ARTICLE IN PRESS

Injury xxx (xxxx) xxx

Contents lists available at ScienceDirect

Injury

journal homepage: www.elsevier.com/locate/injury

Can locking plate fixation and free Vascularised fibular transfer with skin island achieve good functional outcome in the treatment of large bone defects of Tibia ? A study of 26 cases☆,☆☆

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ARTICLE INFO

Keywords:
Open injury
Infected nonunion
Tibial bone loss
Free vascularised fibular graft
Locking plate,QAly

ABSTRACT

Background: Despite the availability of multiple treatment options, management of tibial bone loss continues to be a challenge. Free vascularized fibula graft (FVFG) with a skin paddle offers better advantages over the other methods. We aimed to study the functional outcomes and QALY of patients with large tibial bone defects following FVFG with a locking plate in 26 patients.

Materials and Methods: We analyzed 26 consecutive patients with large tibial bone defects treated by free vascularized fibular graft (FVFG) and stabilization using a long locking plate between 2009 and 2018. All were followed up for a mean period of 42 months (24 months to 120 months). Bony union, graft hypertrophy, and complications such as stress fracture and infections were assessed. Multivariate regression analysis was performed to identify any association between demographic factors, injury characteristics, treatment-related factors, and fibular hypertrophy. Additionally, The EQ-5D quality-of-life (QOL) indices were obtained using the SF-12 score to evaluate the patients' overall quality of life.

Results: The mean age of the patients at the time of presentation was 36.26 yrs (range, 18–60 years). The cause of bone loss was open injury in 16 patients and infected nonunion in 10 patients. Complete union was achieved in 25 patients (96 %) without any requirement of additional surgical procedures. The mean union time of the graft was 4.04 months (range, 3–6 months). The mean fibular hypertrophy calculated by De Boer index was 0.61 %, 11 %, 28.24 % and 52.52 % at 3,6 months and 1 and 2 years respectively. Patients with metaphyseal bone loss have significant fibular hypertrophy. Participants in our study experienced a quality of life equivalent to 0.88 (range 0.79–0.99) of perfect health.

Conclusions: FVFG with skin paddle and LCP fixation for massive tibial bone loss achieved satisfactory outcome and QALY even in the challenging healthcare environment of South India, a developing country.It maintains alignment, promotes graft hypertrophy, and prevents stress fractures.

Level of evidence: Level 4

Level of clinical care: Level I Tertiary trauma centre

Introduction

Bone loss in long bones can occur primarily during the initial injury or as a result of debridement when loosely attached comminuted bony fragments without soft tissue attachment are removed. Secondary bone loss arises when avascular and necrotic exposed bone segments are excised due to posttraumatic osteomyelitis [1]. Alongside bone loss, challenges are posed by soft tissue loss or scarred and contracted soft

☆ This paper is part of a Supplement supported by Trauma Society of India Supplement ☆☆ **Institution at which the work was performed:** Ganga Medical Centre and Hospitals Pvt. Ltd, 313, Mettupalayam Road, Coimbatore, India.

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https://doi.org/10.1016/j.injury.2024.111465
Accepted 25 February 2024
Available online 28 February 2024

Please cite this article as: Jayaramaraju Dheenadhayalan et al., *Injury*, https://doi.org/10.1016/j.injury.2024.111465

tissues [2]. Various treatment options are available in the literature [3–6].

Although distraction osteogenesis is a versatile method with a high success rate, it requires multiple surgical interventions and can result in complications such as pin tract infections, joint contractures, and septic arthritis of adjacent joints, leading to suboptimal outcomes [6–8]. The Masquelet technique involves a two-staged surgical approach with varying success rates [5,9]. Structural allografts combined with iliac crest autografts have demonstrated positive outcomes in the management of femoral bone loss but have not been extensively described for tibial bone loss [3].

Despite the presence of various treatment options, the management of tibial bone loss remains challenging [10,11] . The utilization of free vascularized fibula graft (FVFG) with a skin paddle offers several advantages that address the previously mentioned drawbacks. This technique is suitable for reconstructing bone gaps of up to 20 cm resulting from open injuries or infections. It is a single-stage procedure and exhibits the property of hypertrophy over time, promoting graft maturation and integration [12–14]. Furthermore, FVFG not only bridges the bone gap but also provides soft tissue coverage through the inclusion of a skin paddle, contributing to enhanced wound healing and protection [6–9].

Combining free vascularized fibula graft (FVFG) with external fixation is a traditional technique for treating tibial bone loss. However, studies indicate that external fixators can lead to complications such as stress fractures, malunion, pin tract infections, and joint stiffness, especially near joints [15–17]. Comparisons between FVFG with external fixator and distraction osteogenesis show no significant differences in fixation duration, rate of complication,union rate, or functional score for post-traumatic tibial defects [18,19]. Therefore, both methods yield similar complication results.

In our initial experience with FVFG for tibia bone loss, external fixators were used but resulted in complications including malunion, stress fractures, joint stiffness, and pin tract infections. These complications are similar to those observed in distraction osteogenesis cases [7].Hence selecting a fixation method that allows early joint mobilization, preserves limb alignment, and protects the graft until hypertrophy is crucial for favorable clinical outcomes.

In our current study, we present our refined technique for reconstructing tibial bone loss using a free vascularized fibula graft (FVFG) with a skin island, combined with a locking plate. While the approach involving FVFG with a locking plate has been previously described in the literature [20,21], our study contributes insights by including a substantial cohort of 26 cases, allowing for a more comprehensive evaluation of the technique's efficacy under diverse clinical scenarios and enhancing our understanding of its applicability and outcomes.

Our objectives include investigating the factors that influence graft hypertrophy and reporting patient-rated outcomes.

Patients and methods

We conducted a retrospective analysis of data that was collected prospectively and approved by the institutional ethics committee. We reviewed medical records and radiographs from our hospital's archives spanning the period between 2009 and 2019. The study included patients who were at least 18 years old and had tibia bone loss that was managed using FVFG fixed with a locking plate. Patients who were under 18 years of age or had FVFG fixed with an external fixator were excluded. We also excluded patients with incomplete medical reports, incomplete X-ray documentation, and those with less than 2 years of follow-up. We identified a total of 31 patients with tibia bone loss who underwent reconstruction with FVFG in our hospital records during the study period. Among them, 5 patients who were treated with external fixators were excluded, leaving a study group of 26 patients with tibial bone loss reconstructed using FVFG fixed with a locking plate. We obtained demographic data including the diagnosis, patient's age, site of bone loss, and number of prior procedures from the medical records, operative time and size of skin paddle.For open fractures, we documented the Gustilo fracture type [22] and the Ganga Hospital Open Injury Score [23]. Digital radiographs with standard magnification were used for measurements.The initial length of bone loss was determined using preoperative radiographs and medical records. We examined serial radiographs to assess bone union and fibular hypertrophy. And we noted complications such as stress fractures of the graft, neurovascular deficits, and ankle instability after fibula harvest from the opposite limb. Bony union was defined [24] as the presence of uninterrupted external bony borders between the fibular graft and recipient's bone, with obscured or absent osteotomy lines at both junctions. Graft hypertrophy was evaluated using X-ray films immediately after surgery and at the final follow-up, measured by the De Boer and Wood's hypertrophy [25] index at 3, 6 months, and 1–2 years. Stress fractures were identified by the presence of a fracture line or localized periosteal callus formation in the fibular graft [25]. To assess the outcomes of the treatment, we utilized two patient-reported outcome measures (PROMs): the Lower Extremity Functional Scale (LEFS) and the Medical Outcomes Short Form 12 (SF-12). The LEFS [26] is designed to evaluate a patient's functional capabilities in performing daily tasks associated with the lower extremities. The SF-12 is a survey that provides insights into the patient's general health condition, yielding both a Physical Component Subscore (PCS) and a Mental Component Subscore (MCS). PCS evaluates an individual's physical health and functioning, while the MCS assesses their mental health and emotional well-being.Quality of life (QOL) indices based on the SF-12 data were derived using a previously published formula known as the EQ-5D [27].

Statistical analysis

The information was inputted into a Microsoft Excel spreadsheet and analyzed using SPSS 22 software (IBM SPSS Statistics, Somers NY, USA). Frequencies and proportions were used to present categorical data, while the mean and standard deviation were used to represent continuous data. We ran a multivariable logistic regression model predicting fibular hypertrophy based a priori on the variables of age,site, defect length and type of bone loss. Data from this model are presented as 95 % confidence intervals (CIs). All analyses were performed with use of STATA version 14, and the level of significance was set at $p < 0.05$.

Surgical procedure

In open fractures with bone loss, staged procedure was utilized. In the initial stage, intravenous antibiotics were promptly administered upon the patient's entry into the hospital. The first debridement of devitalized and contaminated tissues was carried out under tourniquet control by a senior plastic surgeon using loupe magnification. All free tibia fragments without soft tissue attachments were removed, resulting in segmental bone defects, and tibial length was preserved and secured with an external fixator. Secondary debridement was performed for patients with extensive contamination. Postoperatively, first-generation cephalosporin was administered for 72 h, and no local antibiotic beads or cement were used in the initial management. Among the 16 patients, 7 underwent soft-tissue coverage within 72 h, while 9 patients required multiple procedures before the soft tissue cover, as detailed in the table. The index procedure was performed once the wound had healed.

In cases of infected nonunion, we utilized a two-stage procedure. Stage 1 involved thorough debridement, removal of infected material and unhealthy granulation tissue, with bone ends freshened till they show bleeding signs. Excised tissue was cultured to identify the microorganism and to look for sensitivity pattern. Copious amount of saline was used to wash the bone during the procedure. Antibiotics were given for a period of 6 weeks, as guided by the culture reports. Regular monitoring of white blood cell count (WBC), erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP) levels were checked on a weekly basis. Infection was considered successfully eliminated when white blood cell (WBC), erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP) levels returned to normal ranges, and there were no clinical symptoms such as fever, local warmth, or active pus discharge(Fig. 1). In cases of active infections, multiple debridements were done, and antibiotics were administered based on culture results until infection control. Patients were discharged once the infection was under control. Once the infection was under control and there was no pus discharge, reconstructive surgery was performed.

In our surgical technique, the procedure involved a collaborative effort between a microsurgical team responsible for harvesting the vascularized cutaneous free fibula and an orthopedic team responsible for stabilizing the skeleton. The surgical approach consisted of making a longitudinal skin incision over the leg, guided by the previous soft tissue cover and vascular anastomosis. This approach provided a better view of the vessel and facilitated assessment of the bony defect.

The free fibula harvested from the opposite leg was then inserted into the medullary canal of the proximal and distal tibial ends. To enhance vascularity and reduce the risk of infection, the muscle along with the graft was placed in the avascular and scarred surface surrounding the tibia. The decision regarding the length of fibula harvested was based on the level of the pedicle, and the extra length of the fibula was pegged into the medullary cavity of the host tibia to increase contact and surface area. Throughout the procedure, care was taken to protect the vascular pedicle of the fibula (Fig. 2).

The plate length was precisely chosen and contoured to accommodate three locking screws on each side. Selection of the bone surface for plate application was guided by considerations for vascular anastomosis. Medial plating was performed when the recipient vessel was the anterior tibial artery, and lateral plating was chosen for cases involving the posterior tibial artery. The plate was positioned opposite to the vascular anastomosis site to ensure its protection.

Subsequently, the anastomosis between the free fibula and the recipient vessel was performed. The posterior tibial artery was used in 17 patients, the anterior tibial artery in 4 patients, the popliteal artery in 4 patients, and the peroneal artery in 1 patient. Corresponding venae comitantes were anastomosed with the peroneal vein. In 7 cases, the saphenous vein, which was easily accessible through the same incision, was used for anastomosis.

Postoperatively, the patient was immobilized for three weeks until the flap healed, protected with an above-knee slab. After three weeks, non-weight-bearing mobilization with a walker was initiated. At six weeks, the slab was removed, and toe-touch weight-bearing walking and knee mobilization were initiated. Patients were allowed to bear weight with crutches after three months, once bone union was confirmed. Follow-up X-rays were taken every three months to monitor hypertrophy.

Results

A total of 26 patients fulfilled the inclusion and exclusion criteria and were part of the study (24 males and 2 females, mean age 36.26 yrs range 18–60 years).None of the patients had any medical comorbidities. There were 16 patients with bone loss following open fracture (Table 1), 10 patients following infected nonunion(Table 2). Twenty patients had diaphyseal bone loss (n = 20,77 %)and 6 patients had metaphyseal/ periarticular bone loss (n = 6,33 %) All open fractures were classified as having Gustilo type-IIIB injuries, and the mean total Ganga Hospital Open Injury Score was 14 (range, 14 to 17).The mean number of surgical procedures done before the index procedure (FVFG with locking plate fixation) was 3 [2–7]. The mean time between debridement for infected nonunion and the index procedure was 7 weeks (ranging from 6 to 12

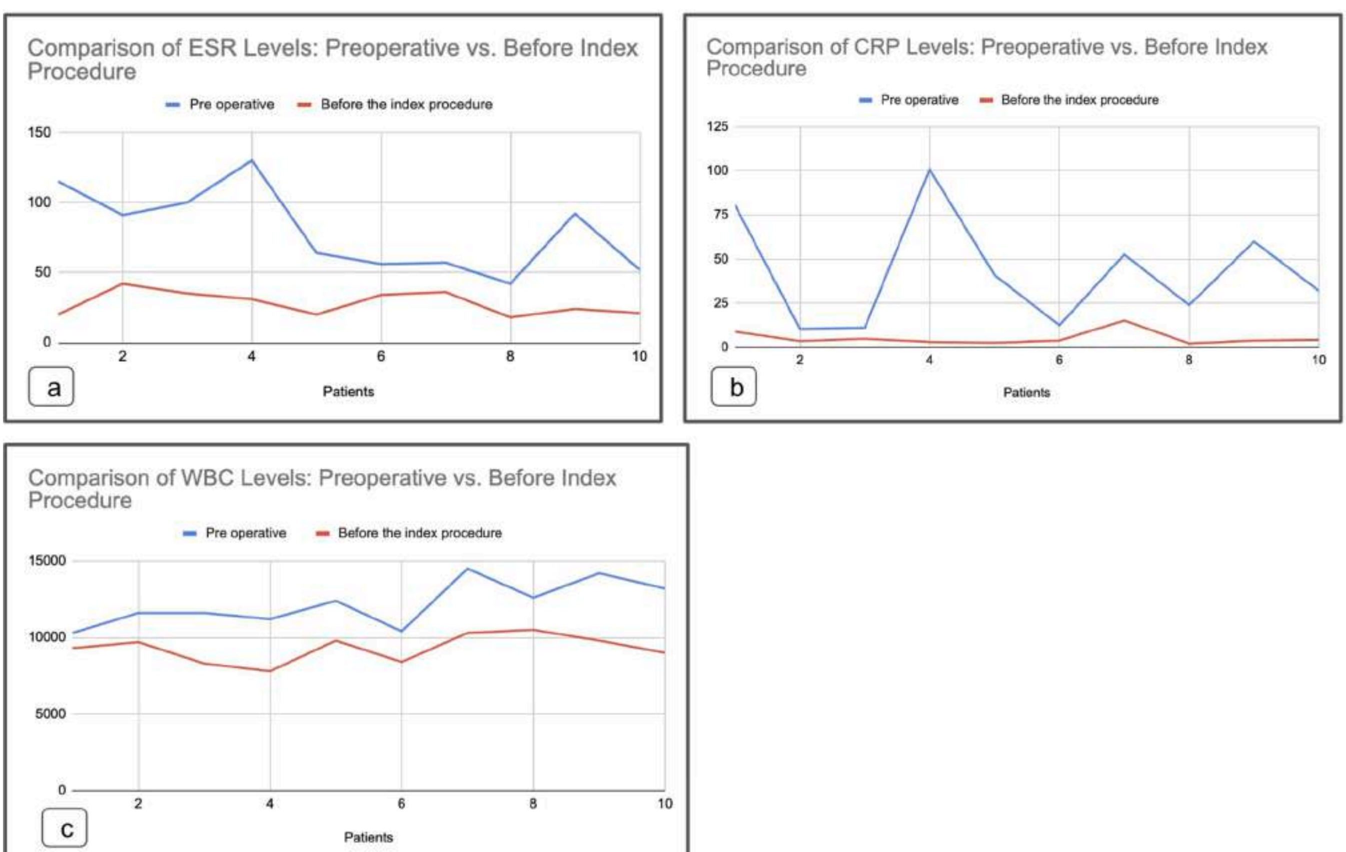

Fig. 1. A Line Chart Illustrating Preoperative (Before Debridement) and Before Index Procedure ESR (a), CRP (b), and White Blood Cell(WBC) (c) Values.

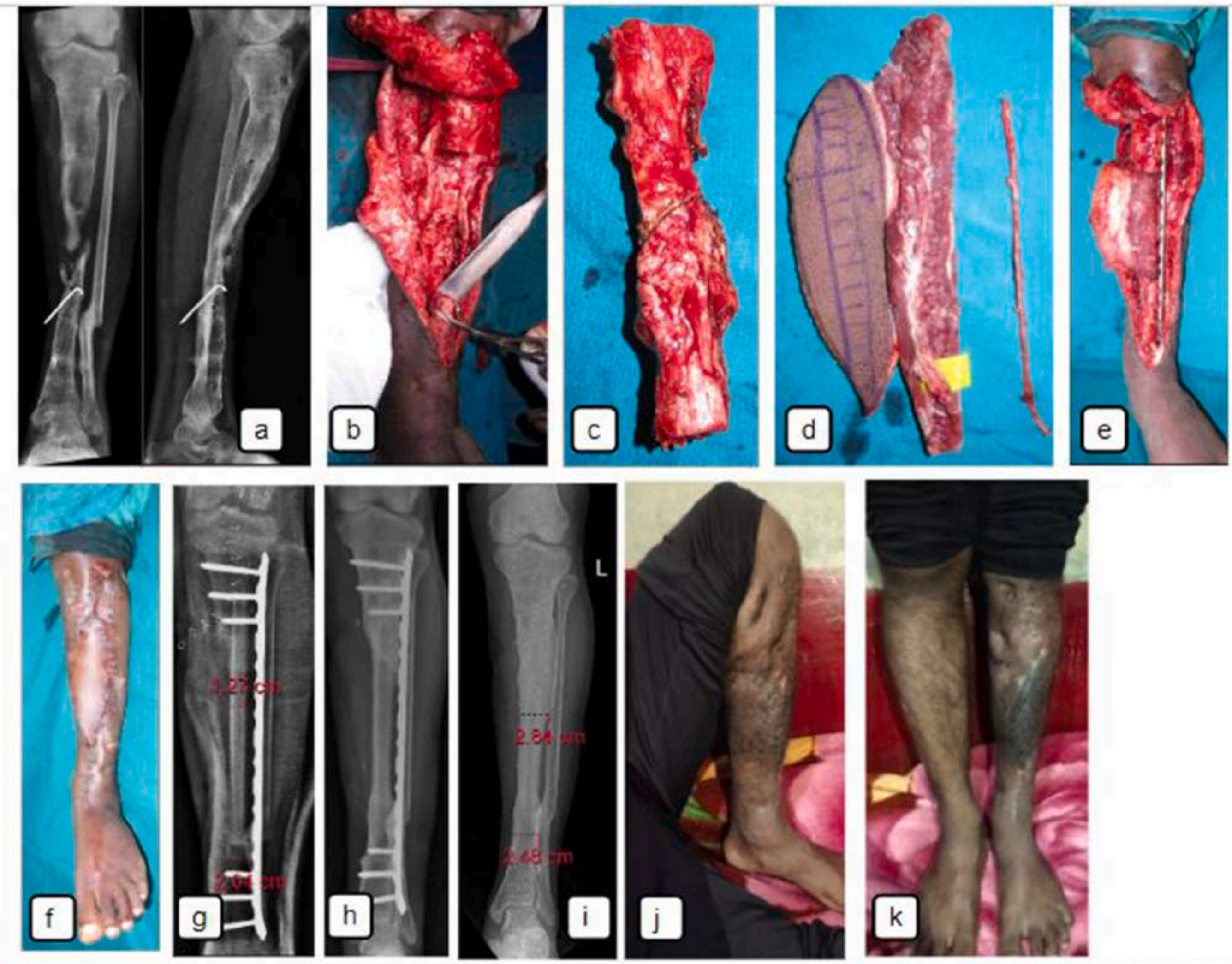

Fig. 2. (a)- Case of a young male with an infected nonunion with sclerotic bone ends, (b& c)- Resection of avascular bone ends till bleeding edges, (d)- harvested free fibula with skin paddle and vein graft for anastomosis, (e)- Fixation of free vascularized fibular graft with 4.5 locking plate, (f)- Suturing of skin paddle to the recipient skin, (g & h). Progression of hypertrophy, (i) X-ray showing complete union and 142 % graph hypertrophy at the end of 36 months and implant removal (j & k)- Clinical pictures showing good range of motion and no length discrepancy.

weeks). Eight patients required a single debridement before the index procedure, while two patients needed two debridements to control the infection before the index procedure.The mean length of bone loss was 17 cm (range 12 cm to 25 cm). The mean length of the harvested fibula was 21.9 cm (17 cm to 28 cm). In 16 patients (open fractures 12 and infected nonunion 4), skin paddle was used for covering the soft tissue defect, and in 10 patients, (open fractures 4 and infected nonunion 6) skin paddle was used purely for monitoring the viability of vascularised fibular graft. The size of the skin paddle varied from 8 cm × 6 cm to 17 cm × 10 cm, with a mean size of 14.12 cm × 8.02 cm.The mean operating time was 390 min (330 - 450 mins), with recipient site preparation taking 60 min(30 - 90 mins), graft harvesting - 120 min (90 - 150 mins), bone fixation lasting for 60 mts (50 - 70 mins), and anastomosis of vessels requiring 150 min (120–180 mins). The mean follow-up was 42 months (range: 24 to 120).

Twenty-five (96 %) patients achieved bone union after FVFG transfer and locked plate stabilization. The mean bone union time of the graft was 4.04 months (range, 3–6 months). The time to fully weight bear was at a mean of 4.2 months (range, 3–6 months). The degree of fibular hypertrophy was 0.61 %, 11 %, 28.24 % and 52.52 % at 3,6 months and 1 and 2 years respectively(Fig. 3).The mean graft hypertrophy at final follow up was 75.92 %, ranging from 40 to 140 % and the LEFS score was 69 (range 50–80). No incidences of stress fractures through the graft or presence of ankle instability were encountered. The mean knee flexion achieved was 104 deg(range 40–140°). We identified two patients who experienced wound dehiscence at the donor site, necessitating split-thickness grafts during the immediate postoperative period. Additionally, weakness in the flexor hallucis longus at the donor site was observed in two patients at the final follow-up.One patient who had reconstruction of a 24 cm defect after 7 surgical procedures before the index procedure had an anastomosis failure that went onto graft resorption.After implant removal and debridement, the patient underwent a revision surgery involving tibialization of the fibula.One patient developed a superficial infection settled with antibiotics. Two patients with exposed implants after complete union with significant graft hypertrophy, needed removal of implant.(Table 3).

Multivariable logistic regression was performed to identify the effects of gender, age,site,type and length of bone loss on the fibular hypertrophy. Of the predictor variables, patients with metaphyseal bone loss had significant fibula hypertrophy (Table 4).

The mean PCS in our study was 44.90 (38.7 - 57.61), slightly below the general population mean of 50, suggesting some challenges in physical health. The mean MCS was 50.54 (42.5 - 57.9), indicating that, on average, individuals rated their mental health similarly to the general

Table 1
Demographics, Gustilo Fracture Type, Ganga Hospital Open Injury Score, and Outcomes in Open Tibial bone loss Reconstruction.

	Age/ Gender	Gustilo Fracture Type	GHOIS	Site of bone loss	No of procedure Before index procedure	Bone loss (cm)	Length of fibula graft (cm)	Time to definitive fixation (days)	Duration of follow up (months)	Bone union (months)	FWB (months)	Graft Hypertrophy (%)	Range of motion of knee	LEFS	PCS	MCS	QALY
1	18/M	IIIB	14	D	3	20	22	10	26	3	3	45	0–100°	60	42.5	42.5	0.79
2	52/M	IIIB	17	D	7	24	24	60						-	–	51.14	–
3	22/M	IIIB	13	D	3	17	21	46	28	4	4	54	0–100°	53	42.5	55.7	0.79
4	35/M	IIIB	16	D	2	17	23	24	29	6	6	56	0–105°	69	51.7	56.68	0.83
5	49/M	IIIB	12	D	2	12	24	26	26	3	3	44	10–105°	51	42.5		0.79
6	40/M	IIIB	14	M	2	16	19	54	25	5	5	44	0–90°	58	51.7	42.5	0.83
7	56/M	IIIB	16	D	3	16	21	41	72	3	3	122	0–100	56	42.5	51.7	0.997
8	19/M	IIIB	14	D	2	12	17	24	84	3	3	142	0–130°	65	57.61	47.77	0.997
9	47/M	IIIB	13	M	2	18	18	32	25	3	4	40	0–105°	50	38.7	42.5	0.83
10	49/M	IIIB	16	D	4	19	20	43	72	5	6	102	0–100°	65	42.5	54.9	0.939
11	45/M	IIIB	14	D	3	18	22	42	40	4	4	138	10–120°	60	38.7	51.55	0.959
12	46/M	IIIB	12	D	2	23	26	32	120	3	3	142	0–40°	70	42.5	51.7	0.997
13	35/M	IIIB	13	M	3	25	28	32	25	3	4	50	0–110°	57	42.5	42.5	0.79
14	31/M	IIIB	15	D	3	22	24	36	24	4	4	50	0–95°	50	48.1	56.68	0.809
15	26/M	IIIB	13	M	2	12	17	25	28	4	4	56	0–100°	56	51.7	42.5	0.83
16	35/M	IIIB	17	M	7	23	26	93	30	6	6	60	0–90°	50	42.5	56.68	0.892

GHOIS-Ganga Hospital Open Injury Score;FWB- Full weight bearing; ROM- Range of motion; LEFS- Lower extremity functional scale;PCS- Physical Component Subscore; MCS-Mental Component Subscore; QALY- Quality-Adjusted Life Year.

Table 2
Demographics, Microbiology, Antibiotic Therapy, and Outcomes in the Reconstruction of Tibial Bone Defects in Patients with Infected Nonunion.

	Age/ Gender	**Site of bone loss**	**No of procedure Before index procedure**	**Microbiology**	**Antibiotics**	**Bone loss (cm)**	**Length of fibula graft (cm)**	**Follow up (mo)**	**Bone union (mo)**	**FWB (mo)**	**Graft Hypertrophy (%)**	**ROM of knee**	**LEFS**	**PCS**	**MCS**	**QALY**
1	25/F	D	4	Staph. coagulase-negative	Linezolid	13	22	48	3	3	86	0–120°	64	51.14	56.68	0.95
2	20/M	D	2	Staphylococcus aureus	Cefazolin	14	24	30	6	6	55	5–135°	56	55.7	51.7	0.877
3	19/M	D	3	Staphylococcus aureus	Linezolid	18	22	60	4	4	114	0–140°	64	42.5	57.9	0.997
4	34/M	D	3	Negative	Clindamycin	18	26	36	5	4	70	0–90°	60	47.77	54.58	0.92
5	22/M	D	4	Negative	Clindamycin	12	18	30	3	3	54	0–130°	58	42.5	56.68	0.949
6	33/M	D	5	Staphylococcus aureus	Cefazolin	17	21	42	4	4	90	0–110°	64	38.7	42.5	0.94
7	60/F	M	2	Negative	Clindamycin	13	17	28	4	4	46	15–70	60	42.5	42.5	0.79
8	31/M	D	4	Staphylococcus aureus	Linezolid	13	23	24	4	4	50	0–130°	61	42.5	48.1	0.79
9	40/M	D	5	Staph. coagulase-negative	Linezolid	19	23	73	4	4	136	0–120°	62	38.7	51.7	0.997
10	54/M	D	4	Negative	Clindamycin	18	23	26	5	6	52	0–105°	59	42.5	54.18	0.79

FWB- Full weight bearing; ROM- Range of motion; LEFS- Lower extremity functional scale;PCS- Physical Component Subscore; MCS-Mental Component Subscore; QALY- Quality-Adjusted Life Year.

Fig. 3. (a)- A case of open 3B fracture with soft tissue loss, (b)-X-ray after debridement showing bone loss of 13 cm, (c & d)- Tibia defect reconstructed with free vascularized fibular graft and locking plate showing increase in functional diameter of the fibula, (e)- Significant hypertrophy was seen at 24 months (f & g) Good outcome without limb length discrepancy and knee range of motion of 0–130°.

Table 3
Showing the number of Complications in Patients after Free Vascularised Fibula Transfer.

Complication	Type of Bone loss	Number of patients	Management
Anastomosis failure	Open fracture	1	Tibialization of fibula
Superficial infection	Open fracture	1	Antibiotics
Exposed implant	Infected nonunion	2	Implant removal

Table 4
Showing the Multivariate and statistical results.

Multivariate	Number of patients	p Value
Gender		0.352
Male	24	
Female	2	
Age		0.991
< 30 years	8	
> 30 years	18	
Site		**0.009***
Diaphyseal	20	
Metadiaphyseal	6	
Type of bone loss		0.223
Open fracture	16	
Infective nonunion	10	

* $p < 0.05$- statistically significant.

population.On average, the participants in our study experienced a quality of life equivalent to 0.88(range 0.79–0.99) times that of perfect health over a specified time period.

Discussion

Open fractures with bone loss present a complex challenge as they require simultaneous reconstruction of both the bone defect and the soft tissue cover [2,28]. Infected nonunion with bone loss poses additional difficulties due to compromised vascularity and scarring of the surrounding tissue [29]. The treatment options depend on the length of the defect [10].When there is a tibial bone loss exceeding 6 cm, treatment choices may involve employing distraction osteogenesis or utilizing a FVFG [11,30].

Distraction osteogenesis is considered the gold standard technique for tibia bone defects ranging from 6 to 12cm(8,19). However, as the defect length increases, distraction osteogenesis was associated with long external fixation time, pin tract infection, joint stiffness (especially periarticular defect), and mechanical axis deviation. These complications often require secondary procedures and may result in poor functional outcomes [19,29].

Our preference to address large tibial defects more than 12 cm with compromised soft tissue cover is to use the FVFG with a skin island. FVFG is a single-stage procedure that can be used for bridging massive bone defects and can also be beneficial in cases of infective nonunion [31,32].Our approach with FVFG involves utilizing a skin island graft, which offers the advantage of effectively addressing the soft tissue defect. Notably, the presence of a skin island allows for wound closure without tension, even when employing a long plate for bone fixation.In infective non union cases, FVFG emerges as a superior option for reestablishing vascularity [29]. Our technique involves incorporating an attached muscle flap into the scar tissue, thereby enhancing vascularity and minimizing the risk of reinfection.

In most centers worldwide, an external fixator is the preferred fixation method for FVFG [16].This allows mechanical stimulation of the graft, promoting graft hypertrophy, which has been well-documented in studies. It also reduces surgical time and is safe in infective non-unions [13,33,34].For larger defects, the duration of external fixation may need to be prolonged to protect the graft until hypertrophy occurs, which can be emotionally demanding for the patient and their family [35].When bone loss is near a joint, fixation becomes technically demanding and spanning the joint may increase the risk of knee stiffness, particularly in the periarticular region of the thigh, which can be limiting during daily activities [15,35]. Several clinical studies have compared distraction osteogenesis versus FVFG fixed with an external fixator for tibia bone loss and have not identified any significant differences [12,18,19]

To achieve a favorable outcome, the surgeon must prioritize early joint mobilization, maintain limb alignment, and protect the graft until significant hypertrophy occurs [32].This is especially crucial when the free vascularized fibula graft (FVFG) exceeds 15 cm in length and is fixed with an external fixator, as it may lead to stress fractures and nonunion due to increased Von Mises stress and interfragmentary motion [36].

Hence, we describe our method of fixing FVFG with a single locking plate and evaluate its outcomes.In our study, 96 % (25/26) of patients achieved union without the need for secondary surgical procedures, with a mean time of 4.04 months. Our results are superior compared to other fixation methods for tibia defects with FVFG [16,17]. Locking plates provide a favorable biological environment by preserving periosteal blood supply and offer greater stability with reduced bone-plate interface compared to external fixators [20,21].

One of the major benefits of locking plates as a fixation method is enabling early weight-bearing. The average weight-bearing time in our study was 4.2 months, significantly shorter than the 11 months reported by Sharma et al. [17] and the 15 months observed in G. Wen et al.'s [11] study using external fixation. This suggests a potentially more potentially faster recovery with our method compared to traditional external fixation approaches.Locking compression plates (LCP) contribute to both angular and axial stability, with threaded screw heads acting as a stable unit that allows for early weight-bearing [37].

The ultimate function of the limb depends on the range of motion in the knee and ankle joints. Hence, early initiation of range of motion exercises is essential for attaining optimal limb function [21].The utilization of a locking plate, which provides stable fixation without spanning the knee joint, allows for the early initiation of knee range of motion exercises. In our study, we observed an average knee flexion of 104° (range: 40–140°).

Stress fracture of the graft is a notable complication in the reconstruction of lower limb defects, reported in previous studies with an incidence ranging from 10 % to 47 % [11,12,29,35].Though the mean defect length in our study was 17 cm (range: 10 cm to 25 cm), none of the patients experienced stress fractures.The possible mechanism for a stress fracture is excessive loading of an under-hypertrophied graft with a mismatch in size and malalignment.The locking plate protects the graft by maintaining alignment, functionally increasing the diameter of the graft (Fig. 3), and sharing mechanical stress with the graft.

Fibular graft hypertrophy is considered essential for successful reconstructions [33]. We found factors such as age, sex, type of bone loss, or length of bone loss plays no significant roles in promoting fibular hypertrophy in our study.Our results indicate that patients with metaphyseal bone loss tend to exhibit better hypertrophy compared to those with diaphyseal bone loss.

The success of free vascularized fibula graft (FVFG) transfer for treating tibia bone loss is closely correlated with fibular hypertrophy [33]. The utilization of a locking plate enables early weight-bearing, leading to significant fibular hypertrophy (Fig. 4).Moreover, it allows for a good range of motion in the knee and ankle joints, facilitating an early return to the patient's original occupation and ultimately improving their quality of life. It is noteworthy that, to the best of our knowledge, no previous studies have specifically evaluated the quality of life in patients with bone loss. It is therefore worth emphasizing that the use of a locking plate to fix the FVFG is associated with favorable physical and mental health outcomes, contributing to an overall better quality of life for these patients.

LEFS scores and PCS were comparable, suggesting reasonable lower extremity function. The excellent Quality-Adjusted Life Years (QALY) in our study can be attributed to the overall positive impact on quality of life, primarily driven by the high MCS in the SF-12.The high MCS indicates strong mental well-being.

Although we treated 10 cases of infective nonunion, none of them experienced deep infection during the follow-up period. Based on this observation, we hypothesize that the use of free vascularized fibular graft (FVFG) with a skin and muscle paddle provides a favorable vascular bed. Combined with locking plating, this technique offers stable fixation, effectively preventing reinfection.

Complications are not uncommon with such an extensive procedure. The lack of soft tissue and the use of a broad 4.5 locking plate are associated with an increased risk of implant exposure. In our series, two cases presented with exposed implants, necessitating implant removal after significant graft hypertrophy and union. None of these cases experienced stress fractures after the removal of the implants during our latest follow-up. Additionally, one case experienced an anastomosis failure with resorption of the graft as shown in Fig. 5. After implant removal and debridement, the patient underwent a revision surgery involving tibialization of the fibula.

Our institution(Ganga Medical Centre), a level 1 trauma center in south India [38], in a developing country managing approximately 15, 000 injuries annually, provided a robust foundation for planning and conducting these surgeries. The extensive experience gained in vessel anastomosis and soft tissue coverage significantly influenced our successful outcomes. Notably, the procedures were conducted by two highly experienced plastic surgeons with over 25 years of expertise each and two senior orthopedic surgeons, ensuring a high standard of care.

Thus, our study is limited by its retrospective design, which prevents access to preoperative LEFS and quality of life scores, restricting a full assessment of baseline functional status and subsequent changes. Additionally, being a single-center study, it lacks a comparison with other fixation methods, limiting the applicability and broader interpretation of our results.

Conclusion

The combination of FVFG with a skin paddle and LCP fixation is a viable option for treating massive tibial bone loss resulting from open

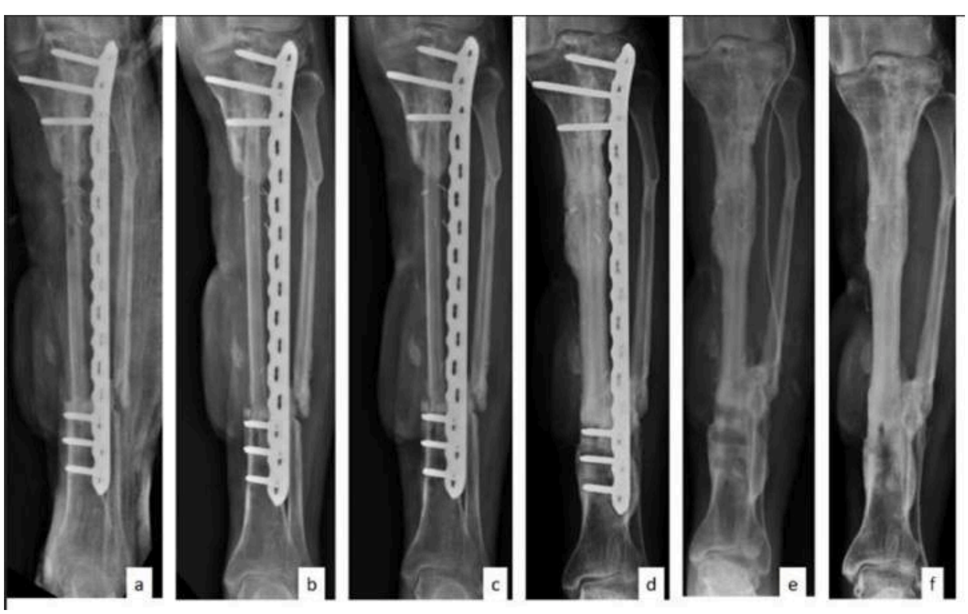

Fig. 4. (a)-A case of infective nonunion with tibia bone loss treated with FVFG with a locking plate. Progressive fibula hypertrophy seen at (b)- 3 months, (c)- 6 months, (d)- 1 year, (e)- 2 years, (f)- 3 years respectively.

Fig. 5. Case example showing graft resorption and anastomotic failure. (a & b): Presenting picture of a comminuted open 3B fracture. (c)- Wound after primary debridement, (d)- Poor condition of the wound in spite of multiple debridements, (e)- X-ray showing resultant 24 cm of bone loss .(f & g)- Clinical and X-ray images showing reconstruction with FVFG with LCP. (h & i)- Clinical image showing exposed implant and X ray showing graft resorption at 8 months. (j)- Post operative X ray of tibialization of ipsilateral fibula using external fixator and screws. (k)- At final followup at 30 months, united proximal and distal tibiofibular joint.

fractures and infective nonunion even in the challenging healthcare environment of South India, a developing country.This approach effectively maintains alignment, promotes graft hypertrophy, and importantly, prevents stress fractures. Additionally, it has yielded better patient-reported outcomes, making it an advantageous treatment option for massive tibial bone loss.

Ethics approval

Approval was obtained from the Institutional ethics committee. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Consent to participate

and publish: Informed consent was obtained from all individual participants included in the study

Funding

No funding was received for conducting this study.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT-3.5 in order to improve the language and readability. After using this tool/ service, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

CRediT authorship contribution statement

Jayaramaraju Dheenadhayalan: Conceptualization, Formal analysis, Project administration. **Asif Imran:** Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Agraharam Devendra:** Supervision, Validation, Visualization. **Hari Venkatramani:** Supervision, Validation, Visualization. **Purnaganapathi Sundaram Velmurugesan:** Supervision, Validation, Visualization. **Shanmuganathan Rajasekaran:** Conceptualization, Supervision, Validation, Visualization. **Shanmuganathan Raja Sabapathy:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

I am immensely grateful to Dr Nagashree for her invaluable guidance and support in crafting this manuscript.

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