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Ludwig Schwering * and Vanni Tim Foerster

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Transverse Tibial Bone Transport: Another Brick in the Wall for the Treatment of Recalcitrant Diabetic Foot Ulcers—A Pilot Study

Ludwig Schwering *, Vanni Tim Foerster

Ludwig Schwering, Department of Traumatology and Orthopedics, Section of Reconstructive Orthopedics, Hospital Weilheim-Schongau, Germany

* Correspondence: L.Schwering@gmx.de

Abstract

Background/Objectives: Recalcitrant diabetic foot ulcers represent a major clinical challenge and are associated with a high risk of limb loss, particularly in patients with advanced ischemia and neuropathy. Improvement of local perfusion is a key prerequisite for wound healing. Transverse bone transport (TBT), based on the Ilizarov tension–stress principle, has been shown to enhance microcirculation but remains largely unfamiliar in Western healthcare systems. This pilot study aimed to evaluate the feasibility, safety, and preliminary clinical outcomes of transverse tibial bone transport (TTBT) in patients with severe diabetic foot syndrome. **Methods:** This prospective, single-center, single-arm pilot study included ten consecutive patients with advanced diabetic foot ulcers who were referred for major amputation. All patients underwent TTBT using a unilateral external fixator according to a standardized distraction protocol. Ulcer severity was classified using the IWGDF–PEDIS system. Clinical outcomes, complications, operative time, and wound healing were assessed over a follow-up period of 6 months. **Results:** The cohort comprised seven men and three women with a mean age of 63.8 years. Seven patients had type II diabetes mellitus and three had type I diabetes mellitus. Perfusion was graded as PEDIS 3 in nine patients and PEDIS 1 in one patient; all patients had advanced polyneuropathy. Average ulcer area was 28.5 cm², and patients had undergone a mean of 4.2 prior surgical procedures. Mean operative time was 72 minutes and decreased over the course of the series, reflecting a learning curve. No intraoperative complications occurred. One patient developed a postoperative hematoma requiring revision. Complete wound healing was achieved in eight patients, while two patients showed marked improvement with ongoing healing. **Conclusions**: This pilot cohort proved TBT as a feasible and safe treatment modality, and demonstrated encouraging preliminary wound healing outcomes in patients with recalcitrant diabetic foot ulcers. TTBT may represent a valuable adjunctive limb-salvage strategy and warrants further investigation in larger controlled studies.

Keywords: diabetic foot syndrome; diabetic foot ulcer; transverse tibial bone transport; distraction osteogenesis; limb salvage; external fixation; microcirculation; pilot study

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1. Introduction

Diabetic foot syndrome (DFS) develops as a consequence of an unfavourable metabolic milieu, impaired proprioception, reduced vascular supply, and pathological biomechanics resulting in abnormal plantar pressure distribution. Clinically, DFS manifests as foot deformities and ulcerations with or without infection and may ultimately lead to partial or complete limb loss.

According to epidemiological data from the International Diabetes Federation [1], diabetic foot ulcers affect millions of patients worldwide each year, and up to 25% of individuals with diabetes may develop a foot ulcer during their lifetime. The presence of an ulcer constitutes a major risk factor for lower extremity amputation [2].

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The IWGDF–PEDIS classification system is widely used to assess perfusion, ulcer extent and depth, infection severity, and loss of protective sensation [3]. In advanced cases—particularly in the presence of osteomyelitis or gangrene—treatment options include multimodal wound care, biomechanical offloading, antibiotic therapy, vascular reconstruction, and minor or major amputation. Despite these strategies, limb salvage frequently fails in patients with therapy-refractory ischemia and extensive tissue loss.

The refractory nature of DFS is largely attributable to combined microvascular and macrovascular disease, compounded by diabetic neuropathy and persistent hyperglycemia, which further accelerates vascular damage. Consequently, improvement of local perfusion is a fundamental prerequisite for wound healing, in addition to optimized wound care and pressure redistribution.

The Ilizarov tension–stress principle [4,5] describes the ability of controlled mechanical distraction to induce regeneration of bone and surrounding soft tissues, including skin, muscle, nerves, and blood vessels. Based on this concept TTBT was developed to enhance microcirculation and promote tissue regeneration through controlled transverse distraction of a corticotomized tibial bone segment.

TTBT has been applied extensively in China for more than two decades [6–8], with large clinical series demonstrating high healing and limb-salvage rates. However, experience with this technique in Western healthcare systems remains limited.

Recent international publications have further described the surgical technique and expanded indications of TTBT [9,10].

The present pilot study aimed to evaluate the feasibility, safety, and preliminary clinical outcomes of TTBT in a Western cohort of patients with recalcitrant diabetic foot ulcers.

2. Materials and Methods

2.1. Study Design

This prospective, single-center, single-arm observational pilot study included ten consecutive patients with advanced diabetic foot ulcers who were referred for major amputation at external institutions. After detailed informed consent, all patients elected to undergo TTBT as a limb-salvage procedure. The follow-up period was 12 months.

All surgical procedures and postoperative follow-up were performed by the same experienced surgical team.

2.2. Inclusion and Exclusion Criteria

Inclusion criteria were:
(i) diagnosis of diabetes mellitus;
(ii) advanced diabetic foot ulcer classified according to the IWGDF–PEDIS system;
(iii) absence of further standard limb-salvage options.
Exclusion criteria were:
(i) complete occlusion of the popliteal artery;
(ii) inability to tolerate surgical intervention due to general medical conditions.

2.3. Ethical Considerations

The study was conducted in accordance with the Declaration of Helsinki. All patients provided written informed consent for the surgical procedure and for the use of anonymized clinical data and images.

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2.4. Surgical Technique

All procedures were performed with the patient in the supine position. A thigh tourniquet was applied but not inflated. Anticoagulation therapy was not discontinued.

At the medial face of proximal tibial diaphysis, a template was fixed to define the corticotomy site. A curved skin flap approximately 10 cm in length was prepared down to the periosteum. A rectangular cortical bone segment was corticotomized on three sides using an oscillating saw under continuous saline irrigation.

Two monocortical screws were inserted into the bone segment, and a unilateral external fixator (Orthofix TL-Elevate) was mounted. Proximal and distal bicortical screws were placed under fluoroscopic guidance, and the corticotomy was completed on the fourth side. A test distraction was performed and radiographically documented before returning the bone segment to its initial position (Figures 1 and 2).

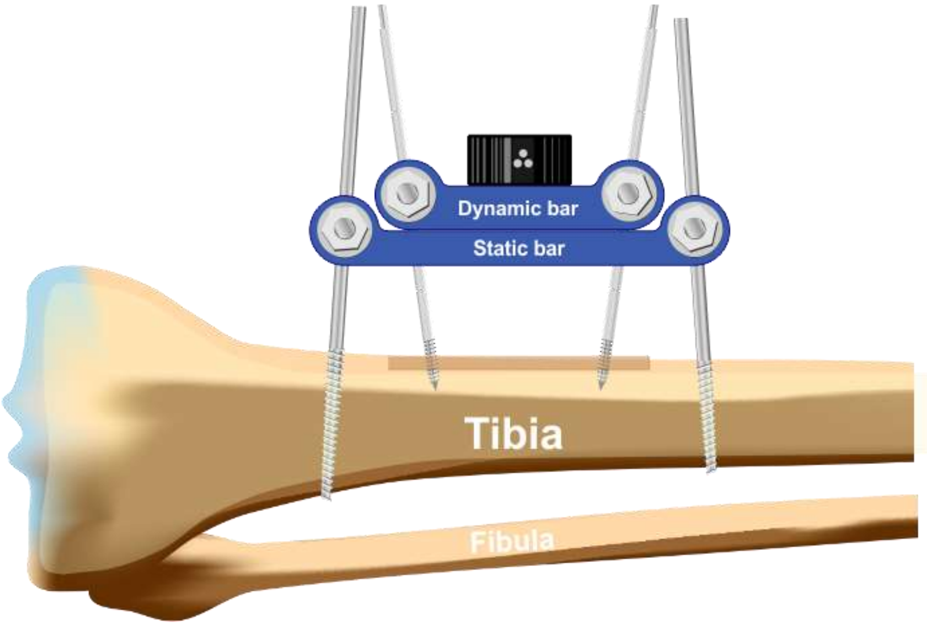

Figure 1. Schematic illustration of the unilateral external fixator (TL-Elevate; Fa. Orthofix) mounted at the proximal medial tibial diaphysis in neutral position following corticotomy. The dynamic bar allows controlled transverse distraction of the cortical bone segment, while the static bar provides stable fixation to the tibial shaft.

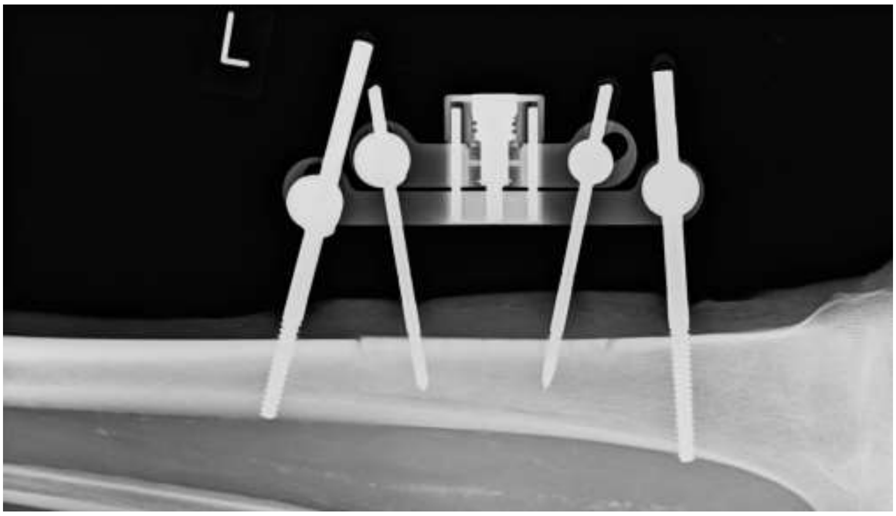

Figure 2. Anteroposterior radiograph of the proximal tibia demonstrating the unilateral external fixator in the initial neutral position prior to transverse distraction. The corticotomized tibial bone segment is visible, with

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stable fixation achieved by monocortical screws connected to the dynamic bar and bicortical screws anchoring the static bar to the tibial shaft.

2.5. Distraction Protocol and Postoperative Management

Distraction was initiated on postoperative day six at a rate of 0.25 mm x 2 times per day for 28 days. After radiographic confirmation and a latency period of three days, reverse transport was performed at 0.5 mm x 2 times per day until the bone segment returned to its original position (Figures 3–5). The fixator was removed four weeks later.

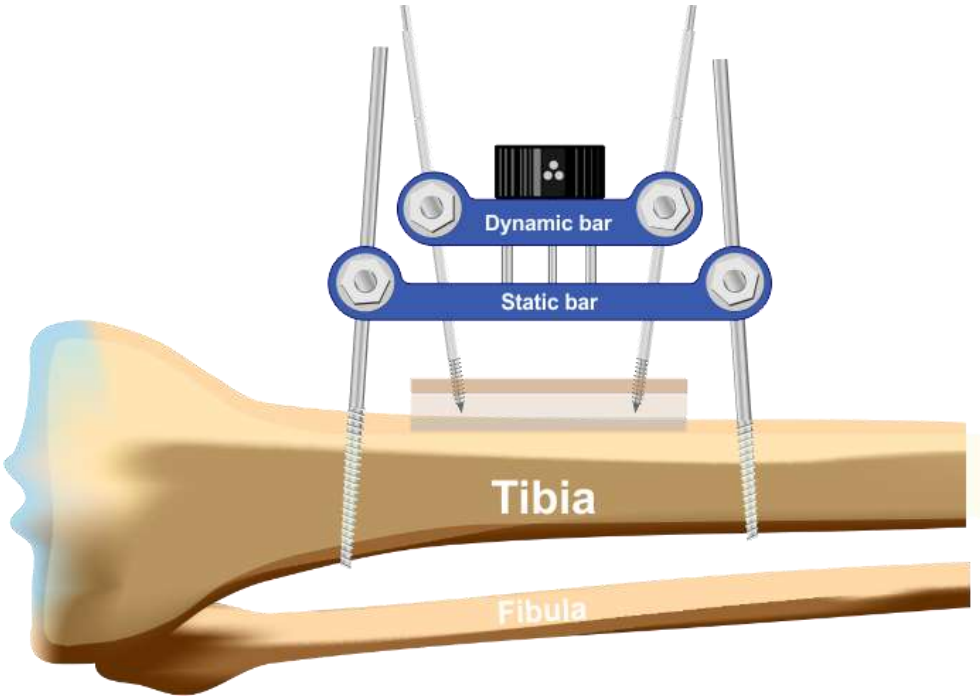

Figure 3. Schematic illustration of the unilateral external fixator at the end of the transverse distraction phase. The cortical bone segment has been displaced medially according to the distraction protocol, while stable fixation of the tibial shaft is maintained. This configuration represents the maximum extent of transverse transport prior to reverse distraction and repositioning of the bone segment.

Patients were instructed to avoid weight bearing during the distraction phase. Fixator placement was combined with additional necessary procedures, including debridement of necrotic and infected tissue. Wounds were documented weekly by standardized photography.

Ten patients were included (seven men, three women) with a mean age of 63.8 years. Seven patients had type II diabetes mellitus and three had type I diabetes mellitus. Perfusion was graded as PEDIS 3 in nine patients and PEDIS 1 in one patient. All patients exhibited advanced diabetic polyneuropathy.

The mean ulcer area was 28.5 cm^2, with a mean depth of 1.0 cm. Infection severity was graded as PEDIS 4 in five patients and PEDIS 3 in five patients. Prior to TBT, patients had undergone a mean of 4.2 surgical procedures on the affected foot.

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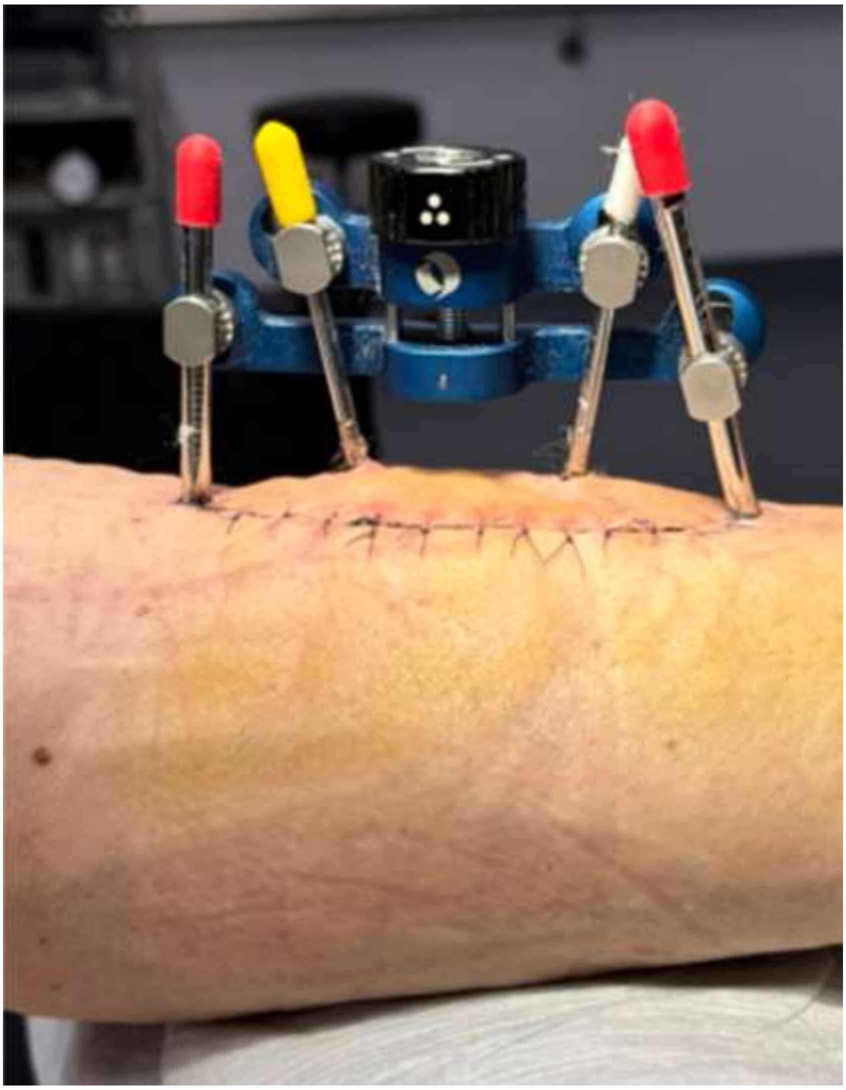

Figure 4. Clinical photograph demonstrating the unilateral external fixator mounted at the medial face of the proximal tibial diaphysis at the end of the transverse distraction period. The cortical bone segment has reached its maximum transverse displacement according to the distraction protocol. The surgical incision is healed without signs of infection or wound complications.

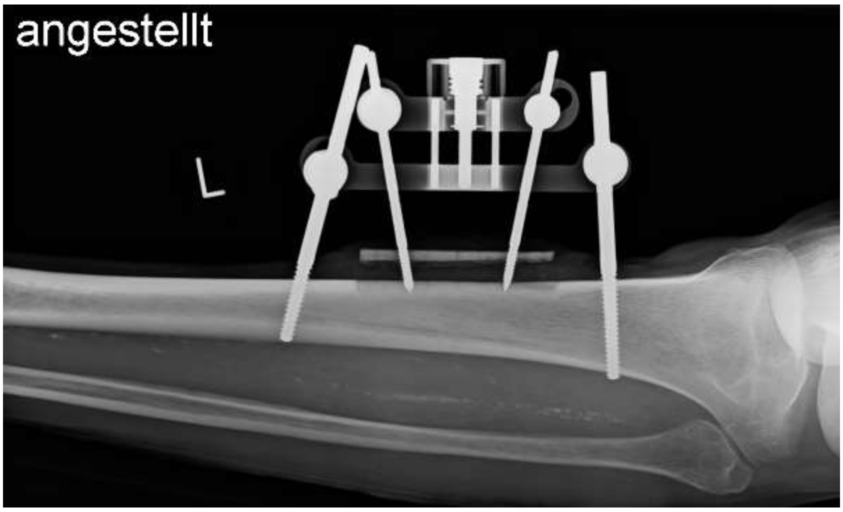

Figure 5. Anteroposterior radiograph of the proximal tibia at the end of the transverse distraction phase. The corticotomized tibial bone segment is shown in its maximally displaced transverse position, while stable fixation

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of the tibial shaft is maintained by the unilateral external fixator. This configuration represents the endpoint of transverse transport prior to initiation of reverse distraction.

3. Results

Mean operative time was 72 minutes and decreased from 93 minutes in the first case to 50 minutes in the last, indicating a learning curve. No intraoperative complications occurred. One patient developed a postoperative hematoma requiring surgical evacuation.

Complete wound healing was achieved in eight patients. In the remaining two patients, wounds showed marked improvement and were in an advanced stage of healing at the last follow-up.

A representative case demonstrates progressive wound healing of a large plantar ulcer measuring approximately 60 cm², with early granulation observed within days, substantial improvement at one month, advanced epithelialization at three months, and complete wound closure after four months.

A clinical follow up of the first patient is illustrated below (Figures 6–9).

Figure 6. Preoperative clinical appearance of a large plantar diabetic foot ulcer following previous resection of the first ray. The wound demonstrates extensive soft-tissue loss with exposed deep tissue and signs of chronic infection in the setting of advanced diabetic foot syndrome.

Figure 7. Clinical appearance of the diabetic foot ulcer four days after initiation of transverse tibial bone transport and surgical debridement. The wound demonstrates early granulation tissue formation and improved wound bed appearance, indicating an initial biological response following commencement of the distraction protocol.

Figure 8. Clinical appearance of the diabetic foot ulcer on postoperative day 31 following transverse tibial bone transport. The wound shows extensive, stable granulation tissue with marked reduction of necrotic tissue and progressive epithelialization at the wound margins, indicating sustained improvement during the distraction and early consolidation phase.

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Figure 9. Clinical appearance of the diabetic foot ulcer three months after initiation of transverse tibial bone transport. The wound shows advanced epithelialization with substantial reduction of the ulcer area and no signs of active infection, indicating sustained and progressive wound healing.

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4. Discussion

This pilot study demonstrates that TTBT is feasible and safe in a Western clinical setting and may represent a promising adjunctive limb-salvage method for patients with recalcitrant diabetic foot ulcers. Even in a cohort of patients previously considered candidates for major amputation, TTBT resulted in complete wound healing in the majority of cases.

Early and sustained wound improvement was observed following initiation of transverse distraction, with rapid granulation tissue formation and progressive epithelialization. The representative case illustrates that even large plantar ulcers can heal within a clinically reasonable time frame without additional revascularization procedures.

The biological rationale of TTBT is supported by the Ilizarov tension–stress principle and experimental evidence demonstrating stimulation of angiogenesis, improved microcirculation, and activation of tissue metabolism. Large prospective cohorts from Asia have reported high healing and limb-salvage rates, providing strong biological plausibility for the observed effects [4,7].

Compared with existing literature [6,7], the present study differs by focusing on a small, well-defined cohort treated with a standardized protocol and a commercially available fixation system. The low complication rate and decreasing operative time further support the reproducibility of the technique.

Limitations include the small sample size, single-center design, and absence of a control group. As a pilot study, the aim was not to establish efficacy but to explore feasibility, safety, and early clinical signals. Larger controlled studies are required to define the role of TTBT within multidisciplinary diabetic foot care.

5. Conclusions

In this pilot study, TTBT proved to be a feasible and safe adjunctive treatment for patients with recalcitrant diabetic foot ulcers. The procedure demonstrated encouraging preliminary wound healing outcomes and may represent a valuable limb-salvage option in selected patients. Further controlled studies are warranted.

Funding: This research received no external funding.

Institutional Review Board Statement: Ethical review and approval were waived due to the pilot character of the study and because the intervention was performed as an individual therapeutic attempt in patients without remaining standard treatment options.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent for publication of clinical images was obtained from the patient(s).

Data Availability Statement: The data presented in this study are available on request from the corresponding author and are not publicly available due to patient privacy and ethical restrictions.

Acknowledgments: graphics were prepared by CorelDraw18

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

DFS	Diabetic Foot Syndrome
IWGDF	International Working Group on the Diabetic Foot
TBT	Transverse Bone Transport
TTBT	Transverse Tibial Bone Transport

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