditions. Aneurysmal bone cyst represented the most frequent indication, accounting for 5 cases and nearly half of all reconstructions performed. Malignant tumors comprised a significant portion of the cohort, with synovial sarcoma, chondrosarcoma, and Ewing sarcoma contributing 5 cases. Individual cases were observed for chondromyxoid tumor and Nora's lesion, each representing 8.3% of the total patient population. None of the patients developed local recurrence or systemic metastases during their follow-up.

In this study, the distribution of reconstructed metatarsals included the first and fifth in 7 cases and the second and third in 8 cases (Table 1). K-wires were applied as an index fixation method in all patients. The non-vascularized fibular autograft with double-barrel configuration was used in 4 complex reconstructions in this series (larger first metatarsal defects or multi-metatarsal involvement). (Figure 3)

Mean operation time was 104.3 ± 24.6 (median: 110, range: 60-135) minutes. The mean harvested fibular autograft length was 6.1 ± 1.7

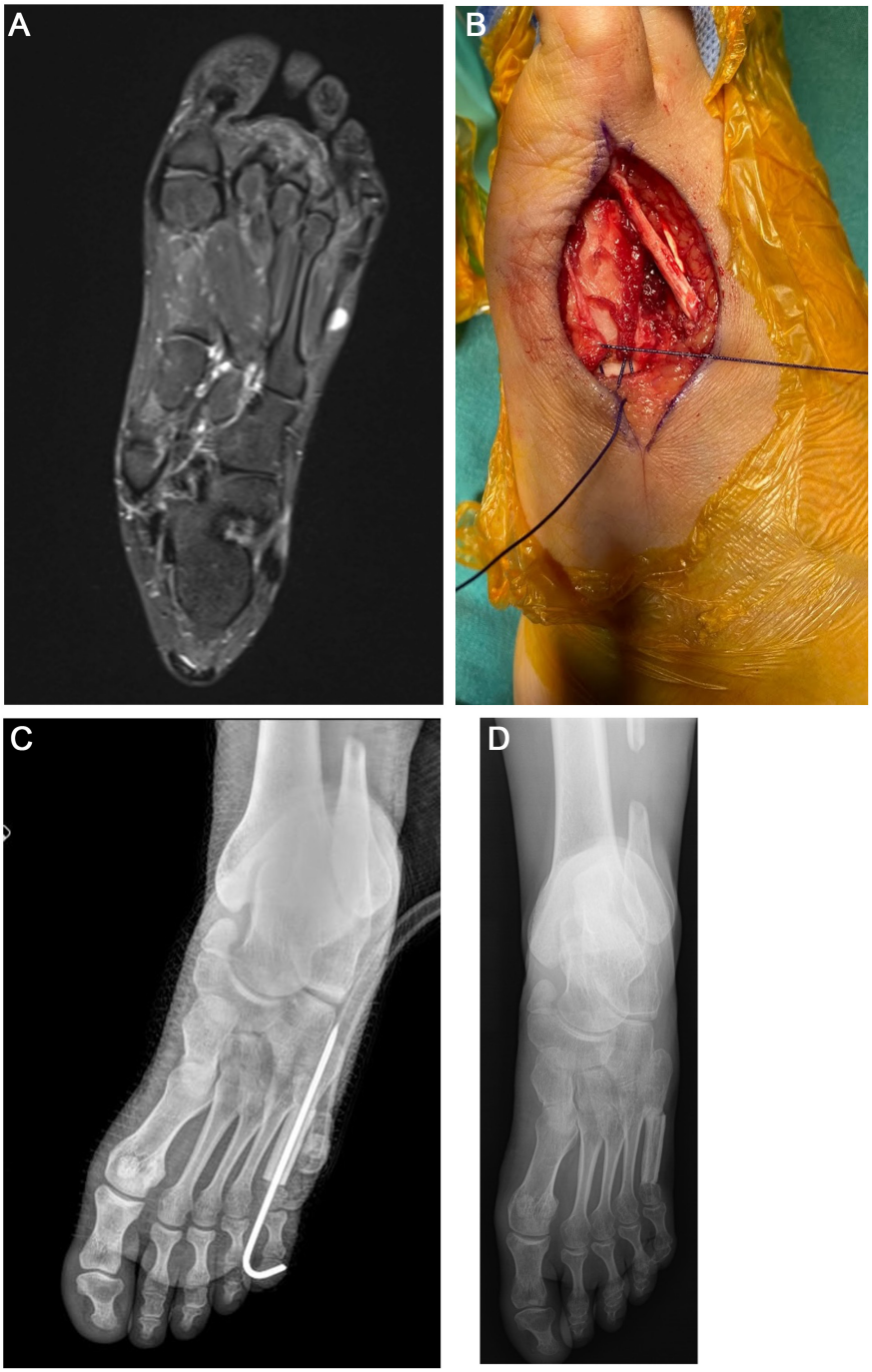


Figure 2. Preoperative magnetic resonance imaging, intraoperative, and postoperative radiographs of a 27-year-old female patient with synovial sarcoma of the fifth metatarsal. Resection and reconstruction with a non-vascularized fibular autograft were performed. At 3-year follow-up, radiographs and computed tomography scans demonstrated graft incorporation and consolidation.

cm (median: 6 cm; range: 3-9 cm). Autograft length was not significantly correlated with proximal or distal union time ($P > .05$); therefore, no cut-off value could be reliably defined in this cohort. The mean time to weight-bearing was 4.7 ± 1.4 weeks (3-8). The mean time to union was 7.1 ± 1.1 weeks (6-9) for proximal end and 10.1 ± 0.8 weeks (9-11) for distal end. The mean K-wire removal time was 7.1 ± 1.1 weeks (6-9) and the median removal time was seven weeks.

The patients were evaluated by FADI, AOFAS, MSTS, and preoperative/postoperative VAS scores to assess functional outcomes and pain management. The mean FADI score was 74.7 ± 4.2 (median: 75, range: 68-81), indicating generally good functional outcomes across all patients with scores consistently above 68. Similarly, the AOFAS scores demonstrated satisfactory ankle-hindfoot function with a mean of 82 ± 6.6 (median: 82, range: 72-94), with most patients achieving scores above 80. The MSTS evaluation revealed excellent musculoskeletal tumor surgery outcomes, with a mean score of 27.5 ± 1.9 (median: 28, range: 24-30), reflecting minimal functional impairment. Regarding pain management, there was a significant improvement from preoperative to postoperative periods, with VAS scores decreasing from a mean of 6.9 ± 1.8 (median: 7, range: 4-9) preoperatively to 2.3 ± 0.8 (median: 2, range: 1-3) postoperatively,

Table 1. Demographic and clinical characteristics of patients undergoing metatarsal reconstruction

Patient no.	Age	Sex	Diagnosis	Location	Neoadjuvant chemotherapy	Neoadjuvant radiotherapy	Reconstruction type	Adjuvant chemotherapy	Follow-up (months)
1	7	Male	Aneurysmal bone cyst	Third metatarsal	None	None	Single joint arthrodesis	None	40
2	29	Male	Nora's lesion	Fifth metatarsal	None	None	Intercalary reconstruction	None	33
3	20	Female	Ewing sarcoma	Second metatarsal	6 cycles	50 Gy/25 fractions	Single joint arthrodesis	6 cycles	31
				Third metatarsal			Single joint arthrodesis		31
4	27	Female	Synovial sarcoma	Fifth metatarsal	None	50 Gy/25 fractions	Intercalary reconstruction	None	29
5	22	Female	Aneurysmal bone cyst	Third metatarsal	None	None	Intercalary reconstruction	None	39
6	40	Male	Chondrosarcoma	First metatarsal	None	None	Single joint arthrodesis	None	63
				Second metatarsal			Single joint arthrodesis		63
7	49	Male	Chondromyxoid tumor	First metatarsal	None	None	Intercalary reconstruction	None	35
8	28	Male	Chondrosarcoma	Second metatarsal	None	None	Double joint arthrodesis	None	33
				Third metatarsal			Single joint arthrodesis		33
9	14	Male	Aneurysmal bone cyst	Second metatarsal	None	None	Intercalary reconstruction	None	30
10	36	Female	Aneurysmal bone cyst	First metatarsal	None	None	Intercalary reconstruction	None	38
11	30	Male	Aneurysmal bone cyst	First metatarsal	None	None	Single joint arthrodesis	None	39
12	30	Female	Synovial sarcoma	First metatarsal	None	50 Gy/25 Fractions	Single joint arthrodesis	None	157

demonstrating effective pain control following surgical intervention. Pearson correlation analysis demonstrated a negative correlation between FADI, AOFAS, MSTS scores and surgical duration (P=.004, P=.002, P=.002).

The reconstruction techniques were classified into 2 predefined groups based on whether an arthrodesis was performed. Arthrodesis-based reconstruction included procedures involving fusion (n=9: single-joint arthrodesis, n=8; double-joint arthrodesis, n=1). Intercalary reconstruction included non-arthrodesis segmental reconstructions (n=6). Analysis of variance testing revealed that the intercalary reconstruction group had significantly better scores of FADI, AOFAS, and MSTS (P=.012, P=.022, P=.005). Intercalary reconstruction demonstrated a shorter duration of surgery compared to arthrodesis-based reconstruction (P < .001) (Table 2). No significant differences were observed between the reconstruction groups (arthrodesis-based vs. intercalary) in metatarsal length, fibular autograft length, time to full weight-bearing, time to K-wire removal, or time to bone union. Similarly, no significant differences were found between weight-bearing (first and fifth) and non-weight-bearing (second and third metatarsals) metatarsal groups for the same parameters except full weight-bearing time. Union times were compared between weight-bearing metatarsals and non-weight-bearing metatarsals for both proximal and distal sites. The first and fifth metatarsal group demonstrated median union times of 6 weeks for proximal and 10 weeks for distal sites, while the second and third metatarsal group showed median union times of 7.5 weeks for proximal and 10 weeks for distal sites. No significant differences were observed in proximal or distal union times between weight-bearing and non-weight-bearing reconstructions (proximal P=.665; distal P=.775) (Table 3).

Following tumor resection, 6 patients developed complications classified according to Henderson's criteria for biological reconstructions.[13] Three patients developed Type 1A complications, including wound dehiscence requiring flap reconstruction in 2 cases and skin necrosis managed with debridement and skin grafting in 1 case. Three patients experienced Type 1B complications, consisting of wound dehiscence treated with debridement and primary closure in 2 cases, and wound management with Vacuum Assisted Closure (VAC) therapy followed by closure in 1 case.

Discussion

Metatarsal reconstruction after tumor resection remains challenging because of the limited soft-tissue coverage, the small caliber of the bones, and the need to restore forefoot alignment and load transmission.[2,7-9] In this retrospective series of 15 reconstructions in 12 patients, non-vascularized fibular autografts achieved radiographic union at both junctions in all cases, with a relatively short time to union (mean 7.1 weeks proximally and 10.1 weeks distally) and without nonunion, graft fracture, or revision surgery. These findings support non-vascularized fibular autograft reconstruction as a feasible biological option in selected metatarsal defects when stable fixation and careful postoperative protection are provided.

Published experience with non-vascularized fibular grafts in the metatarsal region is limited and heterogeneous. Padão et al[10] reported nonunion requiring additional procedures in 2 of 3 patients treated for aneurysmal bone cyst. In contrast, this cohort—including 5 reconstructions for aneurysmal bone cyst—demonstrated consistent union at both graft–host interfaces without reoperation. Similarly, early union within weeks has been reported in small-bone reconstructions



Figure 3. Preoperative radiographs and postoperative follow-up images of a 20-year-old female patient with Ewing sarcoma of the second and third metatarsals. Reconstruction was performed using double-barrel non-vascularized fibular autografts. At 3-year follow-up, radiographs demonstrated complete healing and consolidation with excellent function (Musculoskeletal Tumor Society score: 30).

using non-vascularized fibula, such as metacarpal series in pediatric malignancies, where graft–host size compatibility was proposed as a favorable factor for incorporation.[8] The results of this study in metatarsals are in line with these observations and suggest that, in this anatomical context, a non-vascularized graft can provide sufficient biological potential for healing when the construct is mechanically protected.

Fixation strategy is a critical determinant of success in small-bone reconstructions. Prior reports describe various fixation methods (K-wires, Steinmann pins, plates), yet pseudoarthrosis and reoperation have been described.[10-11] In this series, intramedullary K-wire fixation combined with press-fit graft preparation and short-term immobilization provided adequate stability until union was achieved, with a mean fixation duration of approximately 7 weeks and without implant-related failure. Press-fit placement has also been emphasized in prior oncologic reconstructions using non-vascularized fibular grafts, particularly for cavity filling.[14] These results are also consistent with the stable union achieved with intramedullary pin fixation in metatarsal allograft reconstructions after wide resection for Ewing sarcoma.[15] Collectively, these data suggest that simple intramedullary fixation can be sufficient for metatarsal reconstructions when rotational control and early protection are ensured, and when fixation removal is timed to radiographic consolidation.

Operative time represents a crucial factor in surgical planning and patient safety. Donati et al demonstrated that surgical interventions utilizing free vascularized fibula with massive bone allograft reconstructions require substantially longer operative times (9.4 ± 1.7 hours) compared to pedicled vascularized fibula techniques (5.7 ± 1.3 hours).[16] Non-vascularized fibular bone grafts offer significant practical advantages, being associated with shorter operative times and requiring less interdisciplinary involvement, resulting in a more straightforward surgical approach while providing valuable therapeutic benefits.[17] This series demonstrated a mean operative time of 104 ± 23.1 (median: 110, range: 60-135) minutes, which is

Table 2. Comparison of FADI, AOFAS, MSTS scores, and duration of surgery between intercalary and arthrodesis reconstruction groups

Reconstruction type		FADI score	AOFAS score	MSTS score	Duration of surgery (minutes)
Intercalary (n=6)	Mean ± SD	77.4 ± 3	86 ± 5.4	28.9 ± 1.2	82.9 ± 13.8
	Median	78 (73-81)	86 (80-94)	29 (27-30)	85 (60-100)
Arthrodesis (n=9)	Mean ± SD	72.4 ± 3.6	75.5 ± 5.7	26.4 ± 1.6	122.5 ± 8.5
	Median	75 (68-71)	80 (72-85)	27 (24-28)	120 (110-135)
P		.012	.022	.005	<.001

AOFAS, American Orthopaedic Foot and Ankle Society; FADI, Foot and Ankle Disability Index; MSTS, Musculoskeletal Tumor Society.

Table 3. Comparison of proximal and distal union times between weight-bearing (first and fifth) and non-weight-bearing (second and third) metatarsal groups

Metatarsal Group		Proximal union time (weeks)	Distal union time (weeks)
First and fifth metatarsals (n=7)	Mean ± SD	7 ± 1.3	10 ± 0.8
	Median	6 (6-9)	10 (9-11)
Second and third metatarsals (n=8)	Mean ± SD	7.3 ± 0.9	10.1 ± 0.8
	Median	7.5 (6-8)	10 (9-11)
P		.665	.775

substantially shorter than vascularized techniques. Pearson correlation analysis demonstrated a negative correlation between FADI, AOFAS, MSTS scores and surgical duration, suggesting that shorter operative times may contribute to better functional outcomes.

Postoperative loading protocols reported in the literature vary substantially, reflecting differences in defect size, fixation, and soft-tissue conditions. In previous non-vascularized metatarsal fibular graft reports, partial weight-bearing has been delayed to 10-12 weeks with later progression to full weight-bearing, whereas other authors delay weight-bearing until union is evident.[10-12] In this series, weight-bearing was initiated at a mean of 4.7 weeks and advanced gradually based on radiographic and clinical findings, without graft failure or delayed union. This supports an individualized progression strategy rather than a fixed timetable, particularly in constructs that demonstrate early bridging callus and remain clinically stable.

Functional outcomes were generally favorable with a marked improvement in pain. When reconstructions were analyzed by technique, intercalary reconstruction demonstrated better functional scores and shorter operative time than arthrodesis-based reconstruction, although the retrospective design and small subgroup sizes preclude causal inference. Nevertheless, findings of this study align with the general principle that preserving adjacent joints, when oncologically safe and technically feasible, may benefit postoperative function.

Complications in metatarsal reconstructions are frequently driven by soft-tissue vulnerability. Vascularized osteomyocutaneous fibular reconstructions have been associated with skin-related complications and revision procedures in some series, despite acceptable functional outcomes.[9] Six patients experienced soft-tissue complications (Henderson Type 1A/1B), all managed without amputation, graft loss, or revision of the bony reconstruction in this series. Importantly, no cases of nonunion were observed, suggesting that while soft-tissue issues remain a relevant burden in this region, the biological reconstruction itself can be reliable with meticulous wound management and surveillance.

This study has limitations inherent to a retrospective, single-center design, including the lack of a control group and the heterogeneity of tumor diagnoses and resection types. The small sample size limits statistical power for identifying predictors (including any potential graft-length threshold) and restricts subgroup comparisons. Cost-effectiveness was not formally analyzed; therefore, statements regarding costs should be interpreted as descriptive rather than comparative.

Non-vascularized fibular autograft reconstruction after tumor-related metatarsal resection achieved reliable healing in this series, with reduced time to surgery when compared to vascularized fibula. Union occurred rapidly (mean 7.1 weeks proximally and 10.1 weeks distally) and weight-bearing was initiated early (mean 4.7 weeks), with generally favorable functional outcomes. None resulted in nonunion, graft fracture, or revision surgery in the short to midterm; supporting this technique may be a good and reproducible option for selected metatarsal defects.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Artificial Intelligence Usage Statement: The authors declared that no Artificial Intelligence tool was used in the preparation of the manuscript.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Baltalimanı Bone Diseases Training and Research Hospital (Approval no: 28/195, Date: 28.10.2024).

Informed Consent: Verbal informed consent was obtained from the patients or their legal guardians who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Design - O.E.A., B.D., S.T. Supervision - O.E.A., N.I., B.P. Data Collection - S.T., B.P. Analysis - O.E.A., B.D., B.P. Literature Search - O.E.A., S.T., N.I. Writing - O.E.A., S.T., B.D. Critical Review - B.P., B.D., N.I.

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