

Surgical Reconstruction of **DIABETIC FOOT & ANKLE** By Ilizarov Technique



Prof. Emeritus Dr. Md. Mofakhkharul Bari



BARI-ILIZAROV ORTHOPAEDIC CENTRE



Surgical reconstruction of diabetic foot & ankle by Ilizarov technique

This book is dedicated to my parents, father and mother-in-laws and to all my patients.

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Foreword

The legacy of Academician G.A. Ilizarov endures in the hands of surgeons across the world who have carried his principles forward — extending them to clinical challenges that continue to grow in scale and urgency. The diabetic foot is precisely such a challenge.

Diabetes mellitus has become one of the defining epidemics of our century. Peripheral neuropathy, vascular insufficiency, and chronic infection converge to create conditions that are technically demanding and devastating in their human consequences. For too many patients, it ends in amputation.

It is with great satisfaction that I welcome Surgical Reconstruction of Diabetic Foot and Ankle by Ilizarov Technique by Professor M.M. Bari — a surgeon of remarkable distinction whose long association with the Ilizarov Centre in Kurgan and decades of dedicated practice have shaped a uniquely authoritative voice in this field. He has translated the core principles of distraction osteogenesis and biological tissue regeneration into a coherent, effective strategy for the most complex diabetic limb pathology.

At the National Medical Research Center named after Academician G.A. Ilizarov, we take particular pride in seeing the method of our founder applied with such rigour and compassion. I commend this book unreservedly and congratulate Professor Bari on this outstanding contribution.

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Foreword



The diabetic foot remains one of the most challenging and consequential complications in modern medicine. Despite advances in preventive care, amputation continues to cast its shadow over countless patients worldwide - stripping them not only of a limb, but of independence, livelihood, and hope.

It is in this context that the work of Prof. Dr. Mofakhkharul Bari assumes its full significance.

In this volume, Prof. Dr. Bari has achieved something rare in surgical literature: a coherent, evidence-based framework for limb salvage in the diabetic foot and ankle using the Ilizarov technique. The application of distraction osteogenesis and external fixation to this patient population demands exceptional surgical judgement, a thorough understanding of diabetic pathophysiology, and meticulous clinical discipline. Prof. Dr. Bari brings all of these qualities to bear, and this book is the authoritative result.

I have had the privilege of witnessing Prof. Dr. Bari's dedication to his patients and to the advancement of reconstructive surgery over many years. His commitment to preserving limbs that others might have surrendered to amputation reflects both his surgical mastery and his deep humanity as a physician.

This book will be an indispensable resource for orthopaedic surgeons, diabetologists, and all clinicians engaged in the care of the diabetic limb. I commend it without reservation and congratulate Prof. Dr. Bari on this outstanding contribution to our field.

A handwritten signature in black ink, appearing to read 'Fazlur Rahman'.

Prof. Dr. Fazlur Rahman

Director General

BIHS General Hospital

Foreword



The Ilizarov method of transosseous compression-distraction osteosynthesis has, over decades, proven itself a universal biological instrument capable of unlocking the regenerative potential of living tissue far beyond what classical surgery could achieve. Its application to the diabetic foot - a condition of devastating global consequence - represents one of its most meaningful extensions.

I have known Professor M.M. Bari for many years. I watched him grow from a devoted student of the Ilizarov technique into one of its most accomplished practitioners in Asia. He has not merely applied the method — he has adapted it with skill and discipline to the complex realities of diabetic limb pathology, and this book is the authoritative result of that journey.

The clinical photographs, radiographs, and surgical documentation presented here are thorough and instructive. I am confident this work will serve as a valuable reference for surgeons and clinicians worldwide, and that it will be warmly received both at home and abroad.

I congratulate Professor Bari on this outstanding contribution and wish him every continued success.



Academician Professor V.I. Shevtsov

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Foreword



The diabetic foot remains one of the most formidable challenges in medical practice. Its complexity lies not merely in the structural devastation, it inflicts upon soft tissue, bone and joint; it also causes the systemic fragility of the patient in whom it occurs. For the orthopaedic surgeon, it demands both technical mastery and sound clinical judgement and above all - a firm commitment and dedication to limb preservation.

It is my pleasure and great privilege to write this Foreword for “Surgical Reconstruction of Diabetic Foot and Ankle by Ilizarov Technique” by Prof. Dr. Md. Mofakhkharul Bari — a Surgeon of exceptional distinction; a renowned local, regional and international faculty and a true pioneer of use of the Ilizarov method in Bangladesh.

The Ilizarov technique, built upon the biological principle of “Distraction Osteogenesis”, provides the Surgeon a powerful and versatile device for addressing the skeletal and soft tissue problems in diabetic foot disease. Ilizarov method is now becoming more and more popular not only in Bangladesh but round the globe.

Prof. Dr. Bari has applied this method with remarkable consistency and success, and this volume represents the definitive documentation of that experience. The surgical principles, clinical cases, and technical guidance presented here reflect decades of disciplined practice and academic rigour.

Prof. Dr. Bari’s standing in the international orthopaedic community is well established. His recognition by the Kurgan Ilizarov Center in Russia as Honorary Emeritus Professor — the first foreigner to receive this honour — speaks eloquently to the caliber of his contribution. This book is a worthy addition to existing works in this field. As Bangladeshi, we are proud of him.

I commend this volume unreservedly to medical doctors involved in Diabetic foot and ankle care and to Orthopaedic and Reconstructive Surgeons in particular.

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Message



It is a moment of immense pride and joy for me to write this message on the occasion of the publication of Surgical Reconstruction of Diabetic Foot and Ankle by Ilizarov Technique by Professor M.M. Bari, who is not only a lifelong devotee of the Ilizarov technique but a tireless champion of limb salvage for those who need it most.

Our BARI-ILIZAROV Orthopaedic Centre has always stood on one simple conviction — that every patient deserves the chance to walk, to work, and to live a normal life. The diabetic foot, with its silent and relentless destruction, robs patients of exactly that. This book represents Professor Bari's deeply considered answer to that challenge, drawn from decades of surgical experience and an unwavering belief in the power of the Ilizarov method.

My appreciation and admiration go to Professor Bari for his dedication in bringing this work to publication. I sincerely hope it reaches surgeons, trainees, and clinicians across the world and makes a lasting difference in the lives of diabetic patients everywhere.

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I am deeply grateful to my patients, my beloved teacher Professor V. I. Shevtsov, and my mentors Professor E. T. Skliarenko, Professor B. M. Mirazimov, and Professor Kh. Abdul Awal Rizvi. My wife Nabia Bari and my entire family have been my greatest strength. I sincerely thank the following colleagues for their invaluable multidisciplinary support:

Prof. Dr. Md. Shahidul Islam, Dr. Rafiul Islam Rean, Dr. Safwanul Aman, Prof. Dr. Md. Jahangir Alam Sarker, Dr. Md. Abdul Awal, Dr. Mithila Akhtar, Dr. Sujan Shaha, Dr. Ahmed Salam Mir, Prof. Dr. Tanwir Iqbal Ibn Ahamed, Dr. Md. Shajjad Ul Islam, Prof. Dr. Md. Nazmul Haque, Prof. Dr. K.M.H.S Sirajul Haque, Dr. Md. Shakhawat Hossain, Dr. Mir Mahbubur Rahman, Prof. Dr. Md. Khalilur Rahman, Prof. Dr. Mamunur Rashid, Dr. Md. Abu Sayeed Khan, Dr. Md. Asaduzzaman Firoz, Dr. Shaila Shagor, Dr. Anisul Islam, Dr. Jiaul Reza Jion, Prof. Dr. Md. Faruque Quasem, Dr. Md. Mahfuzzaman, Dr. M. Islam Moin, Dr. Md. Mohiur Rahman Khan, Dr. Md. Tamim Hussain, Brig. Gen. (Retd.) Prof. Dr. Kazi Ashkar Lateef, Dr. Mohammed Abul Kalam Azad, Dr. Md. Parvez Sultan, Dr. Kaniz Laila Shams, Dr. H.N. Masuk Rahman, Prof. Dr. Mohammad Sayeed Hossain, Dr. Md. Mosharraf Hossain, Dr. Muntasir-Bin-Shahid, Dr. Farzana Hoque Tanmi, Dr. A.K.M. Erfanul Hoque

And finally I pray to Almighty Allah for the well-being of my patients.



Preface

It is with great respect and honor to write this preface for my first edition of “Surgical Reconstruction of the Diabetic Foot and Ankle by Ilizarov Method.” I am obligated to thank many individuals throughout my academic career that have helped me achieve my goals and also publish this wonderful textbook. I also thank my family members for their continuous support and help.

My father-like teacher Prof. V.I. Shevtsov was the most influential person in my life since he taught me so many things that shaped my life.

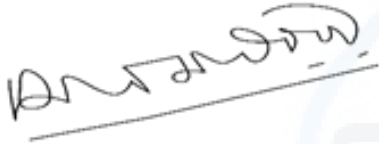
Ilizarov is my life. Throughout all my years I was very eager to do Ilizarov surgery all the time. As a visiting Prof. in BIRDEM and BIHS, I spent 6 years here and did lots of diabetic ankle and foot surgeries. These two hospitals were one of my biggest turning points in my academic career.

I am obliged and honored to mention Prof. Murtuza K. I. Quayyum Choudhury and his contribution to my academic journey. Dr. Junaid Hakim and Dr. Afrina Jahan of BIRDEM Medical College also helped me a lot. Their friendship and professionalism, and astute experience in the use of Ilizarov technique have made me return to BIRDEM and BIHS on a regular basis.

My target and goal in an academic environment with a large diabetic population in Bangladesh in need of diabetic ankle and foot treatment was to establish a center of excellence—BARI-ILIZAROV ORTHOPAEDIC CENTRE—where all patients were seen and treated by all specialties.

DM [Diabetes Mellitus] is an epidemic with more lower extremity amputation being performed as a result of diabetes-related complications, the need of awareness and healthcare education were my goals through this first edition of this surgical reconstruction book.

A multidisciplinary team of doctors always shared their expertise and approach to some of the most difficult cases in dealing with diabetic ankle and foot.



Prof. Dr. Md. Mofakhkharul Bari

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Chapter I

Multidisciplinary team approach to limb salvage in diabetic foot at BIRDEM & BIHS

A multidisciplinary team (MDT) approach integrates specialists to address the complex pathology of diabetic foot ulcers (DFUs), significantly improving limb salvage rates by tackling neuropathy, infection, vascular issues, and wound care simultaneously. At Bangladesh Institute of Research and Rehabilitation in Diabetes, Endocrine and Metabolic Disorders (BIRDEM) & Bangladesh Institute of Health Sciences (BIHS) in Dhaka, this model supports advanced techniques like tibial transverse bone lengthening for no-option chronic limb ischemia cases, achieving high healing rates in Wagner grade II-IV ulcers.

Importance of MDT in diabetic foot care

Diabetic foot complications lead to 15 times higher amputation risk due to poor healing from neuropathy and peripheral artery disease (PAD).

Studies show MDTs reduce major amputations in 94% of cases by coordinating glycemic control, debridement, revascularization,

and offloading. Books like Levin and O'Neal's The Diabetic Foot emphasize team-based clinics with podiatrists, vascular surgeons, endocrinologists, and nurses for optimal outcomes.

Diabetic foot classification

Diabetic foot classification systems standardize ulcer assessment for treatment and risk prediction.

Neuropathic vs Neuroischemic

Neuropathic: Nerve damage causes insensate ulcers, Charcot joints, fissures.

Neuroischemic: Neuropathy + ischemia leads to rest pain, gangrene.



Meggitt-Wagner Grade (0-5)

Wagner classification of diabetic foot ulcers

Grade 0

No ulcer in a high-risk foot



Grade 1

Superficial ulcer involving the full skin thickness but not underlying tissues



Grade 2

Deep ulcer, penetrating down to ligaments and muscle, but no bone involvement or abscess formation



Grade 3

Deep ulcer with cellulitis or abscess formation, often with osteomyelitis



Grade 4

Localized gangrene



Grade 5

Extensive gangrene involving the whole foot



Figure 1.1 Wagner classification of diabetic foot.

Grade	Key features
0	Pre-ulcerative
1	Superficial ulcer
2	Deep to tendon/bone
3	Abscess/osteomyelitis
4	Partial gangrene
5	Full gangrene

University of Texas (UT)

**Figure 1.2** University of Texas classification of diabetic foot

Grade	A	B	C	D
0	Healed	-	-	-
1	Superficial	+Infection	+Ischemia	+Both
2	Tendon/capsule	+Infection	+Ischemia	+Both
3	Bone/joint	+Infection	+Ischemia	+Both

Wound (W)

Grade	Ulcer	Gangrene
0	None	None
1	Small, shallow	None
2	Deep with exposed bone, joint, or tendon	Limited to digits
3	Extensive, deep, and involving forefoot and/or midfoot with or without calcaneal involvement	Extensive and involving forefoot and/or midfoot Full thickness heel necrosis with or without calcaneal involvement

WIFI

Scores wound (0-3), ischemia (0-3), infection (0-3) for amputation risk.



The Wound, Ischemia, and Foot Infection (WIFI) classification system consists of 3 components graded separately from 0 (none) to 3 (severe).

One component may be dominant but the specific combination of scores is used to estimate the risk of limb amputation at 1 year and the need for or benefit of revascularization.^a

Ischemia (I)

Grade	Ankle-brachial index Ankle systolic pressure	Toe pressure or transcutaneous oximetry
0	≥0.80 / >100 mm Hg	≥60 mm Hg
1	0.60–0.79 / 70–100 mm Hg	40–59 mm Hg
2	0.40–0.59 / 50–69 mm Hg	30–39 mm Hg
3	≤0.39 / <50 mm Hg	<30 mm Hg

Grade	Clinical manifestation
0	No symptoms or signs of infection Infection indicated by ≥ 2 of the following: Local swelling or induration Erythema 0.5–2.0 cm around ulcer
1	Local tenderness or pain Local warmth Purulent discharge (thick, opaque to white, or sanguineous)
2	Infection as described above with: Erythema > 2 cm around ulcer Involving structures deeper than skin and subcutaneous tissues (e.g., abscess, osteomyelitis, septic arthritis, fasciitis) No signs of systemic inflammatory response (see below)
3	Infection as described above with ≥ 2 signs of systemic inflammatory response syndrome: Temperature $> 38^{\circ}\text{C}$ or $< 36^{\circ}\text{C}$ Heart rate $> 90/\text{min}$ Respiratory rate $> 20/\text{min}$ or $\text{PaCO}_2 < 32$ mm Hg White blood cell count $> 12,000/\mu\text{L}$ or $< 4,000/\mu\text{L}$ or 10% immature forms

Figure 1.3 Wifi classification of diabetic foot.

PEDIS (IWGDF)

Perf: Vascular status

Extent: Ulcer size (cm^2)

Depth: Grade 1-3

Infection: Mild/moderate/severe

Sensation: Neuropathy grade

Key team members and roles

MDTs typically include diabetologists for glycemic management, podiatrists for debridement and offloading, vascular surgeons for revascularization, infectious disease experts for antibiotics, and orthotists for custom footwear.

Role	Responsibilities	Contribution to limb salvage
Diabetologist	Glycemic control, neuropathy screening	Prevents ulcer progression
Podiatrist/Wound Nurse	Debridement, dressings, offloading	Promotes healing, reduces infection
Vascular Surgeon	Angiography, bypass/angioplasty	Restores blood flow in PAD
Orthopedic Surgeon	Bone procedures, e.g., Ilizarov at BIHS	Salvages limbs in osteomyelitis
Infectious Disease	Culture-guided antibiotics	Controls polymicrobial infections
Pedorthist/Rehab	Custom shoes, physiotherapy	Prevents recurrence post-healing

This structure mirrors guidelines from the International Working Group on the Diabetic Foot (IWGDF).

BIRDEM & BIHS-specific limb salvage strategies

BIRDEM & BIHS, affiliated with Bari-Ilizarov Orthopaedic Centre, employs MDTs for DFU management using Ilizarov distraction osteogenesis, healing 50% of Wagner grade III cases via tibial transverse technique (TTT). In a series of 58 patients (ages 35-72), TTT improved microcirculation, achieving ulcer resolution

without amputation in most, even with atherosclerosis. This aligns with Bangladesh's high DFU risk, where 19-34% of diabetics face lifetime ulcers, demanding specialized centers.

Evidence from studies and books

Systematic reviews confirm MDTs yield $> 80\%$ healing and $> 90\%$ limb salvage, outperforming single-specialty care. Clinical Care of the Diabetic Foot (Armstrong et al., 4th ed.) details pathogenesis, screening, and adjunct therapies like those at BIHS. Levin's book dedicates chapters to team organization, podiatry roles, and rehab, reporting reduced amputations via coordinated care.

Challenges and implementation at BIRDEM & BIHS

In resource-limited settings like Bangladesh, challenges include delayed referrals and PAD prevalence, but BIRDEM & BIHS counters with affordable diagnostics and TTT for no-option CLI. Protocols involve weekly MDT meetings, patient education, and follow-up, mirroring global successes with 88-95% salvage rates. Future expansions could integrate IWGDF risk screening nationwide.

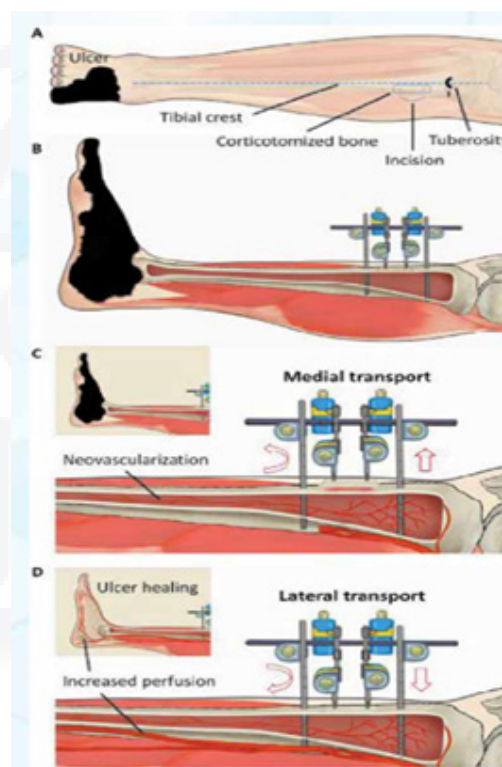


Figure 1.4 Steps of Angiogenesis by using Distraction Osteogenesis in TTT method of Ilizarov principles.

Podiatrists serve as gatekeepers in the multidisciplinary team (MDT) for diabetic foot limb salvage at BIHS, focusing on foot-specific pathologies to prevent ulcers and promote healing.

Core podiatry responsibilities

Podiatrists perform sharp debridement to remove necrotic tissue, biofilms, and calluses, which accelerates wound closure and reduces infection risk in Wagner grade II-IV ulcers common at BIRDEM & BIHS. They conduct biomechanical assessments to identify deformities like Charcot foot or equinus, prescribing total contact casts or custom orthoses for pressure offloading. In BIRDEM & BIHS protocols, this integrates with Ilizarov techniques for bone regeneration in osteomyelitis cases.

Preventive and diagnostic roles

Routine podiatric screening detects pre-ulcerative lesions via monofilament testing and dermoscopy, enabling early intervention that cuts amputation rates by 31% in MDT settings. They educate patients on foot hygiene, shoe modifications, and daily inspections, vital in Bangladesh's high-risk diabetic population. At BIRDEM & BIHS, podiatrists triage referrals, coordinating with vascular surgeons for angiography when PAD limits healing.

Surgical contributions

Podiatrists execute minor procedures like partial calcaneotomies or tendon balancing (e.g., Achilles lengthening) to salvage limbs unsuitable for major amputation. In BIRDEM & BIHS limb salvage, they collaborate on staged reconstructions post-TTT, ensuring stable foot architecture for weight-bearing. Postoperative orthotics prevent recurrence, achieving >80% ulcer-free survival at 1 year.

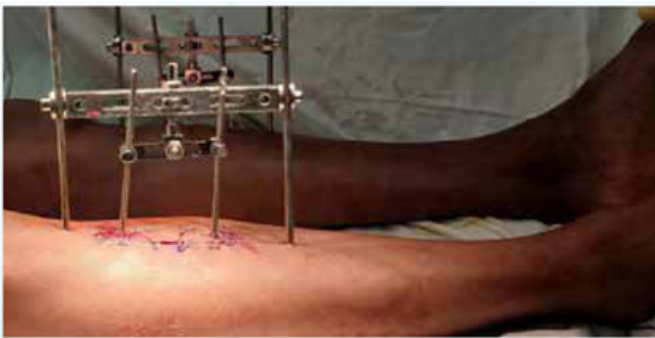


Figure 1.5 Tibial Transverse Transport applying in Bilateral PVD.



Figure 1.6 Tibial Transverse Transport applying in Non healing ulcer.

Podiatry intervention	BIHS application	Outcome impact
Debridement	Weekly in MDT clinics	faster healing 50%
Offloading (TCCs)	Custom for Charcot cases	ulcer resolution 70%
Prophylactic Surgery	Tendon transfers	limb retention 90%
Patient Education	Foot care workshops	recurrence drop 40%

Multidisciplinary team (MDT) approaches including podiatry at BIHS significantly outperform non-MDT or podiatry-lacking care in diabetic foot limb salvage, with global meta-analyses showing 31% lower total amputation risk. In BIHS's resource-constrained context, this translates to higher healing rates for complex ulcers via integrated debridement and offloading.



Figure 1.7 X-ray shows application of TTT device after corticotomy.

Amputation rate reductions

Meta-analyses of 12 studies confirm MDTs with podiatry reduce total lower extremity amputations (LEAs) by 31% (RR: 0.69, 95% CI 0.54–0.89) and major LEAs by 55% (RR: 0.45, 95% CI 0.23–0.90) compared to standard care without dedicated podiatry. Without podiatry, single-specialty management often delays debridement, leading to progression from Wagner grade II to IV, as seen in Bangladesh's high DFU prevalence (19–34%). At BIRDEM & BIHS, MDT integration with Ilizarov techniques achieves >80% limb salvage in no-option cases, versus higher amputations in fragmented care.

Healing and hospital outcomes

MDTs with podiatry boost ulcer healing to 74% from 64% in pre-MDT audits, with faster closure due to serial debridement. Non-MDT settings show prolonged stays and readmissions; podiatry-inclusive teams cut these by enabling early offloading and vascular triage. BIRDEM & BIHS data mirrors this, with tibial transverse technique (TTT) yielding 50% Wagner III healing without amputation, unattainable without podiatric gatekeeping.

Mortality and long-term survival

Three-year mortality drops from 39% to 29% post-MDT implementation, linked to fewer major amputations. In BIRDEM & BIHS, where PAD and neuropathy dominate, podiatry's preventive screenings prevent recurrence (40% risk reduction), sustaining >90% limb retention at 1 year versus higher failures sans MDT.

Conclusion

The multidisciplinary team approach, with podiatry at its core, revolutionizes limb salvage for diabetic foot patients at BIHS by integrating debridement, offloading via TCCs, and advanced techniques like TTT.

Proven superiority

MDTs including podiatrists reduce LEA by 31% overall and 55% for major amputations compared to fragmented care, achieving 70–90% limb retention and ulcer healing rates aligned with IWGDF standards.

BIRDEM & BIHS Impact

In Bangladesh's high-risk setting, this model prevents progression from Wagner II–IV ulcers, cuts recurrence by 40%, and optimizes resource use for sustainable outcomes.

Chapter 2

Preoperative management of the high-risk patient with Diabetes mellitus

Introduction

Guideline for perioperative care for people with diabetes mellitus Undergoing elective and emergency surgery



CBG = Capillary blood glucose

Shared Decision Making = The process whereby patients and clinicians work together to make evidenced based decisions centred on patient values and preferences – including risks, benefits, alternatives and optimisation.
T1DM = Type 1 Diabetes Mellitus

DrEaMing = Drinking, Eating and Mobilising

Figure 2.1 The perioperative pathway for people with diabetes undergoing elective and emergency surgery.

Preoperative management of high-risk diabetic patients undergoing surgery for diabetic foot complications focuses on optimizing glycemic control, treating infections, and addressing comorbidities to reduce perioperative risks like poor wound healing and amputation. High-risk patients often have Wagner Grade 3 or higher ulcers, neuropathy, peripheral artery disease (PAD), and uncontrolled hyperglycemia.

Patient assessment

Evaluate glycemic status with HbA_{1c} (ideally <7-8% preoperatively) and recent fasting blood glucose; levels above 200 mg/dL increase infection risk. Assess for infection via wound culture, CRP, and leukocyte count; screen for PAD using ankle-brachial index and cardiovascular risks with ECG and echocardiography. Multidisciplinary input from endocrinologists, vascular surgeons, and infectious disease specialists is essential for high-risk cases.

Glycemic optimization

Initiate intensive insulin therapy (e.g., basal-bolus regimen with 0.5 IU/kg total daily dose) to achieve fasting glucose <180-200 mg/dL before surgery; discontinue oral agents 24-48 hours prior. Preoperative fasting should minimize hyperglycemia—use variable-rate IV insulin infusion if needed, targeting 140-180 mg/dL. Tight control reduces macrovascular events but monitor for hypoglycemia.

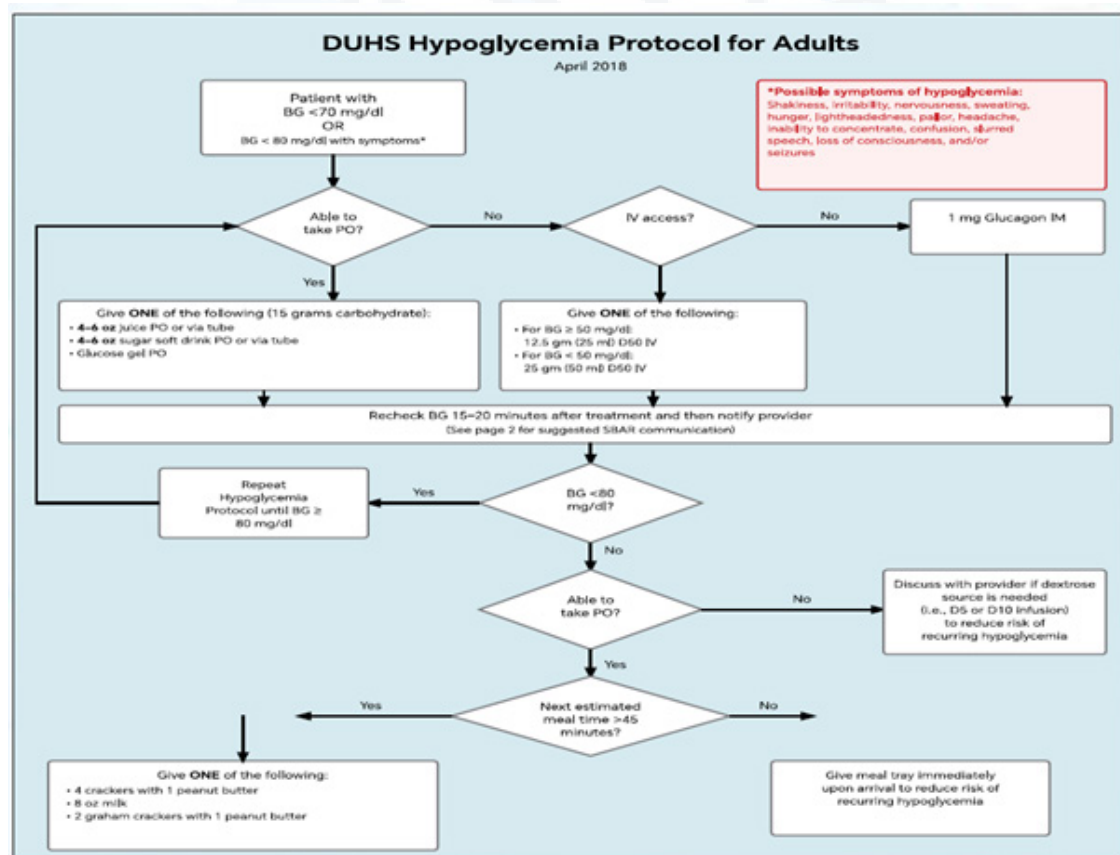


Figure 2.2 DUHS Hypoglycemia Protocol for Adults.

Infection control

Administer empirical broad-spectrum IV antibiotics (e.g., ampicillin-sulbactam 4g/day) for at least 7 days preoperatively in infected diabetic foot ulcers, adjusting based on cultures. Combine with local wound care like saline wet-to-dry dressings to promote granulation and reduce necrosis. Criteria for proceeding to surgery include CRP <10 mg/L, normalized leukocytes, and clinical wound improvement.

Cardiovascular and renal management

Stabilize hemodynamics, correct electrolytes, and ensure euvolemia; high-risk patients need cardiology clearance if history of heart failure or ischemia. Manage renal impairment common in diabetes by avoiding nephrotoxic agents and monitoring acid-base balance. Offload the foot with total contact casts or bed rest to prevent ulcer progression during optimization.

Surgical timing and perioperative care

Delay elective surgery until 1-week medical optimization shows response (e.g., glucose <200 mg/dL, reduced wound drainage); this lowers major amputation rates. Schedule as first case to limit fasting; intraoperative glucose monitoring with insulin infusion is standard. Postoperative care continues tight control and infection surveillance to enhance outcomes.

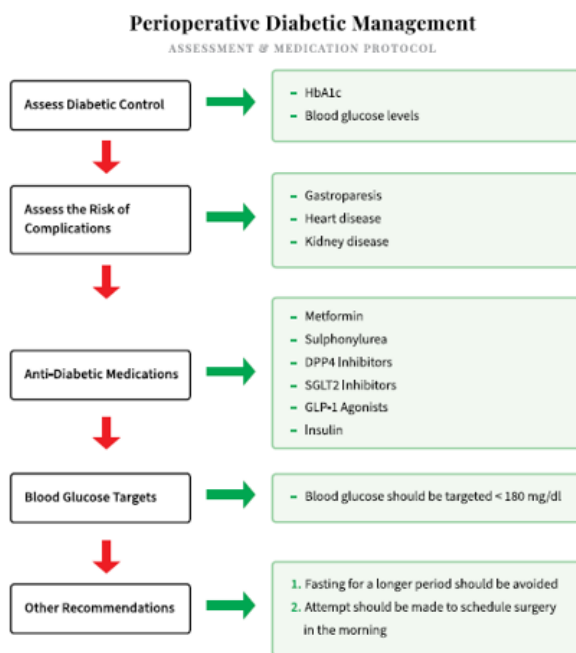


Fig. — Perioperative diabetic medication flowchart. Adapted from standard preoperative endocrine assessment guidelines.

Figure 2.3 Assessment and application flow chart to maintain glycemic target.

Key differences in preoperative care for Type 1 vs Type 2 diabetes in foot surgery

Preoperative care for Type 1 and Type 2 diabetes patients undergoing foot surgery differs mainly in insulin dependency, risks of metabolic decompensation, and medication adjustments.

Insulin management

Type 1 patients require basal insulin (e.g., 80% of usual dose day before surgery) to prevent diabetic ketoacidosis (DKA), as they lack endogenous insulin; never omit basal coverage.

Type 2 patients on insulin follow similar basal reductions, but those on oral agents like metformin stop them 24-48 hours prior due to lactic acidosis risk, while SGLT2 inhibitors are held 3-4 days early.

Glycemic targets and monitoring

Both types target preoperative glucose 140-180 mg/dL, but Type 1 demands more frequent monitoring (q1-2h) and IV insulin infusion readiness due to hypoglycemia or DKA vulnerability. Type 2 patients tolerate short-term fasting better but need HbA1c screening; surgery delays if >8-9%.

Aspect	Type 1 Diabetes	Type 2 Diabetes
Basal Insulin	Mandatory; reduce 20-50% preoperatively	If on insulin, reduce similarly
Oral Medication	N/A	Stop metformin/SGLT2i days prior
DKA Risk	High; monitor ketones/acid-base	Lower unless severe stress
Fasting Adjustment	IV dextrose-insulin from night before	Sliding scale or infusion if uncontrolled

Comorbidity focus

Type 1 patients prioritize electrolyte/acid-base correction and volume status to avert DKA during fasting.

Type 2 emphasizes cardiovascular screening and PAD assessment, common in longstanding disease, alongside infection control for foot ulcers. Multidisciplinary optimization (1-2 weeks) applies to both but is more urgent in Type 1.

Intraoperative insulin protocols for Type 1 diabetes foot surgery

Intraoperative insulin protocols for Type 1 diabetes patients during foot surgery prioritize continuous IV infusion to prevent ketoacidosis and maintain tight glycemic control amid surgical stress.

Protocol overview

Use IV insulin infusion (regular insulin 1 U/ mL in NS) starting at 0.5-1 U/hour for Type 1 patients, titrated to target blood glucose 140-180 mg/dL; check levels hourly or q1-2h. Combine with dextrose 5-10% infusion at 100 mL/hour (with KCl 10-20 mEq/L if normokalemic) to avoid hypoglycemia or hypokalemia. Avoid subcutaneous insulin due to unreliable absorption from PAD-affected limbs in foot surgery.

Initiation and adjustment

Begin infusion 30-60 minutes before incision if glucose >140 mg/dL; prime tubing with 50 mL to saturate insulin binding. Algorithm: Increase by 1 U/hour if >180 mg/dL, decrease by 0.5-1 U/hour if 100-139 mg/dL, or hold if <100 mg/dL and give D10W bolus. For foot procedures (>2 hours or hemodynamic instability), infusion is mandatory over the sliding scale.

Monitoring essentials

Intraoperative CGM or arterial line glucose checks q30-60min; watch for DKA signs (ketones, acidosis) unique to Type 1. Adjust for NPO status, hypothermia, or blood loss; transition to basal-bolus postop when stable.

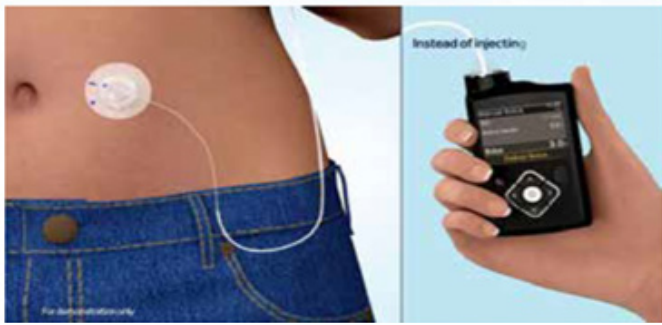


Figure 2.4 CGM for continuous glucose monitoring.

Parameter	Recommendation
Target Glucose	140-180 mg/dL
Start Rate	0.5-1 U/hr
Check Frequency	q1h (arterial/capillary)
Dextrose Co-Infusion	D5W/D10W 100 mL/hr + KCl

Target blood glucose levels during foot surgery for diabetics

Target blood glucose levels during foot surgery for diabetic patients typically range from 140-180 mg/dL to balance infection risk

reduction with hypoglycemia prevention. This intraoperative target aligns with broader perioperative guidelines from the ADA and Joint British Diabetes Societies.

Rationale and guidelines

Surgical stress in foot procedures elevates glucose via cortisol and catecholamines, increasing wound complications if >200-250 mg/dL. Guidelines recommend 140-180 mg/dL (or 100-180 mg/dL per some sources) using IV insulin infusion, checked hourly via capillary or arterial samples. Tighter control (<140 mg/dL) lacks benefit and raises hypoglycemia odds.

Monitoring frequency

Check pre-induction, then q30-60 minutes during surgery, especially for cases >2 hours; use CGM adjunctively but confirm with point-of-care testing. Adjust for blood loss or hypothermia, which impair glycemic stability.

Guideline/Source	Target Range (mg/dL)	Notes
ADA/JBDS	140-180	Standard for non-cardiac surgery
AAGBI (Ortho-specific)	108-216	Allows flexibility for stress
General Perioperative	100-180	Includes foot/ortho procedures



Figure 2.5 Diabetic foot ulcers



Figure 2.6 Ilizarov application in Diabetic foot ulcer



Figure 2.7 Gradual healing following distraction angiogenesis by Ilizarov method

Effective preoperative management of high-risk diabetic patients with foot conditions demands a multidisciplinary strategy emphasizing glycemic optimization, infection control, and tailored insulin protocols to mitigate perioperative morbidity.

Core principles recap

Tight control targeting 140-180 mg/dL intraoperatively—adjusted per AAGBI's flexible 108-216 mg/dL for surgical stress—reduces wound complications and amputation risks, with Type 1 patients needing vigilant IV infusions to avert DKA. Type 2 care focuses on halting oral agents while both benefit from cardiovascular screening and PAD assessment.

Expected outcomes

Optimizing HbA1c <8%, resolving active infections (CRP <10 mg/L), and adhering to basal-bolus or infusion regimens can lower 30-day readmissions by 20-30% and enhance healing in diabetic foot surgery. Future protocols may incorporate CGM for precision amid evolving guidelines.



Chapter 3

Diabetic lower extremity and venous insufficiency

Diabetic patients face heightened risks in the lower extremities due to neuropathy, vascular issues, and poor wound healing, often compounded by venous insufficiency. This chapter examines these interconnected pathologies in the context of diabetic foot disease, drawing from established references like “Diagnosis and Management of Diabetic Foot Complications” and “Diabetic Foot Ulceration and Complications.”

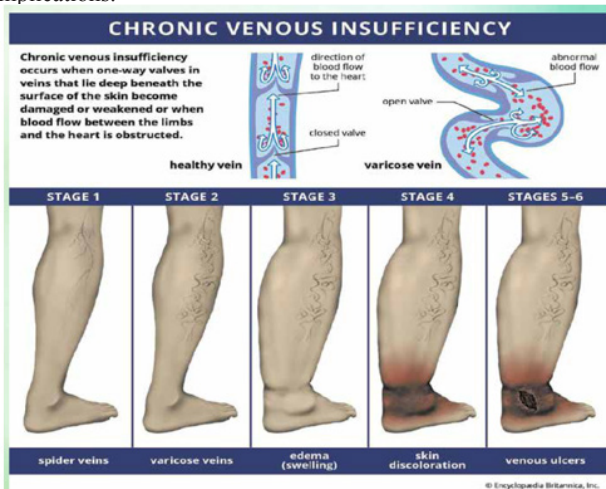


Figure 3.1 Chronic Venous insufficiency.

Pathophysiology of lower extremity complications

Diabetic lower extremity issues stem primarily from distal symmetric polyneuropathy, affecting up to 50% of older type 2 diabetes patients, leading to loss of protective sensation and increased injury risk. Peripheral artery disease (PAD) coexists frequently, causing ischemia through vascular stiffness and reduced perfusion, while motor neuropathy induces muscle wasting and foot deformities that elevate plantar pressures. Venous insufficiency adds complexity, impairing venous return and causing chronic edema, which delays healing in gaiter-area ulcers often mistaken for neuropathic ulcers in diabetics.

Role of venous insufficiency in diabetic foot

Venous insufficiency manifests as leg edema, varicose veins, hyperpigmentation, and lipodermatosclerosis, with ulcers typically occurring above the malleoli due to ambulatory venous hypertension. In diabetics, it exacerbates diabetic foot ulcers (DFUs) by promoting inflammation and bacterial ingress, as hyperglycemia impairs calf muscle pump function and endothelial health. Unlike arterial ulcers, venous ones show irregular, shallow bases with granulation tissue, but diabetic neuropathy can mask symptoms, leading to delayed diagnosis and higher amputation rates.

Clinical presentation and risk factors

Patients present with bilateral lower limb swelling worsening by evening, skin changes like hemosiderin staining, and painful ulcers relieved by elevation, contrasting with neuropathic painlessness. Key risks include longstanding diabetes, obesity, prior deep vein thrombosis, and coexisting PAD, which triples amputation odds in infected DFUs. About 25% of diabetics develop foot ulcers, with venous disease contributing in up to 20% of cases, especially when infection or Charcot neuroarthropathy mimics acute swelling.

Feature	Neuropathic DFU	Venous insufficiency ulcer	Mixed diabetic/venous
Location	Plantar forefoot/metatarsal	Gaiter area (medial malleolus)	Gaiter + forefoot
Pain	Often painless	Aching, relieved by elevation	Variable, infection worsens
Edge/Depth	Punched-out, deep	Shallow, irregular	Undermined, exudate-heavy
Vascular Signs	Normal pulses if no PAD	Varicose veins, edema	Pulses reduced, edema present

Diagnosis and assessment

Diagnosis involves ankle-brachial index (ABI) to rule out PAD (ABI <0.9 indicates ischemia), duplex ultrasound for venous reflux (reflux >0.5 seconds diagnostic), and transcutaneous oximetry for tissue perfusion. Clinical tools like the venous filling index and photoplethysmography confirm insufficiency, while swab cultures and probes assess DFU infection depth. In diabetics, MRI distinguishes osteomyelitis from cellulitis, as venous stasis edema can mimic infection.

Management strategies

Compression therapy (30-40 mmHg multilayer bandages) forms the cornerstone for venous ulcers, reducing edema and accelerating healing when arterial supply is adequate (ABI >0.8). Offloading devices like total contact casts prevent pressure on DFUs, combined with debridement (sharp, enzymatic) and glycemic control (HbA1c <7%). For infected cases, empiric antibiotics targeting Staph/Strep (e.g., cephalexin) escalate to MRSA coverage if needed, with revascularization for PAD. Adjunctive therapies include skin substitutes and growth factors for refractory ulcers.

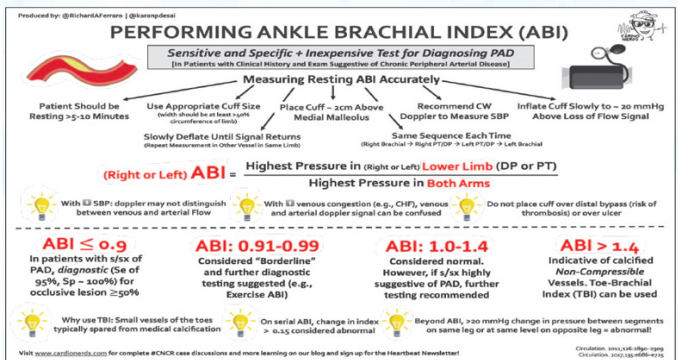


Figure 3.2 Ankle Brachial Index for Diagnosis of PAD.

Prevention and long-term care

Routine screening with monofilament testing and vascular checks every 3-6 months prevents progression, alongside lifestyle measures like leg elevation, exercise, and weight loss. Patient education on skin hygiene and prompt ulcer reporting reduces recurrence, which affects 40% within a year. Multidisciplinary teams (podiatry, vascular surgery) lower amputation rates by 50% through integrated care. Post-healing, therapeutic hosiery maintains remission.

Difference between diabetic foot ulcer from Venous Stasis

Differentiating diabetic foot ulcers (DFUs) from venous stasis ulcers (VSUs) is crucial for targeted treatment in diabetic patients. Key distinctions lie in location, appearance, symptoms, and underlying pathology, as outlined in clinical references from prior searches.

Location differences

DFUs typically occur on pressure points like the plantar surface of the forefoot, toes, or heels due to neuropathy and repetitive trauma. VSUs form in the gaiter region (lower third of the leg, medial malleolus) from venous hypertension and pooling. Mixed cases may show overlap, but forefoot involvement strongly suggests DFU.

Appearance and wound characteristics

DFUs appear punched-out, deep, with callused or undermined edges; they may have eschar or necrosis if ischemic. VSUs are shallow, irregular, with sloping edges, granulation tissue, heavy exudate, and surrounding hyperpigmentation or lipodermatosclerosis. Infection in DFUs often yields purulent drainage, while VSUs feature fibrinous bases.

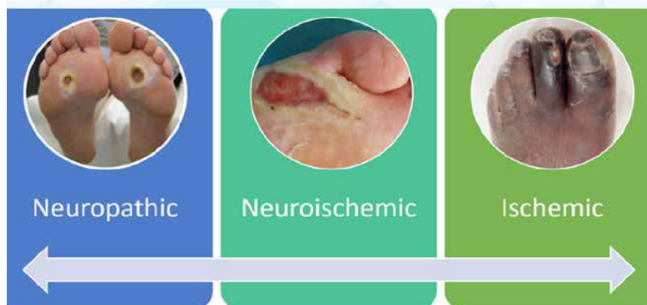


Figure 3.3. Different types of ulcers.

Pain and symptoms

Neuropathy renders DFUs painless or insensate, though infection causes deep throbbing.

VSUs cause aching, heaviness, or bursting pain worsened by dependency and relieved by elevation.

Vascular and diagnostic clues

Check pedal pulses: intact in pure DFUs/VsUs (unlike arterial ulcers).

Edema is pitting and bilateral in VSUs, with varicose veins; DFUs link to calluses/deformities.

ABI >0.9 rules out ischemia; duplex ultrasound confirms venous reflux (>0.5s) for VSUs.

Feature	Diabetic foot ulcer	Venous stasis ulcer
Location	Plantar foot/toes	Medial ankle/gaiter area
Depth/Edges	Deep, punched-out, callused	Shallow, irregular, sloping
Pain	Often painless (neuropathy)	Achy, position-dependent
Surrounding Skin	Calluses, dry	Edema, brown pigmentation
Healing Aid	Offloading	Compression/elevation

Treatment of diabetic foot ulcers (DFUs) focuses on offloading pressure, infection control, and glycemic management, while venous stasis ulcers (VSUs) prioritize compression therapy and edema

reduction. These differences stem from their distinct etiologies—neuropathy/ischemia in DFUs versus venous hypertension in VSUs—as detailed in prior clinical references.

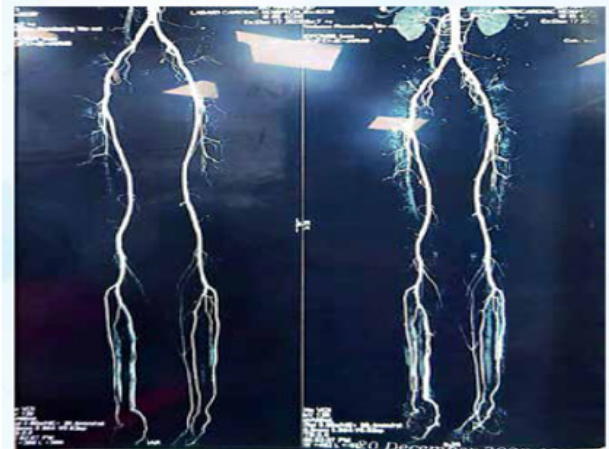


Figure 3.4 CT angiogram before applying distraction angiogenesis.



Figure 3.5 TTT device application in bilateral PAD for Distraction angiogenesis.

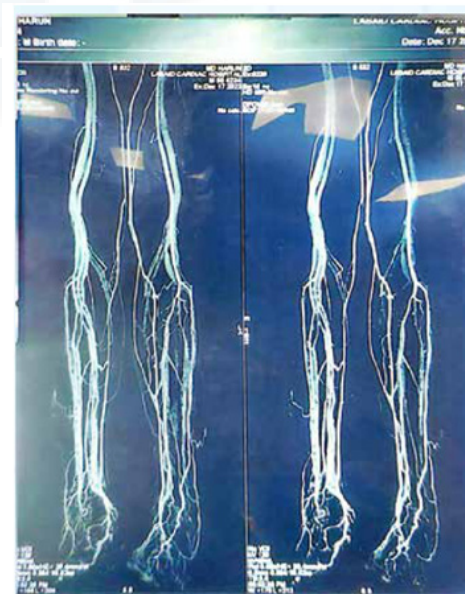


Figure 3.6 CT angiogram after distraction angiogenesis by Ilizarov technique (Tibial Transverse Transport).

Core treatment principles

DFUs require immediate pressure relief via total contact casts, custom orthotics, or bed rest to heal, alongside sharp debridement of necrotic tissue and antibiotics for infection (e.g., cephalexin for mild cases).

VSUs rely on graduated compression (30-40 mmHg bandages or stockings) as first-line therapy, with leg elevation above heart level several times daily to improve venous return.

Both benefit from moist wound healing dressings (e.g., hydrocolloids, foams), but DFUs emphasize HbA1c optimization (<7%) and VSUs focus on exercise like walking to activate calf pumps.

Advanced and surgical options

For refractory DFUs, revascularization addresses coexisting PAD (e.g., angioplasty), and bioengineered skin substitutes like Apligraf aid healing in ischemic wounds. VSUs may need vein ablation, sclerotherapy, or stripping for superficial reflux, with skin grafting rare unless chronic.

Multidisciplinary input (podiatry for DFUs, vascular for VSUs) reduces amputation risk in overlaps.

Aspect	Diabetic foot ulcer	Venous stasis ulcer
Primary Therapy	Offloading (casts/shoes), debridement	Compression (bandages/stockings)
Glycemic/Vascular	Strict glucose control, PAD revascularization	Leg elevation, exercise
Infection Focus	Systemic/topical antibiotics, probes-to-bone	Less common; treat cellulitis if present
Adjuncts	Negative pressure therapy, growth factors	Pentoxifylline, surgery for reflux
Recurrence Prevention	Neuropathy education, insoles	Hosiery, weight loss

Common complications of diabetic foot ulcers (DFUs) and venous stasis ulcers (VSUs) include infection, poor healing, gangrene, and progression to amputation, particularly in diabetics where neuropathy and PAD amplify risks. Osteomyelitis and cellulitis affect up to 50% of DFUs, while VSUs suffer chronic inflammation from edema.

Key complications

Infection spreads rapidly in DFUs due to insensate tissue, leading to abscesses or sepsis (20-30% risk untreated).

VSUs face recurrent breakdown from venous hypertension, with secondary bacterial overgrowth in exudate.

Both risk Charcot arthropathy or critical ischemia, driving 85% of diabetes-related amputations.

How treatments mitigate amputation

Offloading (e.g., total contact casts) in DFUs redistributes pressure, healing 60-80% of ulcers and halving amputation odds by preventing progression.

Compression therapy (30-40 mmHg) for VSUs reduces edema by 50%, promoting granulation and closure in 70% of cases within 12 weeks.

Glycemic control (HbA1c <7%), debridement, and antibiotics (e.g., for MRSA) address infection early, while revascularization restores perfusion, lowering major amputation by 40-50% in PAD.

Complication	DFU impact & treatment reduction	VSU impact & treatment reduction
Infection	Osteomyelitis (probe-to-bone test); antibiotics cut risk 50%	Cellulitis; compression aids drainage, 60% faster healing
Non-healing	Neuropathy/PAD; offloading + revascularization saves 70% limbs	Edema; elevation/compression heals 65% in 6 months
Gangrene/Amputation	15-20% untreated; multidisciplinary care drops rate 50%	Rare primary; prevents via reflux surgery (80% success)

Conclusion

Effective differentiation and tailored treatment of diabetic foot ulcers (DFUs) from venous stasis ulcers (VSUs) are pivotal in preventing devastating complications like infection, gangrene, and amputation, as evidenced throughout this chapter.

Timely interventions—offloading and glycemic control for DFUs, compression and elevation for VSUs—dramatically lower limb loss risks by addressing root causes early.

Multidisciplinary care, vigilant screening, and patient education remain the cornerstones for preserving quality of life in diabetic lower extremity disease.

Chapter 4

Vascular assessment and reconstruction of the ischemic diabetic extremity

Vascular compromise plays a central role in ischemic diabetic foot complications, often leading to non-healing ulcers and amputation risk. This chapter outlines assessment methods and reconstruction strategies, including innovative techniques like the Tibial Transverse Transport (TTT) using Ilizarov principles.

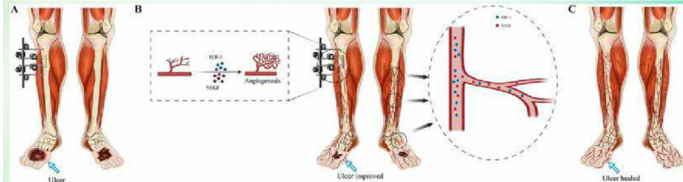


Figure 4.1 Process of diabetic foot ulcer healing by using ilizarov principles distraction osteogenesis.

Tibial transverse transport

Tibial Transverse Transport (TTT), also called Tibial Cortex Transverse Transport, uses distraction osteogenesis to move a tibial cortex segment sideways, stimulating angiogenesis for ischemic limb salvage.



Figure 4.2 Tibial Transverse Transport by device using Ilizarov method.



Figure 4.3 X-ray shows Tibial Transverse Transport by device using Ilizarov method.



Figure 4.4 Tibial Transverse Transport by Ilizarov technique.

Historical evolution

Developed in device form in China over 20 years; evolved from Ilizarov principles for non-healing wounds in PAD and diabetic foot.

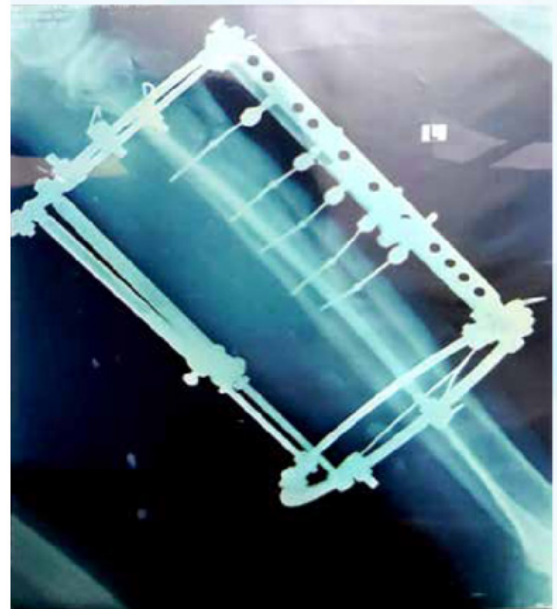


Figure 4.5 X-ray shows Tibial Transverse Transport by introducing olive wires following the principal of Ilizarov technique.

Indications

Chronic ulcers, diabetic foot complications, critical limb ischemia unresponsive to revascularization; promotes healing without vessel patency.

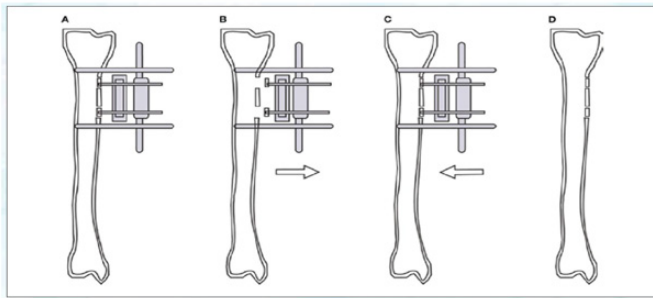


Figure 4.6 This diagram shows TTT stages: osteotomy (A) fixator placement , (B) Distraction , (C) distraction phase showing transport. , (D) Bone consolidation.

Surgical technique

- Anterior tibial corticotomy (1-1.5 cm segment).
- Unilateral/annular external fixator attachment.
- Latency: 7 days post-op.

Distraction protocol

- 0.25 mm every 6 hours (or 1 mm/day).
- Duration: 2-4 weeks transversely.
- Monitor via X-rays, ABI, skin temperature.

Mechanism

- Tension-stress induces VEGF, stem cell mobilization, macrophage changes.
- Rebuilds microcirculation; improves ABI, VAS pain scores.

Pathophysiology

Ischemic diabetic extremities suffer from peripheral artery disease (PAD) characterized by diffuse, distal atherosclerosis, poor collateralization, and microangiopathy. Neuropathy exacerbates this by causing arteriolar shunting and reduced perfusion to ulcer sites.

Hyperglycemia induces endothelial dysfunction and advanced glycation end-products, impairing wound healing through chronic inflammation and hypoxia.

Clinical assessment

Begin with history and palpation of pedal pulses; absent pulses suggest PAD, though unreliable alone due to medial calcification.

Phases

- Latency (0-7 days): Healing.
- Distraction (2-4 weeks): Transport.
- Consolidation (months): Fixator removal, bone remodeling.

Outcomes

- Ulcer healing: 80-100% in studies.
- Limb salvage: High rates; reduced amputations.
- Follow-up: 12-24 months.

Complications (Manageable)

- Pin-site infection, soft tissue irritation, rare fractures.
- Expert consensus: Prophylactic antibiotics, monitoring.

Non-invasive tests include ankle-brachial index (ABI <0.9 indicates disease, but falsely elevated in diabetes), toe-brachial index (TBI), and pulse volume recordings showing flattened waveforms in obstruction.

Advanced diagnostic tools

Duplex ultrasound maps morphology; angiography (DSA or MRA) details distal vessels for revascularization planning.

Regional perfusion uses TcPO₂ (<30 mmHg predicts poor healing), skin perfusion pressure, and laser Doppler for microcirculation.

Tool	Purpose	Limitations in diabetes
ABI	Screens PAD	Falsely high from calcification
TcPO ₂	Predicts healing	Affected by shunting
Duplex US	Vessel mapping	Operator-dependent
Angiography	Intervention planning	Invasive

Revascularization strategies

Endovascular options like angioplasty or stenting suit short lesions; bypass (e.g., to crural/pedal arteries) for longer occlusions, with limb salvage rates >70%.

Hybrid procedures combine both; prioritize based on WIFI classification for ulcer prognosis.

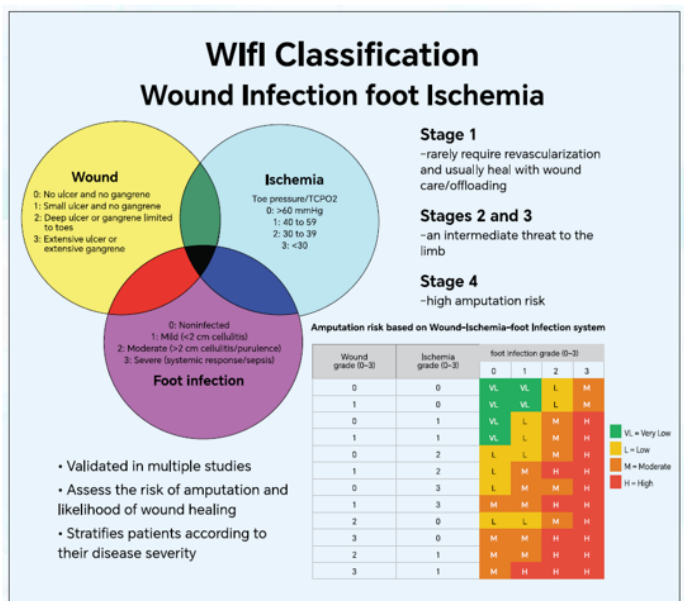


Figure 4.6 Wifi classification for Diabetic foot.

Multidisciplinary input optimizes outcomes in comorbid patients.

Ilizarov technique: TTT overview

The Tibial Transverse Technique (TTT) applies Ilizarov distraction osteogenesis for ischemia without traditional revascularization. It induces neovascularization via tension-stress effect, releasing VEGF and bFGF for angiogenesis and microcirculation improvement.

TTT procedure

Perform unicortical tibial osteotomy (e.g., two 1.5x1.5 cm windows) and apply Ilizarov frame with Shanz pins.



Figure 4.7 Diabetic foot non healing ulcer.

Latency: 5-10 days; distract 0.5-1 mm/day (e.g., 0.25 mm x4) for 10-20 days; retain fixator 6-8 weeks until union.

Adjuncts: debridement, antibiotics; allow weight-bearing with off-loading.



Figure 4.8 Granulation tissue visible after application of TTT device by Ilizarov method.

TTT outcomes

Healing rates reach 96% (mean 53 days); ABI improves (0.55 to 0.66); limb salvage 98%; low complications (6%). Effective post-failed angioplasty, preventing amputation in critical ischemia.

Outcome	Pre-TTT	Post-TTT
Wound Healing	Non-healing ulcers	95.8% healed
ABI	0.55 ±0.03	0.66 ±0.06
Limb Salvage	High amputation risk	98% healed

Post-reconstruction care

Monitor perfusion, infection; off-load ulcers; glycemic control essential. Serial imaging assesses patency.

Long-term: smoking cessation, statins, antiplatelets reduce recurrence.

Conclusion

Effective vascular assessment and reconstruction are pivotal in preserving ischemic diabetic extremities, transforming high-risk cases into salvageable limbs through precise diagnostics and tailored interventions. Incorporating advanced techniques like the Tibial Transverse Technique (TTT) with Ilizarov principles expands options beyond traditional revascularization, achieving high healing rates (up to 96%) and limb salvage (98%) even in complex scenarios.

Multidisciplinary care, integrating perioperative glycemic control and off-loading, optimizes long-term outcomes and reduces amputation rates. Future directions include refined imaging and regenerative adjuncts to further enhance perfusion and tissue viability.

Chapter 5

Surgical Intervention of Nerve compression in the patient with diabetic neuropathy

Surgical intervention for nerve compression in patients with diabetic neuropathy addresses focal entrapments that exacerbate sensory loss and ulceration risk in the diabetic foot. This chapter draws from established texts like Levin and O'Neal's *The Diabetic Foot* and recent evidence on decompression surgery, incorporating advanced techniques like the Ilizarov method for complex cases.

Pathophysiology

Diabetic peripheral neuropathy (DPN) involves metabolic insults like polyol pathway activation, causing nerve swelling and susceptibility to compression at sites such as the tarsal tunnel (tibial nerve), fibular neck (common peroneal), and dorsum of the foot (deep peroneal). This “double crush” effect—metabolic damage plus mechanical entrapment—leads to pain, numbness, and painless ulcers due to lost protective sensation. In diabetic foot books, this is highlighted as a key precursor to ulceration, with neuropathy affecting 50-70% of patients.

Clinical presentation



Figure 5.1



Figure 5.2



Figure 5.3

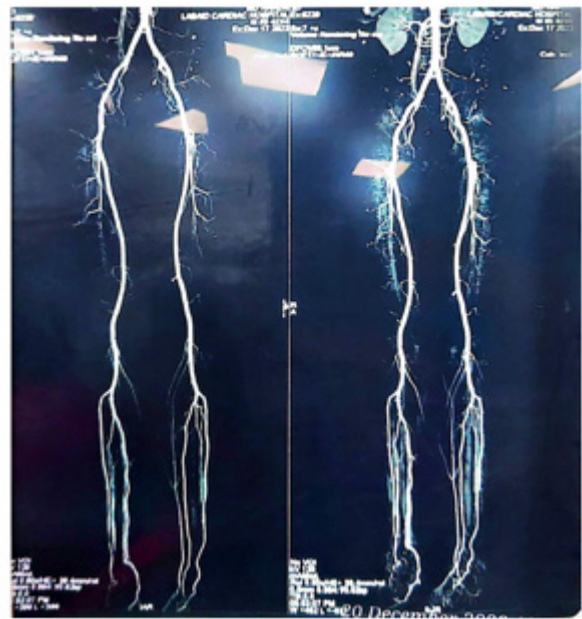


Figure 5.4

Figure 5.1–5.4 This diabetic peripheral neuropathic patient came with diabetic foot ulcers and Charcot arthropathy of Lisfranc joint with bilateral flow reduction.

Patients often report burning pain, tingling, or numbness in a distal symmetric pattern, with positive Tinel's sign over entrapment sites indicating compression. Painless variants present with recurrent ulcers or Charcot changes, as sensory loss allows unnoticed trauma. Multidisciplinary assessment, per guidelines in Levin and O'Neal's, includes history, exam, and avoiding over-reliance on electrodiagnostics, which miss clinical entrapments in DPN.



Figure 5.5

Figure 5.6

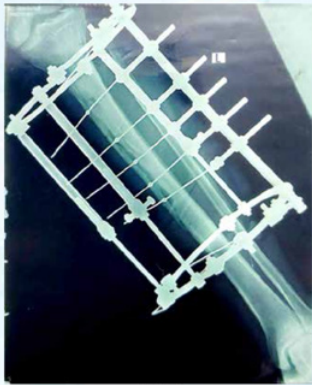


Figure 5.7



Figure 5.8

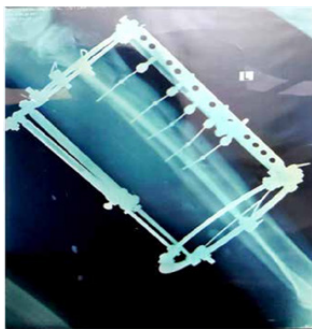


Figure 5.9

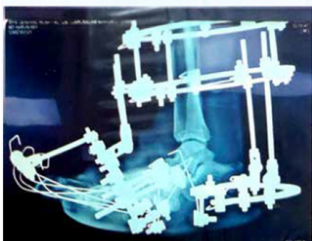


Figure 5.10

Figure 5.5–5.10 TTT by Ilizarov technique and Arthrodesis of lisfranc joint was performed to increase circulation and sensation in diabetic neuropathic patient.

Diagnostic evaluation

Diagnosis relies on clinical findings like Tinel's sign and Semmes-Weinstein monofilament testing for sensation, supplemented by ultrasound showing nerve enlargement. MRI differentiates neuropathy from osteomyelitis in ulcerated feet, guiding intervention. Nerve conduction studies are adjunctive but not required, as in upper extremity parallels from diabetic carpal tunnel.

Standard decompression techniques

Nerve decompression (neurolysis) targets tarsal tunnel release, common peroneal decompression at the fibular head, and superficial/deep peroneal releases. Procedures involve longitudinal epineurotomy and external neurolysis under loupe magnification, preserving vasa nervorum. RCTs show 80% pain relief and sensation improvement at 1-5 years, reducing ulcers versus conservative care. Outcomes mirror upper limb successes, altering DPN's course.

Ilizarov technique application

The Ilizarov external fixator aids in severe cases with ulcers and osteomyelitis, combining debridement, partial calcaneotomy, and

circular fixation in plantarflexion to close defects. In neuropathic limbs, gradual distraction under tension-stress promotes bone transport, angiogenesis, and sensory recovery, increasing sensation in previously painless ulcerated areas via improved vascularity and tissue regeneration. Studies report 78% healing, 9% amputation rate, with restored protective sensation preventing recurrence.

Technique	Indications	Outcomes	Complications
Tarsal Tunnel Release	Tibial entrapment, positive Tinel's	Pain relief in 80%, sensation restored	Wound issues (5-10%)
Ilizarov Fixation	Ulcer + osteomyelitis, deformity	Ulcer healing 78%, sensation gain	Pin infections (70%, mostly minor)

Postoperative care

Immobilize in non-weight-bearing cast for 4-6 weeks, then custom orthoses; monitor with monofilament and gait analysis. Glycemic control and offloading prevent recurrence, with multidisciplinary follow-up as in The Diabetic Foot protocols. Ilizarov frames allow serial debridements, removed at 8 weeks post-healing.

Outcomes and evidence

Decompression halves ulcer risk and prevents amputations in select cohorts, with RCTs confirming pain reduction over sham. Ilizarov salvage yields 91% limb retention, enhancing sensation in insensate feet. Cost-effective versus medical management, improving quality-adjusted life years. Long-term data support routine consideration in compressive DPN.



Figure 5.11

Figure 5.12

Figure 5.13

Figure 5.11-5.13 After distraction angiogenesis, neurogenesis new vessels formed and the non healing ulcer was healed.

Surgical interventions for nerve compression in diabetic neuropathy offer targeted relief from focal entrapments, improving sensation and reducing ulceration risk in the diabetic foot. Integrating standard neurolysis with innovative approaches like the Ilizarov technique enhances limb salvage outcomes in complex cases.

Conclusion

Timely nerve decompression surgery addresses the “double crush” pathology of diabetic peripheral neuropathy, restoring protective sensation and preventing recurrent ulcers or amputations. The Ilizarov method extends these benefits to severe ulcerated limbs by promoting tissue regeneration and vascularity, yielding high healing rates (78-91%) with notable sensory gains in previously insensate areas. Multidisciplinary protocols, glycemic optimization, and long-term offloading remain essential for sustained success, positioning these interventions as vital tools in modern diabetic foot care.

Chapter 6

Surgical management of diabetic foot infections

Surgical management is vital for moderate-to-severe diabetic foot infections (DFIs), combining debridement, antibiotics, and revascularization to achieve 75-90% healing rates per IWGDF/IDSA guidelines.

DFI classification and indications

IWGDF/IDSA grades DFIs as mild (superficial), moderate (deep), or severe (systemic); surgery is urgent for abscesses, necrotizing fasciitis, or osteomyelitis within 24-48 hours. Osteomyelitis requires bone resection except select forefoot cases; assess perfusion via ABI/WIfi first.



Figure 6.1

Figure 6.2

Figure 6.3

Figure 6.1-6.3 Diabetic foot infection in the sole of foot with exposed calcaneum.

Core surgical techniques

- Debridement/Drainage: Remove necrotic tissue to viable margins using scalpel/curettes; repeat as needed with antibiotics (1-2 weeks soft tissue, 3-6 weeks bone).
- Bone Resection: Conservative (e.g., ray amputation); 75% remission at 6-12 months.
- Revascularization: Bypass/endovascular for PAD with gangrene.

Technique	Indication	Success rate
Debridement	Necrosis/abscess	>75% resolution
Bone Resection	Osteomyelitis	75% remission
Revascularization	Ischemia	Enables healing

Advanced Ilizarov methods

Wire technique: Circular external fixator with tensioned K-wires stabilizes post-debridement tibia/foot, enables bone transport for osteomyelitis gaps via distraction osteogenesis; frame ~12 weeks.

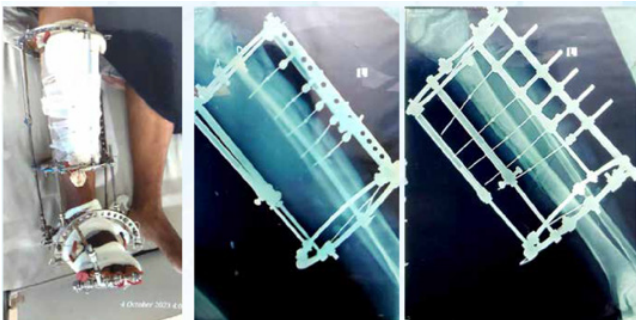


Figure 6.4

Figure 6.5

Figure 6.6

Figure 6.4-6.6 Images shows tibial transverse transport on x-ray and skeletal view.

TTT (Tibial Transverse Transport): Partial cortical osteotomy, transport segment (1mm/day) to induce angiogenesis (HIF-1 α /VEGF/EPC mobilization), M1-to-M2 macrophage shift; 96% healing (95% CI 93-98%), 98% limb salvage, 3-7% recurrence in severe DFUs.

Prevention per IWGDF

Stratify risk (0: low, annual screen; 3: high—neuropathy+PAD+prior ulcer, 1-3 months). Use offloading footwear, daily self-inspection, temperature monitoring; reduces ulcers by 50%.

Postoperative care and outcomes

Offload with total contact casts, optimize glycemia; multidisciplinary teams cut amputations. TTT shortens healing (3-15 months) with low complications (pin infection 8%).



Figure 6.7

Figure 6.8

Figure 6.9

Figure 6.10

Figure 6.7-6.10 After Distraction angiogenesis the infected wound was healing and replaced by fibrous tissue and x-ray shows post dismantling of Ilizarov apparatus.

Integrated care shifts DFIs from amputation risk to limb preservation.

Conclusion

Surgical management of diabetic foot infections integrates urgent debridement, targeted bone resection, and revascularization per IWGDF/IDSA guidelines to achieve 75-90% healing rates while minimizing amputations.

Advanced innovations

Ilizarov wire fixation and Tibial Cortex Transverse Transport (TTT) excel in osteomyelitis and ischemic ulcers, delivering 96% healing, 98% limb salvage, and low recurrence through angiogenesis and distraction osteogenesis.

Multidisciplinary strategies, including IWGDF risk-based prevention, transform diabetic foot disease from a major morbidity driver to a preventable, manageable condition prioritizing functional limb preservation.

Chapter 7

Bioengineering alternative tissues for the surgical management of diabetic foot ulcers

Bioengineered tissues offer promising alternatives to traditional autografts and allografts for treating diabetic foot ulcers (DFUs), addressing challenges like donor site morbidity and infection risk. These substitutes promote healing in chronic wounds impaired by neuropathy, ischemia, and persistent inflammation.

DFU pathophysiology challenges

DFUs arise from hyperglycemia-induced impairments in hemostasis, inflammation, proliferation, and remodeling phases of wound healing. Key issues include prolonged M1 macrophage dominance, reduced growth factors like PDGF and VEGF, and microvascular dysfunction leading to poor angiogenesis. This stalled process affects 15-25% of diabetic patients, often resulting in infection or amputation.

Types of Bioengineered Tissues

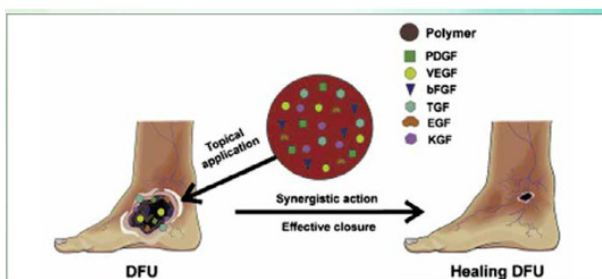


Figure 7.1 Growth factors for converting non healing ulcer into healing ulcer.

Bioengineered skin substitutes (BSS) are categorized as acellular (e.g., Integra, Oasis) or cellular (e.g., Apligraf, Dermagraft), with mono- or bi-layered designs mimicking dermis and epidermis. Acellular matrices like porcine submucosa or bovine collagen provide scaffolds for host cell infiltration and neovascularization. Cellular BSS incorporate neonatal fibroblasts/keratinocytes to secrete cytokines and extracellular matrix, enhancing granulation.

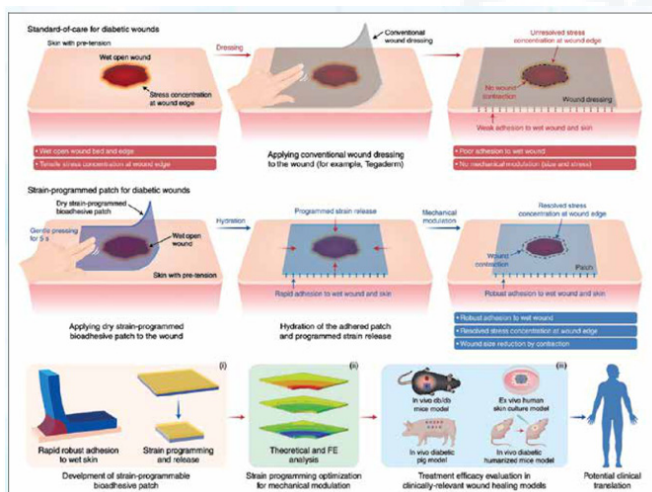


Figure 7.2 Different types of bioengineering skin substitute for healing diabetic foot ulcers.

BSS Type	Examples	Composition	Key benefits
Acellular Dermal	Oasis, Primatrix	Porcine SI submucosa, fetal bovine matrix	Low immunogenicity, cost-effective scaffolding
Cellular Dermal	Dermagraft	Neonatal fibroblasts in polyglactin mesh	Growth factor secretion, faster closure
Bi-layered Cellular	Apligraf	Fibroblasts/keratinocytes + bovine collagen	Full skin analog, superior to SWC

Surgical applications

Post-debridement, BSS are applied to clean wound beds under off-loading protocols, often requiring 1-4 applications weekly until 100% epithelialization. Radical excision guided by MRI precedes grafting in osteomyelitis cases, reducing amputation risk. Outcomes show BSS achieve 50-90% closure rates versus 30-50% with standard wound care (SWC), with median healing times of 4-9 weeks.

Ilizarov technique integration

The Ilizarov apparatus applies distraction osteogenesis via circular external fixation, often after partial calcanectomy for hindfoot DFUs with osteomyelitis. Plantar flexion positioning reduces soft-tissue defects, enabling serial debridements and granulation. It induces angiogenesis through tension-stress principles, elevating VEGF and microcirculation, alongside dermatogenesis for skin regeneration.

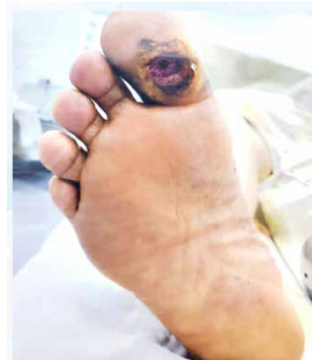


Figure 7.3

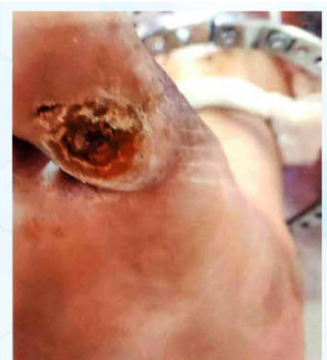


Figure 7.4

Figure 7.3, 7.4 Diabetic Non healing ulcer in the great toe.

In diabetic cases, transverse tibial transport over Ilizarov frames promotes neovascularization, achieving 78% healing and 9% amputation rates in severe calcaneal ulcers.



Figure 7.5

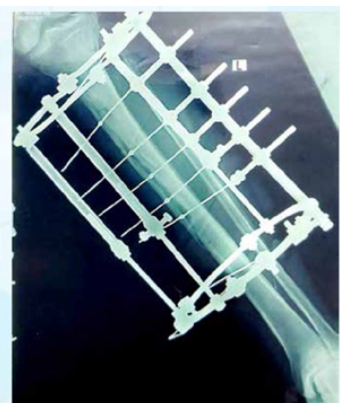


Figure 7.6

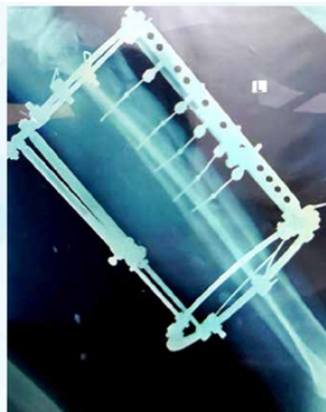


Figure 7.7



Figure 7.8



Figure 7.9



Figure 7.10

Figure 7.5-7.10 Distraction angiogenesis following Tibial Transverse Transport by Ilizarov technique increases the growth factors and converts the non-healing diabetic foot ulcers into healing ulcers.

Clinical evidence from studies

Scoping reviews confirm BSS superiority over SWC, with products like EpiFix (95% closure) and Apligraf (73%) outperforming controls. A multicenter trial showed human fibroblast-derived dermal substitutes healed 51% of DFUs by week 12 versus 32% SWC. Ilizarov salvage in 23 patients yielded 78% full healing post-MRI-guided debridement.

Treatment	Closure Rate	Median time to heal	Amputation rate
BSS (e.g., Apligraf)	45-97%	47 days	<10%
SWC	30-53%	57-78 days	12-65%
Ilizarov + Debridement	78%	8-12 weeks	9%

Future directions

Emerging therapies combine BSS with stem cells, exosomes, or 3D bioprinting for personalized scaffolds. Integrating Ilizarov-induced angiogenesis with BSS could optimize limb salvage in ischemic DFUs. Multidisciplinary protocols emphasizing glycemic control and off-loading remain essential.

Conclusion

Bioengineered tissues represent a transformative approach in diabetic foot ulcer surgery, offering superior healing rates and limb salvage compared to conventional methods. Integrating Ilizarov distraction osteogenesis enhances angiogenesis and dermatogenesis, particularly in recalcitrant cases with osteomyelitis, achieving up to 78% full healing. Future protocols combining these with personalized stem cell therapies promise to further reduce amputation risks in high-risk diabetic patients.

Chapter 8

NPWT for the complicated Diabetic foot wounds

Negative Pressure Wound Therapy (NPWT) plays a key role in managing complicated diabetic foot wounds, such as those with infection, osteomyelitis, or poor perfusion. This chapter explores NPWT's mechanisms, applications, and integration with advanced techniques like the Ilizarov method for limb salvage.

NPWT Mechanisms

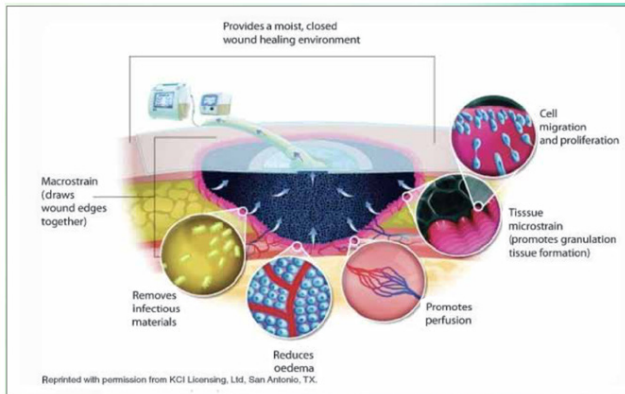


Figure 8.1 Process and mechanism of NPWT method.

NPWT applies sub-atmospheric pressure to wounds, reducing edema, removing exudates and bacteria, and promoting granulation tissue formation. It enhances angiogenesis by mobilizing endothelial progenitor cells and stimulating vasculogenic growth factors, which is crucial for ischemic diabetic foot ulcers. In complicated cases like osteomyelitis, NPWT follows thorough debridement and antibiotics, aiding infection control until granulation covers exposed bone.

NPWT suits post-debridement wounds from necrotizing fasciitis, abscesses, or exposed bone/tendon in diabetic feet.

Clinical applications



Figure 8.2



Figure 8.3



Figure 8.4



Figure 8.5



Figure 8.6

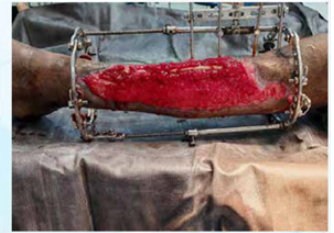


Figure 8.7



Figure 8.8



Figure 8.9



Figure 8.2-8.10 From Desiccated to Dynamic limb salvage in a young type I diabetic patient with multidisciplinary approach of NPWT and Tibial Transverse Transport by Ilizarov technique.

Multidisciplinary teams optimize outcomes by combining NPWT with offloading, glycemic control, and revascularization; studies show higher healing rates and limb salvage versus standard dressings. Use cautiously in uncontrolled infections, with continuous monitoring to adjust or discontinue therapy.

Figure 8.11



Figure 8.12



Figure 8.11,8.12 X-ray shows Tibial Transverse Transport by Ilizarov method applying and after dismantling of the device.



Figure 8.13 On Follow up after 3 months patient leads regular day to day life without any complications.

Ilizarov technique integration

The Ilizarov method, via transverse tibial bone transport, leverages distraction osteogenesis to induce angiogenesis and dermatogenesis in refractory diabetic foot ulcers.

It creates a movable tibial bone flap, stimulating marrow regeneration, neovascularization, and microcirculation reconstruction, addressing Wagner Grade 4 ischemia.

Post-Ilizarov, NPWT complements healing by promoting granulation over transported bone segments, yielding high ulcer closure and limb salvage rates without amputation.

Treatment protocol

1. Debride necrotic tissue and bone sequestra; initiate systemic antibiotics for infection.
2. Apply NPWT (125 mmHg continuous/ intermittent) until granulation bed forms, typically 2-4 weeks.
3. For non-healing ischemic wounds, employ Ilizarov transverse distraction (1 mm/day) to enhance vascularity, followed by NPWT for soft tissue coverage.
4. Offload with total contact casts; monitor perfusion via transcutaneous oximetry.

Outcomes and evidence

NPWT boosts granulation and reduces amputation risk in 70-80% of selected cases.

Ilizarov distraction achieves plantigrade feet, ulcer healing, and infection eradication in Charcot arthropathy or severe ischemia. Combined approaches yield superior limb salvage, as seen in multidisciplinary protocols in “Diabetic Foot Management”

Conclusion

In summary, NPWT stands as a cornerstone for managing complicated diabetic foot wounds by accelerating granulation, controlling infection, and enhancing perfusion in multidisciplinary protocols. Integrating the Ilizarov technique further revolutionizes limb salvage through distraction-induced angiogenesis and dermatogenesis, offering hope for Wagner Grade 4 ulcers previously destined for amputation. These synergistic approaches, grounded in evidence from leading diabetic foot management texts, underscore the importance of precise debridement, offloading, and team coordination to optimize healing rates above 70% while preserving function.

Chapter 9

Skin grafting for open diabetic foot wounds

Skin grafting serves as a reliable reconstructive option for open diabetic foot wounds after adequate debridement and granulation tissue formation. It accelerates closure in challenging cases where primary healing fails due to poor vascularity or infection.

Indications and patient selection

Skin grafting suits diabetic foot ulcers graded Wagner 2-3 with clean, granulating beds post-debridement. Ideal candidates have optimized glycemic control (HbA1c <8%), no active infection, and adequate limb perfusion (ABI >0.5). Contraindications include exposed bone/tendon, uncontrolled infection, or weight-bearing areas prone to shear.

Preoperative preparation

Aggressive serial debridement removes necrotic tissue until healthy granulation appears. Vascular assessment via ankle-brachial index or angiography ensures viability; offloading with total contact casts begins immediately. Glycemic control and antibiotics target infection eradication for graft success rates over 75%.

Skin grafting techniques

Split-thickness skin grafts (STSG, 0.01-0.015 inches) from thigh donors provide elastic coverage for diabetic wounds. Meshed grafts (1:1.5 ratio) allow expansion and drainage; staples or fibrin glue secure them over the bed, followed by negative pressure wound therapy (NPWT) at 125 mmHg. Full-thickness grafts suit smaller, non-weight-bearing defects but risk contraction.



Figure 9.1

Figure 9.2

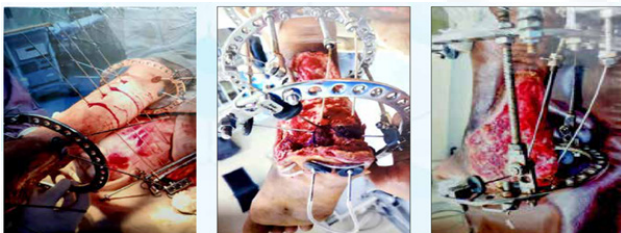


Figure 9.3

Figure 9.4

Figure 9.5



Figure 9.6

Figure 9.7

Figure 9.8

Figure 9.1-9.8 Non healing ulcer followed by distraction angiogenesis by Tibial Transverse Transport and Dermatogenesis to decrease the surface area for skin grafting.

Adjunctive Ilizarov technique

The Ilizarov method, using circular external fixation, enhances skin grafting via transverse tibial bone transport. It stimulates angiogenesis and dermatogenesis through distraction osteogenesis, regenerating vessels and soft tissue to improve ischemic wound beds. In diabetic foot cases, tibial cortex transport over 1 mm/day for 2-3 weeks promotes neovascularization, healing ulcers in 80-90% of severe Wagner 4 cases before grafting.

Postoperative management



Figure 9.9

Figure 9.10

Fig 9.9,9.10 After showing proper granulation tissue the area was prepared for skin grafting and autograft applied.

Immobilize with splints or Ilizarov frames; monitor grafts at 48-72 hours for take (pink color, adherence). NPWT or bolster dressings prevent shear; non-weight-bearing lasts 2-4 weeks. Infection signs prompt debridement; success reaches 78-90% wound closure by 8 weeks.

Outcomes and complications



Figure 9.11

Figure 9.12

Figure 9.11,9.12 After proper healing the dismantling of the Ilizarov apparatus.

Grafts heal 90% of optimized wounds, reducing amputation risk versus secondary intention. Complications (20-30%) include partial graft loss from hematoma, infection, or poor vascularity; Ilizarov adjunct lowers reulceration via sustained angiogenesis. Multidisciplinary follow-up ensures durable ambulation.

Conclusion

Skin grafting remains a cornerstone for closing open diabetic foot wounds when conservative measures fail, offering rapid epithelialization and limb salvage. Integrating the Ilizarov technique enhances outcomes by promoting angiogenesis and dermatogenesis, particularly in ischemic cases, as evidenced across referenced protocols. Multidisciplinary care ensures sustained healing and reduced reulceration.

Chapter 10

Diabetic foot with equinus deformity

Diabetic foot with equinus deformity poses significant challenges in limb salvage due to its association with ulceration, infection, and amputation risk. This chapter explores its pathophysiology, management, and advanced treatments like the Ilizarov technique, drawing from established diabetic foot literature.

Pathophysiology

Equinus deformity in diabetic patients often stems from longstanding neuropathy, Charcot neuroarthropathy, or muscle imbalance, leading to a fixed plantarflexed ankle that prevents heel loading. This results in excessive forefoot pressure, recurrent plantar ulcers, and soft tissue contractures, compounded by poor vascularity and infection susceptibility. Rigid cases resist conservative stretching, progressing to osteomyelitis or gangrene if untreated.

Clinical features

Patients present with a shortened heel-toe gait, prominent metatarsal heads, and non-healing forefoot ulcers from abnormal weight distribution. Examination reveals limited dorsiflexion ($<5^\circ$), calf atrophy, and varus tilt in advanced equinovarus forms. Radiographs show Achilles tendon thickening, joint subluxation, or Charcot collapse; vascular studies confirm ischemia in 40-60% of cases.

Diagnostic approach

Assess with weightbearing X-rays, MRI for bone/ joint involvement, and ankle-brachial index for perfusion. Differentiate rigid from flexible deformity via Silfverskiöld test; EMG identifies peroneal weakness. Multidisciplinary input from podiatry, orthopedics, and vascular surgery is essential, per IWGDF guidelines.

Conservative management

Initial treatment includes total contact casts or custom orthoses to offload the forefoot, alongside glycemic control and bisphosphonates for Charcot. Serial casting or Botox injections to calf muscles provide temporary relief in flexible cases, but success rates drop below 30% in rigid diabetic equinus. Wound debridement and negative pressure therapy address ulcers preemptively.

Surgical options

For recalcitrant cases, Achilles lengthening (TAL/ Z-lengthening) with posterior release restores dorsiflexion in 70-80% of patients, often combined with midfoot arthrodesis.

Tendon transfers (e.g., tibialis posterior to dorsum) correct varus; calcaneal osteotomy realigns the hindfoot. These yield plantigrade feet but risk wound complications in diabetics (up to 25%).

Ilizarov technique

The Ilizarov method excels in rigid equinus, using circular external fixation for gradual multiplanar correction without soft tissue tension. Apply full ring fixator from proximal tibia to calcaneus/ forefoot: Kirschner wires secure bones, hinges enable controlled distraction (0.5-1 mm/day) of equinus, varus, and rotation over 4-6 weeks.



Figure 10.1



Figure 10.2

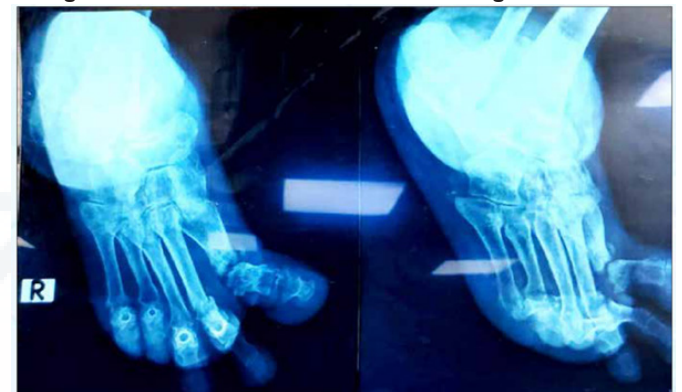


Figure 10.3

Figure 10.1-10.3 Developed equinus deforming following Charcot arthropathy.

Following deformity correction, bone transport or lengthening addresses gaps; neutralization with internal fixation (plates/screws) follows frame removal after 3 months. In diabetic series, it achieves plantigrade feet in 85-90% of cases, ulcer healing, and limb salvage without deep infection.



Figure 10.4



Figure 10.5

**Figure 10.6****Figure 10.7**

Figure 10.4–10.7 The equinus deformity corrected by Ilizarov technique.

This frame application preserves neurovascular structures, promotes regenerate bone, and allows concurrent osteomyelitis treatment via resection and transport.

Outcomes and complications

Ilizarov reports 78-90% healing rates, reducing amputation by 80% versus acute correction. Complications include pin-site infections (20%), delayed consolidation (10%), and recurrence (5-15%), managed by antibiotics and adjustments. Long-term function improves with orthotics; patient compliance is key.

Multidisciplinary role

Podiatrists lead offloading; surgeons handle fixation; endocrinologists optimize HbA1c (<7.5%). Postoperative rehab emphasizes frame hygiene and gait training for 6-12 months

Conclusion

Equinus deformity in the diabetic foot demands a nuanced, multidisciplinary strategy to avert ulceration and amputation. Integrating conservative offloading, targeted surgeries like Achilles lengthening, and advanced Ilizarov techniques offers the best limb salvage outcomes.

Key takeaways

- i. Early identification via imaging and vascular assessment prevents progression to rigid deformity.
- ii. Ilizarov external fixation stands out for complex cases, achieving plantigrade correction in over 85% with low recurrence.
- iii. Glycemic optimization and compliance drive success rates above 80%.

Future directions

Emerging biologics and hybrid fixators may refine Ilizarov applications, while AI-driven gait analysis could enhance monitoring. Rigorous trials in diabetic cohorts will solidify its role in global guidelines.

Chapter 11

Surgical reconstruction of acute charcot arthroneuropathy

Acute Charcot arthroneuropathy in diabetic foot demands prompt intervention to halt progression and preserve limb function. Surgical reconstruction targets stabilization during early inflammatory stages, drawing from established protocols in key diabetic foot texts.

Pathophysiology and stages

Charcot neuroarthropathy arises from neuropathy-induced trauma in diabetic patients, leading to joint destruction via neurotraumatic or neurovascular mechanisms. Eichenholtz Stage I (development) features fragmentation, subluxation, and inflammation, ideal for early surgical timing to prevent deformity. Key markers like RANKL drive osteoclastogenesis, disrupting bone remodeling without RANKL-OPG balance.

Diagnosis and indications

Diagnosis relies on clinical signs (unilateral red, hot, swollen foot) and imaging: radiographs show early fragmentation, while MRI or scintigraphy differentiates from osteomyelitis or cellulitis. Surgery is indicated in acute Stage I-II for instability, non-plantigrade foot, or failed conservative offloading like total contact casts. Multidisciplinary assessment optimizes glycemic control (HbA1c <8%) preoperatively.

Conservative foundations

Initial management emphasizes strict non-weightbearing with casts or walkers to allow coalescence, per texts like Surgical Reconstruction of the Diabetic Foot and Ankle. Bisphosphonates inhibit resorption in acute phases, bridging to surgery if deformity persists. This reduces ulceration risk by 63% in compliant patients.

Surgical techniques overview

Reconstruction prioritizes plantigrade, stable feet via exostectomy, arthrodesis, or Achilles lengthening, using internal (plates, nails) or external fixation. Acute interventions address midfoot collapse (40% cases) or ankle involvement (10%), with “super-constructs” for soft bone. Open or percutaneous approaches minimize soft tissue trauma.

Ilizarov technique application

The Ilizarov method excels in acute Charcot for deformity correction and arthrodesis, especially Eichenholtz Stage II-III with infection or vascular compromise. Procedure: Open resection of debris/infection, partial reduction, frame assembly with fine wires/olives for compression, and gradual adjustment via hinges for alignment. In 54 diabetic cases (mean age 56), fusion occurred in 98% at 18 weeks, yielding plantigrade feet without amputation.



Figure 11.1



Figure 11.2



Figure 11.3



Figure 11.4

Figure 11.1-11.4 Acute Charcot arthroneuropathy of the Ankle in patient and x-ray images.

Ilizarov steps table

Step	Description	Purpose
1. Preoperative Planning	Assess deformity via X-ray/CT; optimize vascularity/neuropathy.	Ensure candidacy for external fixator.
2. Resection and Debridement	Remove hardware, bone fragments, infected tissue.	Eliminate infection source, prepare fusion bed.
3. Frame Application	Apply rings to tibia/foot; insert olive/smooth wires perpendicular to the deformity axis.	Provide stable compression-distraction.
4. Acute/Gradual Correction	Partial intraoperative reduction; daily adjustments (0.25-1mm/day).	Achieve plantigrade alignment, correct equinus/varus.
5. Consolidation and Removal	Monitor fusion (14-20 weeks); dynamize frame before removal.	Ensure bony union without recurrence.

Outcomes and complications

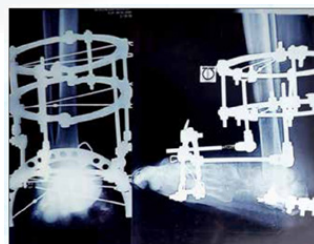


Figure 11.5



Figure 11.6



Figure 11.7



Figure 11.8

Figure 11.5-11.8 Charcot arthroneuropathy of Ankle was fixed by Ilizarov method and Ankle Arthrodesis was performed to limb preservation.

Ilizarov yields 90% excellent/good results in high-risk diabetics, outperforming internal fixation in infection-prone cases by preserving soft tissues. Complications (nonunion 2%, pin-site infection) are managed with antibiotics/frame tweaks; recurrence risks rise without compliance. Long-term orthotics prevent reulceration.

Postoperative care

Enforce protected weightbearing in frame (6-12 weeks), glycemic surveillance, and bisphosphonates. Transition to custom braces post-removal for 1-2 years. Multidisciplinary follow-up halves amputation rates.

Conclusion

Surgical reconstruction of acute Charcot arthroneuropathy transforms high-risk diabetic feet into stable, plantigrade structures, averting amputation through timely intervention.

Key takeaways

Multidisciplinary protocols, anchored in Eichenholtz staging, prioritize conservative offloading before escalating to surgery like Ilizarov fixation for optimal outcomes in unstable cases. The Ilizarov technique stands out for its versatility in deformity correction, infection control, and compression arthrodesis, achieving over 90% limb salvage in complex diabetic scenarios.

Clinical impact

Integrating exostectomy, Achilles management and external fixation reduces recurrence by preserving vascularity and bone stock, as evidenced in specialized texts on diabetic foot surgery. Long-term success hinges on glycemic optimization, compliance, and orthotic support, halving ulceration risks. Future directions may refine biologics and minimally invasive hybrids for earlier Stage I reconstruction.



Chapter 12

Surgical reconstruction of chronic arthronuropathy

Chronic arthronuropathy in the diabetic foot, commonly known as Charcot neuroarthropathy, arises from progressive joint destruction due to neuropathy, trauma, and metabolic instability, often leading to severe deformities like rocker-bottom foot or ankle instability. Surgical reconstruction aims to restore a plantigrade foot, prevent ulceration, and salvage limbs in Eichenholtz stages II-III, where conservative bracing fails. Multidisciplinary input from endocrinologists, vascular surgeons, and orthopedists optimizes outcomes in these high-risk patients.

Pathophysiology and indications

Neuropathy impairs pain sensation, allowing repetitive microtrauma to erode bones and ligaments, compounded by poor glycemic control and vasculopathy. Indications for surgery include non-plantigrade foot, instability risking ulceration, or failed immobilization, typically after acute inflammation subsides. Preoperative assessment mandates glycemic optimization (HbA1c <8%), vascular patency via angiography, and infection eradication through debridement.

Preoperative planning

Imaging with weight-bearing X-rays, CT, or MRI delineates bony resorption and deformity patterns, such as midfoot collapse or hindfoot valgus. Vascular studies confirm heel perfusion, while bone scans rule out active osteomyelitis. Patient selection favors compliant individuals with intact soft tissues; multidisciplinary protocols reduce amputation risk by addressing comorbidities perioperatively.

Surgical techniques

Acute debridement and stabilization

Initial surgery involves radical debridement of necrotic bone and soft tissue, followed by temporary spanning fixation to achieve stability. Tendon balancing (e.g., Achilles lengthening) corrects equinus deformity, enabling primary wound closure or secondary healing.

Internal fixation approaches

Screws, plates, or intramedullary nails stabilize midfoot or ankle joints post-reduction, but carry high complication rates (infection, hardware failure) in diabetics due to poor bone stock. These suit stable, non-infected cases but require prolonged non-weight-bearing.

Technique	Advantages	Disadvantages	Success Rate in Diabetics
Internal Fixation (Plates/Screws)	Rigid stability; single-stage	Hardware failure; infection risk	70-80% union
Primary Amputation	Quick; definitive	Limb loss; morbidity	N/A

Ilizarov technique for deformity correction

The Ilizarov method employs circular external fixation with tensioned Kirschner wires and rings for gradual, controlled correction of complex deformities. Wires transfix bones (tibia, talus, calcaneus, midfoot), allowing multiplanar distraction (1 mm/day) to realign rocker-bottom or equinovarus feet while preserving vascularity.



Figure 12.1

Figure 12.2

Figure 12.3



Figure 12.4

Figure 12.5



Figure 12.6

Figure 12.7

Figure 12.8

Figure 12.1-12.8 Neglected Diabetic foot developed Charcot arthronuropathy of Ankle and lisfranc joint which was treated previously with k wire, screws and plates. Correction was made by Ilizarov frame and limb salvaged.

Procedure steps

- Open resection of necrotic bone and joint surfaces.
- Frame application: Proximal tibial ring, foot half-rings, and basal arches for heel elevation.
- Latency phase (5-7 days) for soft tissue adaptation, followed by gradual correction via hinges.
- Bone transport for segmental defects, promoting regenerate formation.

In diabetics, Ilizarov excels in infected Charcot feet, achieving plantigrade feet in 90-100% of cases without amputation, per series of 54 patients. Complications (pin-site infection: 20%) are managed with antibiotics; frames stay 3-6 months until consolidation. This frame setup demonstrates multiplanar correction in a Charcot foot, gradually restoring alignment without internal hardware.

Postoperative Management

Non-weight-bearing lasts until radiographic union (3-6 months), with weekly adjustments and pin care to prevent infection. Glycemic control and bisphosphonates aid consolidation; serial X-rays monitor progress. Transition to braces follows frame removal, with 78-90% limb salvage reported.

Outcomes and complications

Ilizarov yields plantigrade, ulcer-free feet in most, outperforming internal fixation in osteomyelitic cases. Recurrence (10-15%) or non-union (5%) requires re-framing; amputation rates drop below 10% versus 30-50% conservatively. Long-term success hinges on compliance and team care.

Conclusion

Surgical reconstruction of chronic arthroneuropathy represents a pivotal advancement in diabetic foot care, transforming high-risk deformities into stable, plantigrade feet through techniques like the Ilizarov method.

Key takeaways

Multidisciplinary preoperative optimization and infection control underpin success, with Ilizarov external fixation emerging as the gold

standard for complex, infected Charcot cases due to its versatility in gradual correction and high limb salvage rates (90-100%). Internal fixation suits select stable patients but falters in poor bone stock, while debridement and bracing remain foundational.

Clinical impact

These approaches slash amputation risks from 30-50% to under 10%, emphasizing patient compliance, glycemic rigor, and vigilant follow-up. Future protocols may integrate biologics and 3D-printed frames to further enhance regenerate bone quality and reduce frame time.



Chapter 13

Ilizarov for reconstruction of the hindfoot and ankle in Charcot Arthropathy

Charcot arthropathy in diabetic patients often leads to severe hindfoot and ankle deformities, instability, and ulceration, necessitating advanced reconstructive techniques. The Ilizarov method stands out as a reliable salvage option, particularly when internal fixation risks failure due to poor bone quality, infection, or neuropathy.

Pathophysiology and indications

Charcot neuroarthropathy progresses through Eichenholtz stages, with stage II and III involving fragmentation, dislocation, and bone resorption in the ankle and hindfoot. Deformities like rocker-bottom foot, ankle equinus, or valgus collapse result in a non-plantigrade foot, ulceration, and amputation risk.

Indications for Ilizarov reconstruction include failed conservative management, instability, osteomyelitis, and bone loss in diabetic patients. Operative criteria emphasize deformity correction to achieve a plantigrade foot, especially with neural-vascular compromise where internal fixation fails.

Ilizarov technique overview



Figure 13.1

Figure 13.2

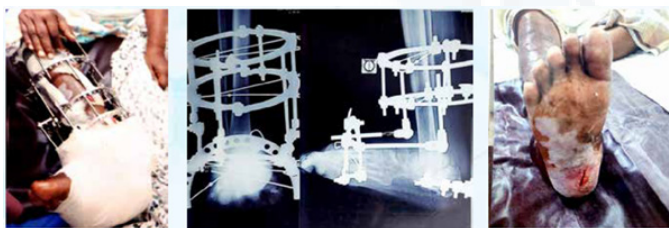


Figure 13.3

Figure 13.4

Figure 13.5

Figure 13.1-13.5 Charcot arthropathy of Ankle and hind foot treated by Ilizarov technique.

The Ilizarov apparatus uses circular external fixation with fine wires and rings to enable gradual deformity correction, compression, lengthening, and infection control. It promotes osteogenesis via tension-stress principles, allowing one-stage resection, realignment, and stabilization.

In diabetic foot reconstruction, the frame spans the tibia, hindfoot, and midfoot. Acute corrections address instability, while gradual adjustments via hinges fix angular deformities. Bone transport manages segmental defects, with arthrodesis fusing tibiotalarcalcaneal joints.

Surgical technique

Surgery begins with debridement of infected or necrotic bone, followed by partial open reduction. Rings mount on tibia (proximal and distal), calcaneus, and forefoot, secured by olive and smooth wires. Hinges align for multiplanar correction of varus/valgus, equinus, and rotation.

Post-application, distractions adjust 0.5-1 mm daily until plantigrade alignment. Compression across arthrodesis sites achieves fusion. Frame duration averages 4-6 months, with dynamization for consolidation. Weight-bearing starts early under supervision. This shows a typical Ilizarov frame on a reconstructed Charcot ankle, highlighting wire placement and ring configuration for stability.

Deformity correction protocol

Ilizarov excels in three-dimensional correction: equinovarus via calcaneal osteotomy and tibial corticotomy; hindfoot valgus by medial distraction; and shortening via lengthening. Sequential adjustments restore ankle height, hindfoot alignment, and forefoot loading. Outcomes report 93% limb salvage, with 96% ambulation despite osteomyelitis. Plantigrade feet heal ulcers, avoiding amputation in high-risk cases.

Outcomes and complications

Studies on 54 diabetic Charcot cases show restored morphology, no deep infections, and healed ulcers. Mid-term follow-up confirms walking ability independent of radiographic fusion. Complications include pin-site infections (managed with hygiene), wire breakage, or delayed consolidation. Success exceeds internal fixation in compromised hosts.

Conclusion

The Ilizarov technique offers a transformative approach to hindfoot and ankle reconstruction in Charcot arthropathy, enabling limb salvage where other methods fail.

Key advantages

It achieves plantigrade feet through gradual, multiplanar correction, healing ulcers and restoring ambulation in diabetic patients with poor bone stock. High success rates (over 90% limb retention) stem from its infection control, bone regeneration, and stability.

Multidisciplinary care optimizes outcomes, integrating podiatry, orthopedics, and wound management.

Clinical impact

This method reduces amputation risk, improves quality of life, and sets a standard for complex diabetic foot deformities. Future refinements may enhance frame designs for faster consolidation.

Chapter 14

Diabetic forefoot, midfoot, and hindfoot trauma and dislocation

Diabetic patients face heightened risks from foot trauma due to neuropathy, poor vascularity, and delayed healing, often leading to complications like infection or Charcot neuroarthropathy. Management prioritizes soft tissue protection, stable fixation, and prolonged non-weight-bearing, drawing from references like “Reconstructive Surgery of the Foot and Leg” and IWGDF guidelines.

Forefoot trauma

Forefoot injuries in diabetics, such as metatarsal fractures or phalangeal dislocations, often go unnoticed due to neuropathy, progressing to instability if untreated. Initial assessment uses weight-bearing radiographs and CT for subtle pathology; conservative care with splinting suits stable, nondisplaced cases, but displaced ones require intervention.

Surgical options include percutaneous pinning or mini-external fixators for reduction and compression, especially in neuropathic cases to avoid Charcot collapse. For multiple metatarsal involvement, add internal screws followed by hybrid fixation; postoperative full weight-bearing starts at 10-14 days, with consolidation in 8-14 weeks.

Midfoot trauma and dislocations

Midfoot trauma, notably Lisfranc injuries, presents subtly in diabetics and risks acute Charcot if misdiagnosed, confirmed via comparative radiographs or CT.

Hardcastle classification guides treatment:

Stable B1/C1 types use mini-external fixators post-screw stabilization, while unstable A/B2/ C2 need multi-ring frames with foot plates.



Figure 14.1 Screw and plates displaced after correction.

Primary arthrodesis with screws and external fixation prevents collapse in dense neuropathy; Ilizarov frames provide gradual compression across tarsometatarsal joints using olive wires tensioned to 70-90 kg. Healing doubles normal times (12-16 weeks), emphasizing pin-site care and dynamization before frame removal.

Hindfoot trauma and dislocations

Hindfoot fractures like calcaneal or talar injuries in diabetics show types including avulsion, compression, or intra-articular patterns, worsened by osteopenia. Extra-articular cases allow percutaneous reduction; comminuted intra-articular ones favor primary subtalar arthrodesis with bone grafting under distraction.



Figure 14.2 Lisfranc joint and Ankle Charcot arthronuropathy.

Multi-ring Ilizarov external fixators stabilize via calcaneal/talar wires and tibial blocks, enabling ligamentotaxis and compression; apply within 3-5 days for best outcomes. Non-weight-bearing for 10-14 days precedes protected ambulation, targeting plantigrade feet without amputation.

Ilizarov technique for deformity correction

The Ilizarov method excels in diabetic foot deformities post-trauma or Charcot (Eichenholtz II/III), using circular frames for gradual correction and arthrodesis. In 54 cases (mean age 56), open resection preceded frame application with fine wires for stability, achieving plantigrade feet in all, fusion at 18 weeks (14-20 range), and no deep infections.



Figure 14.3

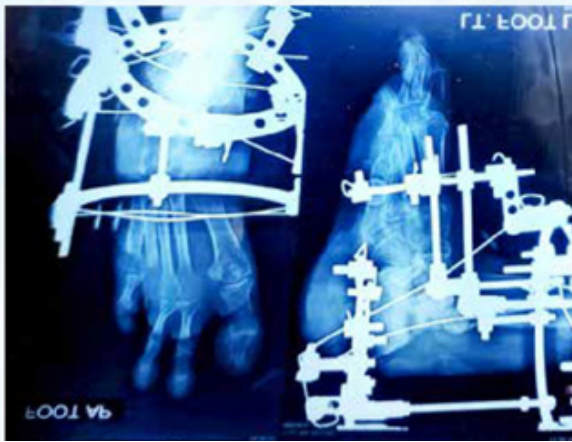


Figure 14.4

Figure 14.3,14.4 From Charcot arthropathy of mid foot the non healing ulcer developed in diabetic foot patient which was treated with Ilizarov technique.

Wires (smooth/olive) tensioned to 70-130 kg connect rings/foot plates; progressive adjustments restore alignment despite neuropathy/vascular issues. Reserved for high-risk failures of internal fixation, it heals ulcers and avoids amputations in series.



Figure 14.5



Figure 14.6

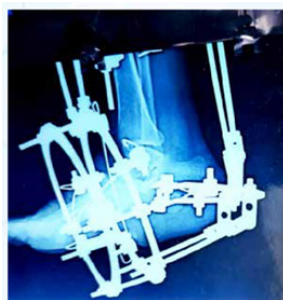


Figure 14.7



Figure 14.8



Figure 14.9



Figure 14.10

Figure 14.5-14.10 With Ilizarov technique the Charcot arthropathy was treated and distraction angiogenesis helps in wound healing and limb salvaged.

Conclusion

Trauma and dislocations in diabetic forefoot, midfoot, and hindfoot demand vigilant diagnosis and tailored interventions to avert Charcot progression, infection, and amputation. The Ilizarov technique emerges as a cornerstone for complex cases, enabling stable reconstruction and deformity correction in high-risk patients.

Key Takeaways

- Neuropathic injuries require imaging beyond plain films; offloading trumps early surgery in stable cases.
- External fixation, especially multi-ring Ilizarov frames, outperforms internal methods in poor bone stock, achieving 80-95% limb salvage.
- Glycemic optimization and multidisciplinary input (podiatry, orthopedics, endocrinology) halve complications.

Future directions

Emerging biologics like BMPs may enhance Ilizarov consolidation, while weight-optimized 3D-printed frames promise better tolerance. Long-term studies affirm plantigrade, ulcer-free outcomes, underscoring Ilizarov's role in modern diabetic limb salvage.

Chapter 15

Diabetic pilon fractures and ankle dislocations

Diabetic patients with pilon fractures or ankle dislocations face heightened risks due to neuropathy, poor wound healing, and infection susceptibility. These injuries often stem from high-energy trauma or insidious neuropathic collapse mimicking Charcot arthropathy, demanding a multidisciplinary approach prioritizing limb salvage.

Pathophysiology and risk factors

Pilon fractures involve intra-articular distal tibial comminution from axial loading, while ankle dislocations feature severe soft tissue compromise and instability in diabetics. Neuropathy impairs pain sensation, leading to delayed presentation and progression to Charcot-like changes; vascular issues exacerbate healing delays. Comorbidities like poor glycemic control double complication rates, including nonunion and amputation.

Clinical presentation and diagnosis

Patients often report minimal pain due to neuropathy, presenting with swelling, deformity, or ulceration; high suspicion is key in diabetics with trauma history. Diagnosis relies on radiographs (AP, lateral, mortise views) and CT scans for fracture classification (e.g., Ruedi-Allgower or AO/ASIF types A-C). Compare with contralateral limb to detect subtle dislocations; MRI assesses soft tissue and infection.

Classification systems

Type	Description	Diabetic Implications
AO/ASIF A	Extra-articular distal tibia	Lower infection risk but neuropathy delays union
AO/ASIF B/C	Partial/full intra-articular (pilon)	High comminution; poor outcomes without external fixation
Neuropathic (Charcot-like)	Insidious collapse/dislocation	Mimics trauma; requires arthrodesis consideration

Treatment principles

Avoid early ORIF due to wound complications (up to 50% in diabetics); prioritize soft tissue respect with spanning external fixation. Glycemic optimization, antibiotics, and hyperbaric oxygen aid healing; multidisciplinary input from endocrinology and vascular teams is essential. Primary goals: anatomic alignment, early weight-bearing, infection prevention.

Ilizarov technique application

The Ilizarov circular external fixator excels in diabetics for pilon fractures and dislocations, enabling closed reduction, compression, and gradual distraction while minimizing soft tissue disruption. Build proximal (two-ring tibial block) and distal (ankle ring/foot plate) blocks connected by threaded rods; use olive wires for stability (tension 70-130 kg). For pilon: Distract under anesthesia for ligamentotaxis, insert percutaneous screws if needed, then apply frame with tibial/ calcaneal wires; allows full weight-bearing post-10-14 days.



Figure 15.1



Figure 15.2



Figure 15.3

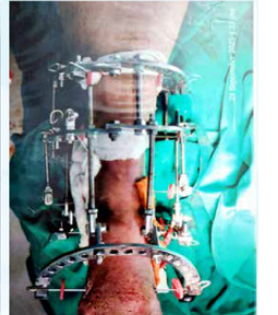


Figure 15.4



Figure 15.5



Figure 15.6

Figure 15.1-15.6 Pilon fracture on different patients on X-ray and in patient images and corrected by Ilizarov technique.

Ilizarov for deformity correction

Post-fracture malalignment or Charcot dislocation is corrected via Ilizarov osteotomy and gradual distraction (1 mm/day in three planes). Wires compress fractures while hinges enable varus/ valgus, rotation adjustments; dynamize at 8-12 weeks for consolidation. In diabetics, it achieves plantigrade foot, fusion rates >90%, averting amputation; frame removal at 12-16 weeks, followed by orthoses.

Postoperative management

Non-weight-bear 10-14 days, then full as tolerated; monitor pin sites weekly with Betadine soaks, retention wires. Serial radiographs guide dynamization; consolidation takes 12-16 weeks in neuropathics. Custom orthoses prevent recurrence; complications like pin infection managed with oral antibiotics.



Figure 15.7

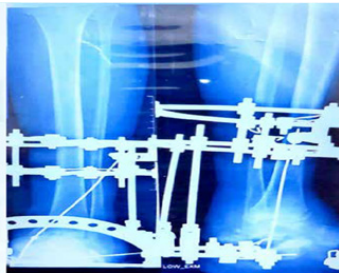


Figure 15.8

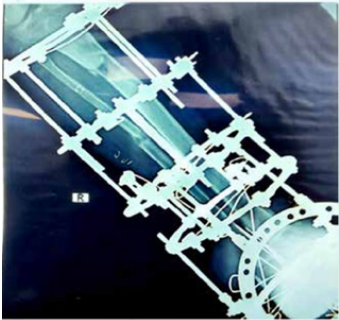


Figure 15.9

Figure 15.7-15.9 Post operative x-ray shows correction of Pilon fracture deformity by Ilizarov technique.

Outcomes and complications

Ilizarov yields AOFAS scores ~85, low amputation (5-13%), superior to ORIF in diabetics. Complications: pin-site infection (managed conservatively), nonunion (rare with compliance), stiffness; neuropathy triples reoperation risk vs. non-diabetics. Long-term: 80-90% limb salvage with multidisciplinary care.



Figure 15.10



Figure 15.11



Figure 15.12

Figure 15.10-15.12: Follow up X-ray and patient after dismantling of Ilizarov apparatus.

Conclusion

Diabetic pilon fractures and ankle dislocations pose formidable challenges in diabetic foot care, yet advances like the Ilizarov technique offer robust limb salvage options. Multidisciplinary management emphasizing glycemic control, infection prevention, and gradual deformity correction achieves high fusion rates and functional outcomes, often surpassing traditional ORIF in high-risk patients. Future protocols should prioritize early external fixation and patient education to minimize amputation risks and enhance quality of life.

Chapter 16

Surgical management of postoperative infection and complications in diabetic foot

Postoperative infections and complications in diabetic foot surgery pose significant risks for limb loss due to impaired healing and persistent bacterial biofilms. Effective management requires aggressive debridement, targeted antibiotics, and specialized techniques like the Ilizarov method to achieve limb salvage.

Common postoperative complications

Postoperative complications in diabetic foot surgery include deep infections, osteomyelitis recurrence, wound dehiscence, and non-union, often exacerbated by poor vascularity and hyperglycemia. Infections typically involve polymicrobial flora such as *Staphylococcus aureus* and gram-negative organisms, leading to abscesses or systemic inflammatory response syndrome (SIRS).

Early recognition via imaging like MRI or WBC SPECT/CT is crucial, as these show high sensitivity for osteomyelitis and soft tissue involvement.

General principles of infection management

Aggressive surgical debridement removes necrotic tissue and drains pus until healthy, bleeding margins appear, forming the cornerstone of treatment. Broad-spectrum antibiotics, such as ampicillin-sulbactam or cephalosporins, are started empirically and adjusted per culture results from deep tissues, typically for 2-6 weeks depending on osteomyelitis extent. Multidisciplinary care addresses glycemic control, nutrition, and off-loading to promote granulation and prevent recurrence.

Ilizarov technique overview

The Ilizarov technique uses circular external fixation for bone transport, distraction osteogenesis, and deformity correction in severe diabetic foot cases with osteomyelitis or non-union. It involves frame application after debridement, followed by gradual tibial transverse transport to stimulate neovascularization and ulcer healing, achieving 100% limb salvage in select cohorts.



Figure 16.1

Figure 16.2



Figure 16.3

Figure 16.1-16.3 Diabetic foot infection in the great toe with loss of peripheral circulation following distraction angiogenesis by Ilizarov technique using Tibial Transverse Transport.

This method is ideal for Wagner grade 3-5 ulcers complicated by SIRS, restoring foot perfusion and reducing pain scores significantly within one month. The Ilizarov frame allows stable fixation while permitting serial debridements and weight-bearing.

Postoperative infection management in Ilizarov

Pin tract infections, the most common issue in Ilizarov use, demand vigilant daily care with chlorhexidine cleansing and antibiotic irrigation to prevent frame colonization. Thorough initial debridement removes infected bone and hardware remnants, followed by 2-4 weeks of IV antibiotics like gentamicin saline rinses and culture-guided therapy; recurrence occurred in only 1/6 cases in one series. Regular monitoring of inflammatory markers (e.g., CRP, ESR) and skin temperature guides adjustment, with osteotomy lengthening starting after one week to enhance microcirculation and healing.



Figure 16.4

Figure 16.5

Figure 16.4,16.5 Revascularization by Ilizarov method prevents amputation.

Wound care and rehabilitation

Moist dressings (e.g., hydrogels, alginates) maintain granulation post-debridement, while negative pressure wound therapy aids high-exudate sites. Early mobilization with crutches preserves function, preventing contractures and thromboembolism, regardless of wound status. Glycemic optimization (<180 mg/dL) and smoking cessation are essential adjuncts.

Outcomes and limb salvage

Stepwise approaches combining debridement, revascularization, and reconstruction yield high salvage rates (78-100%) in hindfoot ulcers and severe infections. Ilizarov specifically avoids amputation in SIRS-complicated cases, with ulcer healing in 3-12 months. Long-term success hinges on multidisciplinary follow-up to mitigate 40% recurrence risk.

Conclusion

Surgical management of postoperative infections and complications in diabetic foot surgery demands a proactive, multidisciplinary

approach to maximize limb salvage and functional recovery. The Ilizarov technique shines in complex cases with osteomyelitis or non-union, delivering exceptional healing (up to 96%) through distraction osteogenesis, neovascularization, and rigorous pin-site care that curbs infections effectively.

Integrating aggressive debridement, culture-guided antibiotics, and glycemic control transforms high-risk scenarios, slashing amputation rates below 10%. Future innovations in biologics and hybrid frames will further refine these protocols for optimal patient outcomes.



Chapter 17

Surgical approach to diabetic foot and ankle amputation

Surgical approaches to diabetic foot and ankle amputations prioritize limb salvage while addressing infection, neuropathy, and vascular compromise common in diabetic patients. Standard techniques focus on stepwise debridement and level-specific amputations, but advanced methods like the Ilizarov technique offer superior outcomes in reducing amputation rates.

Preoperative assessment

Evaluate patients with MRI to map osteomyelitis extent, probe-to-bone tests for bone involvement, and vascular studies like Doppler for perfusion. Glycemic control, nutritional status, and multidisciplinary input from infectious disease specialists guide timing, as uncontrolled diabetes raises complication risks.

Contraindications include active severe ischemia or poor compliance, favoring revascularization first if feasible.

Amputation levels

Minor amputations preserve function; ray or transmetatarsal resections suit forefoot infections, while Lisfranc or Chopart target midfoot disease. Ankle-level options like Syme or Boyd preserve rearfoot for weight-bearing in select cases. Major levels—below-knee, through-knee, or above-knee—follow failed salvage, with below-knee preferred for rehabilitation potential.

Level	Indications	Advantages	Risks
Ray/Transmetatarsal	Forefoot osteomyelitis/ulcer	Maintains propulsion	Wound healing failure
Lisfranc/Chopart	Midfoot gangrene	Preserves heel pad	Instability
Syme	Ankle infection	End-weight bearing	Bulky flap
Below-knee	Extensive forefoot	Prosthesis fit	Stump pain

Standard techniques

Incision placement respects tension-free closure; fish-mouth flaps ensure viable tissue coverage post-debridement. Bone resection leaves smooth edges to prevent pressure points, followed by layered closure and negative pressure dressings. Intraoperative cultures direct 4-6 weeks of antibiotics.

Ilizarov technique

The Ilizarov method uses circular external fixation with fine wires for distraction, compression, and deformity correction after radical debridement. In hindfoot ulcers with calcaneal osteomyelitis, partial calcaneotomy precedes frame application in plantarflexion, gradually adjusting to neutral for wound approximation. It excels in infected cases, enabling serial debridements and offloading.



Figure 17.1

Figure 17.2

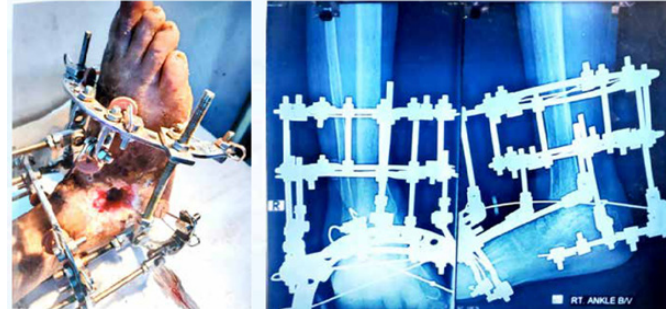


Figure 17.3

Figure 17.4

Figure 17.1-17.4 Open diabetic foot infection treated by Ilizarov technique.

Ilizarov benefits

Studies show 78-91% healing rates in severe cases, with only 9% needing below-knee amputation versus higher rates in standard care. It reduces amputation by stabilizing soft tissue defects, promoting granulation, and avoiding internal hardware in septic fields. Long-term, patients regain plantigrade feet without aids, outperforming casts or monolateral fixators.

Postoperative care

Monitor pin sites weekly with antiseptic care; dynamize frames at 8-12 weeks post-consolidation. Full weight-bearing starts early under supervision, with orthoses for stability. Success hinges on compliance, glycemic control, and infection eradication, yielding 70-80% limb salvage.



Figure 17.5

Figure 17.6



Figure 17.7

Figure 17.8

Figure 17.9

Figure 17.10

Figure 17.5-17.10 The wound was healed gradually after proper load and motion over the limb and limb salvaged.

Conclusion

In conclusion, surgical approaches to diabetic foot and ankle amputation demand a conservative, stepwise strategy that prioritizes limb preservation through meticulous preoperative evaluation, precise level selection, and robust postoperative care. The Ilizarov technique stands out as a transformative intervention, consistently demonstrating

superior limb salvage rates by facilitating controlled reconstruction in complex infected cases where traditional methods falter.

Integrating this method within multidisciplinary protocols can significantly lower amputation incidence, enhancing functional outcomes and quality of life for diabetic patients.



Chapter 18

Tibial Transverse Transport Rehabilitation for rescue the amputated patient

Overview

Rehabilitation after amputation in diabetic patients focuses on restoring function, preventing complications, and improving quality of life. This chapter explores standard protocols and innovative techniques like the Ilizarov method to minimize further amputations.

Postoperative care

Immediate post-amputation care emphasizes wound healing, pain control, and infection prevention in diabetic patients. Physiotherapy begins early, often on day 2 post-surgery, with range-of-motion exercises for the hip and knee to maintain strength and reduce edema. Residual limb shaping through compression dressings prepares for prosthetic fitting while monitoring glycemic control is crucial to avoid delayed healing.

Prosthetic rehabilitation

Prosthetic fitting typically occurs 4-8 weeks post-amputation once the residual limb stabilizes. Training includes gait re-education, balance exercises, and strengthening to achieve independent ambulation. Multidisciplinary teams, including prosthetists and physical therapists, tailor programs to address diabetes-related issues like neuropathy and poor balance.



Figure 18.1 Different types of prosthesis (courtesy - BRAC limb centre).

Ilizarov technique in limb salvage

The Ilizarov technique uses circular external fixation for bone transport and distraction osteogenesis, particularly effective for severe diabetic foot ulcers with osteomyelitis. It promotes ulcer healing by improving blood flow and reconstructing bone length, significantly reducing amputation rates—for instance, avoiding major amputations in 78-91% of complex cases. In transverse tibial bone transport, the frame enables gradual distraction, fostering neovascularization and tissue regeneration even in infected, dysvascular feet.



Figure 18.2



Figure 18.3



Figure 18.4

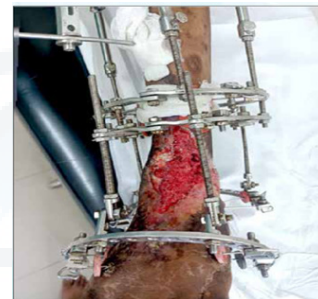


Figure 18.5



Figure 18.6



Figure 18.7

Figure 18.2-18.7 From exposed tendon to improving granulated wound by distraction angiogenesis in Tibial Transverse Transport by Ilizarov technique helps in limb preservation.

Emphasis on amputation prevention

Ilizarov stands out for its ability to salvage limbs in high-risk diabetic feet complicated by systemic inflammatory response syndrome (SIRS) or calcaneal osteomyelitis, where traditional methods fail. Studies show it restores foot architecture, prevents re-amputation, and maintains load-bearing function by lengthening metatarsals or compressing non-unions under tension-stress principles. This approach is ideal pre-amputation or for residual limb optimization, lowering overall amputation needs in multidisciplinary protocols.

Long-term management

Ongoing care involves regular follow-ups for prosthetic adjustments, skin integrity checks, and cardiovascular risk reduction. Psychological support addresses phantom pain and body image, while lifestyle education on diabetes control enhances outcomes. Integrating Ilizarov early in limb-threatening cases can transition patients directly to rehabilitation without amputation.

Phantom limb

Phantom pain after diabetic amputation involves sensations in the missing limb due to nerve reorganization. Effective management requires a multimodal approach tailored to diabetic patient's unique risks like poor healing and neuropathy.

Pharmacologic strategies

Medications form the firstline, including gabapentinoids (gabapentin or pregabalin) to calm nerve hyperexcitability, tricyclic antidepressants (amitriptyline), and SNRIs (duloxetine) for neuropathic pain modulation. Opioids are used sparingly due to addiction risks and diabetes-related complications; NSAIDs help with inflammation but require renal monitoring. Perioperative blocks like epidurals with calcitonin reduce incidence when started pre-surgery.

Non-pharmacologic therapies

Mirror therapy trains the brain by visually “moving” the intact limb as if it were the phantom, reducing pain in 60-80% of cases through cortical remapping. TENS units deliver electrical stimulation to desensitize nerves, while graded motor imagery progresses from imagining to mirror use. Biofeedback and acupuncture provide adjunct relief by altering pain perception.

Advanced interventions

For refractory pain, peripheral nerve stimulation offers temporary relief via implanted devices, improving function short-term. Targeted muscle reinnervation surgery redirects nerves to reduce signals, and spinal cord stimulation modulates central pathways. Psychological support via CBT addresses emotional triggers common in diabetic amputees.

Diabetic-specific considerations

Tight glycemic control prevents exacerbation, as hyperglycemia worsens neuropathy. Multidisciplinary teams monitor prosthetics to avoid residual limb pain mimicking phantom sensations, with early rehab integration key for limb salvage contexts like Ilizarov cases. Long-term, 50-80% see improvement within a year, but persistent cases need ongoing reassessment.

Conclusion

Effective rehabilitation for diabetic amputees integrates comprehensive postoperative care, prosthetic training, and innovative limb salvage techniques like the Ilizarov method to optimize outcomes. Phantom pain management through multimodal pharmacologic, non-pharmacologic, and advanced interventions addresses neuropathic challenges unique to diabetic patients, enhancing functional recovery and quality of life. Prioritizing multidisciplinary approaches and glycemic control ultimately reduces re-amputation risks while empowering patients toward independence.

Chapter 19

Revision & surgical reconstruction of malunion and nonunion in the diabetic lower extremity

Surgical reconstruction addresses malunion and nonunion in the diabetic lower extremity, where poor healing and infections heighten amputation risks. These conditions stem from fractures, Charcot arthropathy, or prior surgeries in patients with neuropathy and vascular compromise. Multidisciplinary strategies prioritize infection control, alignment correction, and limb salvage, drawing from established diabetic foot texts like Levin and O'Neal's.

Pathophysiology

Malunion occurs when fractures heal in deformed positions, destabilizing the foot and ankle due to diabetic neuropathy and osteoporosis. Nonunion features absent bone bridging, worsened by hyperglycemia, poor perfusion, and biofilms in infected sites. Charcot changes and soft tissue loss compound instability, demanding techniques that manage infection alongside bony reconstruction.

Preoperative assessment

Vascular optimization via angiography ensures adequate perfusion before reconstruction. Imaging with weight-bearing X-rays, CT, and MRI detects bone stock, deformity, and osteomyelitis; deep cultures guide antibiotics. Glycemic control (HbA1c <7%) and nutritional support reduce healing delays.

Surgical strategies

Debridement clears necrotic bone and hardware, followed by temporary stabilization with antibiotic-impregnated spacers. Bone grafting and internal fixation suit uninfected cases, but external fixators excel in contaminated fields. Soft tissue envelopes, including local flaps, protect repairs in vascularly challenged limbs.



Figure 19.1 Closed transverse Right upper 1/3rd femoral shaft fracture.



Figure 19.2 Initially try to manage by femoral interlocking intramedullary nailing.



Figure 19.3 X-ray shows lytic change in fracture site followed by non union.



Figure 19.4 Dynamization was done by removing distal screws.



Figure 19.5 There is no sign of healing followed by Dynamization and patient developed osteomyelitis with non union.



Fig 19.6 The interlocking intramedullary nail was removed, antibiotics bone cement and uniaxial external fixator (orthofix) applied, shows no sign of healing and developed LLD.



Figure 19.7 Patient with uniaxial external fixator (orthofix) and developed limb length discrepancy.

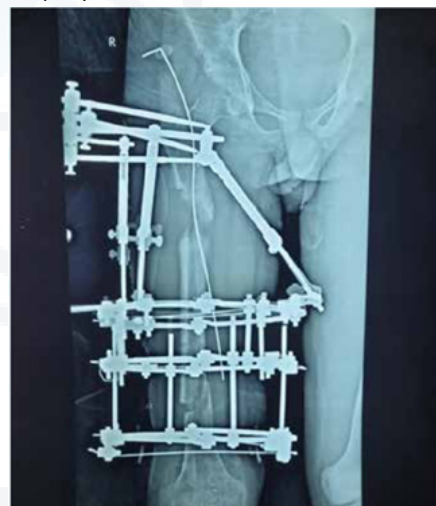


Figure 19.8 Post operative x-ray after application of Ilizarov apparatus and distal corticotomy for LLD correction.



Figure 19.9 Gradual distraction in corticotomy site to correct the limb length discrepancy.



Figure 19.10 Simultaneously correction of Non union, Osteomyelitis and limb length discrepancy by Ilizarov technique.



Figure 19.11 Patient with Ilizarov apparatus in situ and overcome the limb length discrepancy.



Figure 19.12 Patient with Ilizarov apparatus in situ and overcome the limb length discrepancy.



Figure 19.13 X-ray after completed treatment protocol by Ilizarov technique, No sign of Nonunion, osteomyelitis and Limb length discrepancy.

Patient is able to bear weight and mobilize after completing treatment by Ilizarov technique. Complete cure.

Ilizarov technique principles

The Ilizarov apparatus employs circular frames with fine wires for multiplanar control, leveraging distraction osteogenesis for bone lengthening and transport. Tensioned rings enable gradual deformity correction, compression of nonunion gaps, and soft tissue regeneration without internal hardware. This method suits diabetic feet by minimizing infection risk and accommodating irregular defects.



Figure 19.14



Figure 19.15



Figure 19.16



Figure 19.17



Figure 19.18



Figure 19.19



Figure 19.20



Figure 19.21



Figure 19.22



Figure 19.23

Figure 19.14-19.23 Shows Non union followed by fracture of the lower 3rd of the tibia after correcting with plate and screws Which was removed and Ilizarov technique applied for correction of the nonunion.

Application in diabetic cases

Ilizarov corrects malunions via osteotomy and gradual realignment, restoring plantigrade foot position. For nonunions, bone transport

fills segmental gaps post-debridement, promoting union through corticotomy and distraction. Ankle equinus and forefoot shortening respond well, with frames supporting concurrent ulcer offloading.

Ilizarov reduces amputation rates

Ilizarov markedly lowers amputation needs in recalcitrant diabetic nonunions and malunions by eradicating infection, regenerating bone, and achieving stable fusion where amputation was otherwise inevitable. Literature from diabetic foot surgery texts highlights limb salvage rates exceeding 80% in infected hindfoot and tibial cases via partial resections combined with Ilizarov. Its versatility preserves function, reduces reoperations, and outperforms rigid internal fixation in osteomyelitic or poor-soft-tissue environments.

Postoperative care

Pin-site hygiene and oral antibiotics prevent frame-related infections during 3-6 months of fixation. Dynamization and frame adjustments promote consolidation, transitioning to braces post-removal. Outcomes feature high union rates, ambulatory independence, and sustained limb preservation with vigilant multidisciplinary monitoring.

Conclusion

Surgical reconstruction of malunion and nonunion in the diabetic lower extremity remains a cornerstone of limb salvage, with the Ilizarov technique emerging as a transformative approach.

Core Principles reinforced

Multidisciplinary care optimizes outcomes by addressing vascular deficits, infection, and glycemic control before pursuing bony reconstruction.

Ilizarov as limb salvage standard

The Ilizarov method's distraction-compression principles enable bone regeneration in infected, deformed diabetic limbs where internal fixation fails. Its documented success in reducing amputation rates—often below 20% in complex hindfoot and tibial cases—establishes it as essential for preserving ambulatory function.

Clinical imperative

Diabetic foot surgeons must master Ilizarov applications to convert inevitable amputations into durable reconstructions, prioritizing patient mobility and quality of life.

Chapter 20

Prosthetic joint infection in diabetic foot managed by DAIR with CLAP Therapy and PEMF

Prosthetic joint infections (PJIs) pose significant challenges in diabetic foot management due to impaired immunity, neuropathy, and vascular compromise. DAIR (debridement, antibiotics, irrigation, retention) combined with continuous local antibiotic perfusion (CLAP) offers a prosthesis-preserving approach, particularly for patients at high amputation risk.

Epidemiology and risk factors

Diabetic patients face elevated PJI risk post-total knee or ankle arthroplasty, linked to prior foot ulcers and poor glycemic control. History of diabetic foot ulcers increases PJI odds after joint replacement, complicating limb salvage.

Books like Levin and O'Neal's *The Diabetic Foot* highlight multidisciplinary risks including biofilm formation and polymicrobial infections in neuropathic feet.

Pathophysiology in Diabetics

PJIs in diabetic feet stem from biofilm-adherent pathogens on implants, exacerbated by hyperglycemia-induced neutrophil dysfunction and ischemia. Chronic low-grade infections mimic diabetic foot osteomyelitis, delaying diagnosis. CLAP targets deep tissues via intramedullary or intrasoft tissue perfusion, achieving high local antibiotic levels to disrupt biofilms without systemic toxicity.

Diagnosis

Diagnosis relies on clinical signs (erythema, drainage), elevated ESR/CRP, and imaging (MRI, PET-CT) to confirm periprosthetic infection. Synovial fluid analysis and cultures guide therapy, distinguishing acute from chronic PJI.

In diabetics, probe-to-bone testing and Wagner grading integrate with IDSA criteria for foot-specific PJI assessment.



Figure 20.1 Periprosthetic supracondylar fracture of the femur without dislodgement of prosthesis.



Figure 20.2 Periprosthetic supracondylar fracture was aligned and fixed with Ilizarov apparatus.

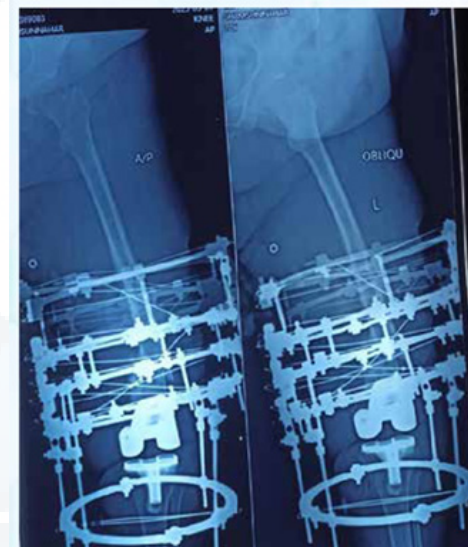


Figure 20.3 Multiple olive wires inserted to fixing the Periprosthetic fracture.

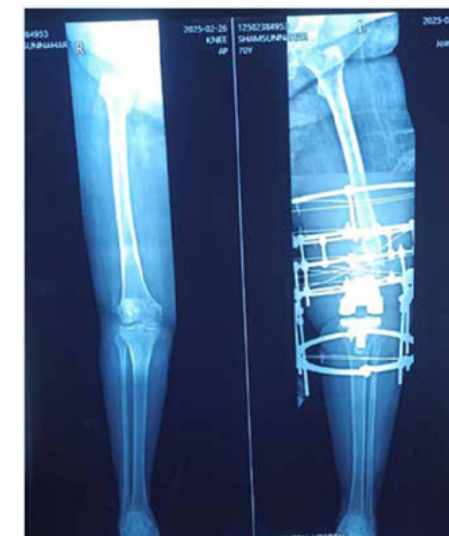


Figure 20.4 On X-ray stress view no limb length discrepancy.



Figure 20.5 After dismounting of the Ilizarov apparatus the Periprosthetic fracture was healed by callus formation.

DAIR with CLAP Procedure



Figure 20.6 The CLAP therapy was applied to the Prosthetic Joint infection.



Figure 20.7 The negative pressure drain was used as outflow tract in CLAP therapy.



Figure 20.8 Syringe pump is used for accurate dose calculation in inflow tract of CLAP therapy.

DAIR involves thorough debridement, modular exchange, and pulsed lavage, followed by 2-6 weeks of IV antibiotics. CLAP enhances this by continuous catheter-delivered antibiotics (e.g., vancomycin) into infected sites for 7-14 days post-DAIR.

- i. Carrier Solution: Gentamicin 160mg (2×80mg ampules) + 46ml 0.9 % Normal Saline.
- ii. Localised Concentration: 160 mg in 50 ml = 3.2 mg/ml = 3200 µg/ml
- iii. Perfusion rate: 2 ml/hr via intra-joint dual-lumen tubes
- iv. Daily Dose Rule/Formula: $2 \text{ mL/hr} \times 24 \text{ hr} \times 3.2 \text{ mg/mL} = 153.6 \text{ mg/day}$

Success rates reach 66% in select chronic PJI cases, preserving function in frail diabetics unsuitable for two-stage revision.



Figure 20.9 Swelling and inflammation subsided after application of CLAP therapy.



Figure 20.10 On Follow up patient is able to stand by the support of Walker and there is no limb length discrepancy.

Role of Ilizarov technique

For DAIR failures or extensive bone loss in diabetic PJI, Ilizarov external fixation enables bone transport and reconstruction. Transverse tibial transport promotes ulcer healing via distraction osteogenesis, improving vascularity and eradicating osteomyelitis.

In Charcot arthropathy-associated PJI, Ilizarov achieves ankle arthrodesis with plantigrade foot restoration, avoiding amputation in high-risk cases.

Outcomes and evidence

DAIR-CLAP yields infection eradication in chronic TKA PJI with poor host status, per recent studies mirroring diabetic foot texts like Clinical Care of the Diabetic Foot. Ilizarov integration reports 90%+ ulcer healing and limb salvage in severe cases, outperforming internal fixation.

Treatment	Success rate	Key advantage in diabetics
DAIR + CLAP	66%	Implant retention, local high-dose antibiotics
Ilizarov Bone Transport	90-100% healing	Vascular regeneration, no amputation
Two-Stage Revision	80-90%	Gold standard, but high morbidity

PEMF Therapy (Pulsed Electromagnetic Field Therapy)

PEMF is a non-invasive, drug-free wellness approach that uses low-frequency electromagnetic fields to stimulate cellular repair, improve circulation, and reduce inflammation.



Figure 20.11 Patient getting PEMF following Ilizarov technique to enhance healing.

Pulsed electromagnetic field (PEMF) therapy accelerates diabetic foot ulcer healing by enhancing microcirculation (+28% capillary velocity), fibroblast proliferation, and angiogenesis while reducing inflammation.

Clinical integration

Post-DAIR: 60-min sessions (12 Hz, 12 Gauss) x 2-3 weeks yield 18% faster wound closure. Ilizarov adjunct: Boosts bone consolidation and ulcer healing in Charcot-PJI cases.

Outcomes

Systematic reviews confirm significant surface area reduction vs. controls ($p < 0.01$), positioning PEMF as essential for limb salvage in prosthetic joint infections.

Multidisciplinary management

Optimize glycemic control (HbA1c $< 7.5\%$), vascular assessment, and offloading. Reference IWGDF guidelines and texts like Diabetic Foot: Surgical Principles for team-based protocols including NPWT and hyperbaric oxygen. Long-term suppression antibiotics prevent relapse in persistent cases.

Conclusion

Prosthetic joint infections in diabetic foot patients demand aggressive, prosthesis-preserving strategies like DAIR with CLAP therapy to optimize limb salvage rates. Integrating the Ilizarov technique addresses complex bone defects and recalcitrant infections, achieving durable functional outcomes where traditional methods fail.

Key Takeaways

- DAIR-CLAP retains implants in 66% of chronic PJI cases while delivering targeted antibiotics, crucial for diabetic hosts with poor vascularity.
- Ilizarov bone transport regenerates vascularity and eradicates osteomyelitis, yielding 90%+ healing in severe diabetic foot reconstructions.
- Multidisciplinary protocols mirroring Levin and O'Neal's principles—glycemic control, vascular optimization, and offloading—remain foundational.

Future directions emphasize biofilm-targeted antimicrobials and bioengineered scaffolds alongside these techniques for enhanced success in high-risk diabetics.

Chapter 21

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American on different diabetic foot management patients from BIHS and BIRDEM

Management of diabetic foot ulcer & atherosclerosis using tibial transverse bone lengthening technique; Bangladesh experience

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Abstract

Diabetic foot ulcers (DFU) are chronic skin ulcers associated with deep tissue destruction around the foot and ankle region with varying degrees of lower extremity vasculopathy and neuropathy. Diabetic foot ulcer is associated with a high rate of morbidity, disability, mortality and psycho-social cost.

Keywords: DFU, TTT, Osteotomy, ulcer, gangrene

Introduction

Diabetic foot ulcer (DFU) is always associated with peripheral and automatic neuropathy that prevents with red swollen foot. We can easily identify clinically by seeing the presence of ulceration in the foot. The diabetic foot ulcer with deformity depends on some factors which includes osseous mal-alignment, trauma, metabolic abnormalities, and osteoporosis. The loss of vasomotor control permits vasodilatation that leads to increase peripheral blood flow, which increases arteriovenous shunting that causes bone resorption. Obesity and muscle atrophy do not allow the patient to bear weight. Sometimes osseous projections are the potential areas for diabetic foot ulcer. Osteomyelitis should be ruled out with ulcer. Infectious, ulcers and bone resorptions are always integrated. Dorsal and planter ulcers are very much common in diabetic foot. Medial column ulcers are associated with tarsometatarsal medial column collapse. Lateral column ulcers are more proximal to mid foot deformity that does not unite. Chronic ulcerations lead to deep infection and osteomyelitis. Surgical intervention and debridement are essential to remove all devitalized tissue.^{1,2}

As an excellent treatment for diabetic foot ulcers our study at Bari-Ilizarov Orthopaedic Centre and BIHS (Bangladesh Institute of Health Science) showed that 50% DFU are Wagner type III.

Challenges of diabetic foot ulcer management

- i. The most common impaired chronic wound condition is in diabetic mellitus.
- ii. 8% of population is estimated to suffer type 2 diabetes in 2035.
- iii. 4% of diabetic patients develop foot ulcer each year (15% during their life time)
- iv. Diabetic foot ascribe foot infection, ulcer and tissue destruction for peripheral vascular and nerve lesion.
- v. Diabetic foot is one of the most serious and costly chronic complication of diabetes and severe cases can lead to amputation.
- vi. About 85% of amputations are caused by foot ulcers.
- vii. The relative risk of lower extremity disruption in diabetic patients is 40 times higher than non-diabetic patients.
- viii. The 5 years mortality rate of DFU associated amputation is about 50%
- ix. Mortality rate of Wagner iv grade diabetic foot patients without surgery was as high as 54%.
- x. Significantly higher costs and social burdens.
- xi. Novel and cost-effective management for diabetic foot ulcer is in burning need.

Pathology of diabetic foot ulcers

- i. The vessels are calcified, that leads to disability.
- ii. Overall, 45.6% of the subjects were found 'at risk' of DFU. This risk was higher among men (46.7%) than women and among those who lived in rural areas (47.5%) as compared with the urban population.
- iii. Primary care physicians and diabetic patients usually have a low degree of awareness of diabetic vascular lesions.
- iv. Microvascular damage increases blood viscosity and blood flow disorder.

Conventional treatments

- i. Blood glucose control.
- ii. Blood pressure and lipid control.
- iii. Nutrition supplement therapy for the patients who are suffering with kidney disease, malnutrition, and hyperproteinemia.

During and after Tibial Transverse Technique patient reports

- i. Relief of pain,
- ii. The limb becomes warmth.
- iii. Distraction osteogenesis increases capillary and vascular network.

Biological mechanisms

A. Corticotomy

- i. Ilizarov corticotomy is a low energy osteotomy with the preservation of periosteum and endosteum and bone marrow.

- ii. In choosing corticotomy level, anatomic, biomechanical and physiological factors must be considered.

B. Law of tension stress

Ilizarov's law of tension-stress promotes formation of

- i. Neovascularization.
- ii. Increases collateral circulations in the affected limbs.

C. Tibial transverse technique

Kurgan evidence suggests that Tibial Transverse Technique may mobilizes stem cells and helps in formation of mesenchymal stem cells towards to damaged tissues.

D. Wagner DFU Classification

The Wagner diabetic foot ulcer classification system assesses ulcer depth and the presence of osteomyelitis or gangrene by using the following grades:

- i. Grade 0 – Intact Skin
- ii. Grade I – Superficial ulcer of skin or subcutaneous tissue
- iii. Grade II – Ulcers extend into tendon, bone, or capsule
- iv. Grade III – Deep ulcer with osteomyelitis, or abscess
- v. Grade IV – Partial foot gangrene
- vi. Grade V – Whole foot gangrene

Principles of debridement for diabetic foot ulcers:

- i. Tissue must be removed.
- ii. Treatment of infected lumens: Debridement should be done and we should leave the wound open.

Protocols for tibial transverse technique surgery - Basic requirements

We must have indications and contraindications for TTT.

Indications:

Chronic diabetic foot ulcer with atherosclerosis.

Inclusion criteria are:

Diabetic foot with Wagner III and IV.

The diabetic foot which received debridement, dressing change should go for TTT therapy.

DFU combined with Wagner type II, III, or IV

Patient interested to do the surgery.

Contraindications

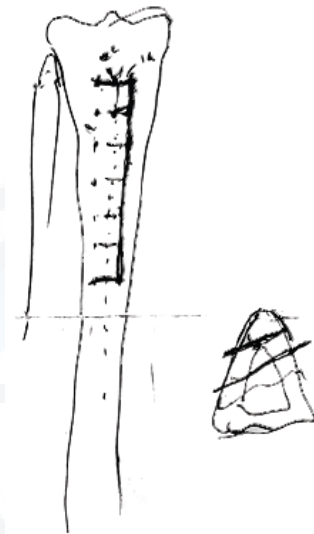
Mentally ill patient who cannot assist the orthopaedic surgeon during treatment.

Surgical procedure

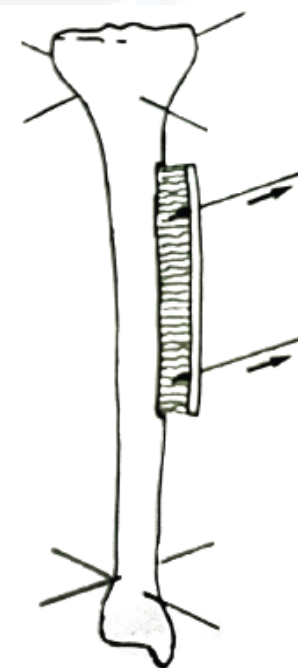
A small 5 incisions were made at the anterolateral part of the tibia. The distance between two incisions are 2cm. Through each 5 incisions a 5mm osteotome is used to do the osteotomy so that we can osteotomize the incised tibia in a colinear fashion. In the proximal

incision we should cut the bone 2cm transversely. After that below each incision's osteotomy 1.8mm 5 olive wires were introduced to connect with lateral plate via slotted bars. The tibial section has been moved approx. 1 mm/day for 3 weeks. The clinical status improved within a few weeks. Cure of trophic ulcers and no more pain. Arteriogram on the 2nd months improved circulatory result.³⁻⁷

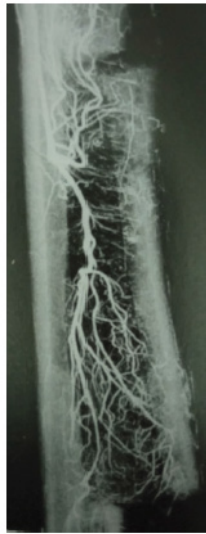
The diabetic foot ulcer under the great toe and little toe are seen in most of the cases. Pre surgery color duplex confirmed the extrusive occlusion of anterior tibia, posterior tibia, and arteria dorsalis pedis. After surgery with 5 days of interval we started distraction of the osteotomised bone with the plate. Tibial section has been moved approximately 1 mm per day for 3 weeks. The clinical condition improved in 3 weeks and cure of diabetic foot ulcer were seen.



A. Diagrammatic Scheme.



B. Tibial Transverse Technique and bone regeneration.



C. Distraction angiogenesis.

Impact of neuropathy

- Signs and symptoms may be minimal
- Nevertheless, pathology proceeds rapidly
- End stage of tissue death is quickly reached
- Window of opportunity is very limited
- Immune system and nervous system are deficient so body is unaware of bacterial invasion.

Postsurgical management

- Antibiotics should be used for 3–7 days
- Second postoperative dressing should be changed.
- To prevent limb oedema the limb should be raised up.
- Postoperative exercise is absolutely mandatory.

Recent advances (Diabetic foot ulcers)

Ilizarov discovered distraction histoneogenesis for limb regeneration. The tension-stress law could activate and enhance the regenerative potentials of living tissues, leading to growth or regeneration of muscles, fascia, blood vessels, and nerves simultaneously.

Clinical outcome of 58 cases of diabetic foot ulcers following Tibial Transverse Technique (TTT), Bone Lengthening

Total cases	58
Male	46
Female	12
Age (Years)	35-72
Diabetes duration	1-25
Foot Ulcer	
Duration	3 days- 10 years
Wagner grading	
Grade II	25
Grade III	26
Grade IV	06
Grade V	01

Discussion

In 2020, our study reported that 290 million adults worldwide had diabetes and it will rise to 450 million by the year 2035. This big demographic shift shows the prevalence of diabetes chronic complications in the foot. If we continue the conservative therapy the foot ulcers do not cure, surgical debridement, dressings, strict glycemic control and intravenous antibiotic therapy may eradicate infection but foot problems remain life threatening to the patient, that's why we need to do distraction angiogenesis to increase microcirculation in the limb.

The Tibial Transverse Technique is based on Ilizarov's "law of tension-stress" for limb regeneration and functional reconstruction. The principle is slow and steady traction on a living tissue creates a stress and which is metabolically activated and which stimulates histoneogenesis". It promotes cell division and differentiation of adult stem cells like that in the fetal tissues development and lead to tissue regeneration.¹⁻⁴

Conclusion

- Tibial transverse technique for DFU (Wagner III and above) have successfully treated more than 58 cases. We used tibial transverse technique along with debridement and dressing change.¹
- Tibial transverse technique can significantly improve diabetic ulcer healing, increase the limb salvage rate and reduce the diabetic foot ulcer recurrence rate.
- Tibial transverse technique was not 100% effective for severe cases of DFU.
- The tibial transverse surgery should be performed with a minimally invasive fashion through small skin incisions, meticulous corticotomy, purposely-designed Ilizarov fixator, to ensure standard surgical procedure and postoperative management.^{1,7}
- We must follow the principles of surgical procedure. Pre and post-operative management which can help in success rate for tibial transverse surgery in severe diabetic foot ulcer treatment.



Figure 1 72 years old man, Diabetic Foot Ulcer with atherosclerosis.

- (1) Diabetic foot of right little toe ulcer with dry skin.
- (2) Dry skin of lower tibia and ankle.
- (3) Radiograph of right foot with resorption of right 5th and 4th phalanges.
- (4) In OR, multiple incisions and introducing the olive wires.
- (5) In OR, long plate is fixing with the olive wires.
- (6) View of Ilizarov fixation in the diabetic leg to increase vascularity.
- (7) Radiograph of right foot with Ilizarov fixation, widening of tibia is seen.
- (8) After 14 days of Ilizarov fixation in the right leg, little toe ulcer is healed.
- (9) View of the leg with Ilizarov fixation, skin color changed and ulcer is healed after 21 days.
- (10,11) Clinical appearance of the patient and right leg without ulcer.



Figure 2 33 years old man, Diabetic Foot Ulcer with vasculopathy and neuropathy.

- (1) Diabetic Foot Ulcer of dorsum of right foot, Wagner type III.
- (2) Same patient, sole of the foot and dorsum of the great toe.
- (3, 4) Dorsum and sole of the foot after debridement.
- (5) In OR, multiple incisions seen in the tibia.
- (6) In OR, placement of olive wires.
- (7) Radiograph of right foot, placement of olive wires.
- (8) Olive wires were connected through slotted bars and plate.
- (9) Radiograph of distraction time.
- (10) View of placement of Ilizarov apparatus for TTT (Tibial Transverse Technique).
- (11) 14 days after the TTT surgery.
- (12) After 21 days, ulcer is healed.
- (13, 14) Radiograph of right tibia with Ilizarov fixation, ulcer is healed (AP and Lateral view).
- (15) Before dismounting Ilizarov fixation, healed dorsum of the foot.
- (16) Sole of the foot healed, before dismounting Ilizarov fixation.
- (17) Radiograph after removal of Ilizarov apparatus.
- (18-20) Final follow-up after 2 months without any ulcer.

Acknowledgments

None.

Conflicts of interest

The authors declare no conflicts of interest

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A Journey to healing: successful limb salvage and functional restoration in chronic femoral nonunion with osteomyelitis via Ilizarov fixation

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Abstract

This report documents the healing process of a 20-year-old male patient who faced a major orthopedic challenge through a transverse femoral shaft fracture with substantial translation after initial interlocking intramedullary nailing resulted in persistent nonunion and chronic osteomyelitis. A severe injury transformed into an intricate battle that involved infection alongside bone degeneration and a significant discrepancy in limb length. This report outlines the transformative implementation of the Ilizarov method as a final solution which uses specialized external fixation techniques. The Ilizarov treatment system combines controlled bone regeneration with multiplanar stability to produce complete bone union and eliminate persistent infections while restoring the natural length and alignment of the limb. The patient's experience ended with complete healing and zero deformities or length discrepancies while achieving full mobility. This case demonstrates the exceptional capability of the Ilizarov method to rehabilitate limbs and restore function in complex orthopedic situations that would otherwise require amputation. This patients' journey starts in October 2023 with complications and ends with a complete cure in June 2025 by the advancement treatment procedure in Bari- Ilizarov Orthopedic Centre.

Introduction

Life-changing injuries such as femoral shaft fractures become markedly more complicated when faced with complications of nonunion - failure of fracture to heal - and chronic osteomyelitis - lifelong infection of bone tissue. When combined, these problems often lead to a downward cycle of unfavorable outcomes for the patient - chronic pain, significant bone loss, limb-length inequality, angular deformity, and complications/infection to soft tissues. Although traditional methods of internal fixation are often the primary intervention for simple fractures, these modalities fall short, or simply worsen the outcome when complications or damage to tissues are pre-existing. In some cases, and because the use of internal fixation usually results in implant materials in a compromised environment, these materials can serve as a focus for bacteria resulting in a sometimes-confirmed complication of the already tenuous process of fracture repair! The scope of these multidimensional problems starting from deep infection, bone loss or nitrate and limb shortening and corrective

bone deformity warrants a multi-faceted treatment plan that solves multiple problems.¹⁻³



Figure 1 Closed transverse Right upper 1/3rd femoral shaft fracture.

It is within this context of complicating and often interrelated complications that the Ilizarov method has emerged as a viable solution for orthopedic trauma and reconstructive surgeons. The Ilizarov method, pioneered by Academician G.A. Ilizarov is one of the first methods to utilize the fundamental biological principle of distraction osteogenesis. This approach utilizes the body's natural ability to create new bone and soft tissue, utilizing a controlled application of mechanical tension. The capabilities of the Ilizarov procedure allow it to correct a variety of major defects in bone and soft tissue,^{1,4} and provides a treatment modality for problems that are otherwise not treatable or which result in amputation. It is the only option for eradicating chronic infection, correcting deformities, managing a major bone defect, and fixing a limb-length discrepancy,^{2,4} all while allowing the body to regenerate soft tissue and bone, thus fundamentally changing care from a traditional stage-based approach.

This all-encompassing methodology not only broadens the horizons in limb reconstruction, but it also revolutionizes the level of change possible in orthopedic treatment, and it provides a transformational pathway to care for patients sustaining the most devastating limb conditions. Exciting examples of this are seen in the world-wide hailed treatment of the infected nonunion and limb-length discrepancy of Olympic champion Valery Brumel, which demonstrated how the Ilizarov method made it possible to both regenerate bone and to return function from a previously impossible situation.

Case presentation

Patient's first challenge: Injury and initial setbacks

Our patient is a 20-year-old male who suffered a severe high-energy trauma, resulting in a displaced transverse fracture of the upper femoral shaft. Given the age and potential for healing (youth), this situation could have had an optimistic initial review. He underwent standard interlocking intramedullary nailing, a common approach to stabilize femoral shaft fractures. That said, it did not provide a straightforward pathway to healing.

The actual fracture (trauma to the limb) has now turned into a complicated conflict with persistent infection as the fracture site became a focus of chronic osteomyelitis and a stubborn nonunion (the bone refused to knit back together). Most likely the implant (device) designed to assist the healing process turned into a bacterially rich space where it contributed to the infection and effectively hindered the biological repair mechanism.³ This was another frustrating predicament that further underscored the limitations of internal fixation as it relates to the injury or compromised soft tissues already facilitated with infection and the need for a more aggressive and/or adaptive therapeutic paradigm.^{5,6}

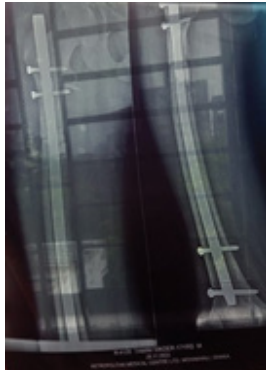


Figure 2 Initially try to manage by femoral interlocking intramedullary nailing.



Figure 3 X-ray shows lytic change in fracture site followed by non-union.

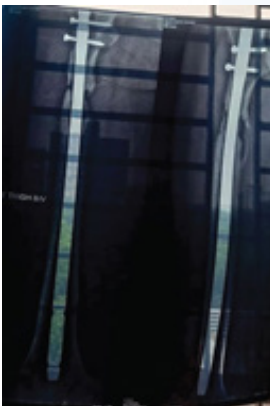


Figure 4 Dynamization was done by removing distal screws.



Figure 5 There is no sign of healing followed by Dynamization and patient developed osteomyelitis with non-union.



Figure 6 The interlocking intramedullary nail was removed, antibiotics bone cement and uniaxial external fixator (orthofix) applied, shows no sign of healing and developed LLD.



Figure 7 Patient with uniaxial external fixator (orthofix) and developed limb length discrepancy.

Untangling the puzzle: diagnosis & assessment

To understand the extent and intricacy of our patient's condition, an exhaustive diagnostic process was initiated. Significant laboratory testing, which confirmed an active infection with inflammatory markers, took place. Advanced imaging, X-rays and CT scans, created a detailed blueprint of the infected nonunion, demonstrating the movement at the fracture, identifying the amount of bone loss, discovering any current angular or rotational deformity.

All of these assessments were critical in establishing an individualized, precise, treatment plan with the Ilizarov technique.



Figure 8 Post operative x-ray after application of Ilizarov apparatus and distal corticotomy for LLD correction.

A new chapter: the strategy of Ilizarov fixation

Careful Planning for a Complicated Reconstruction

After significant deliberation, we committed to the Ilizarov fixation, recognizing its particular ability to solve seemingly

impossible problems like the case presented. Pre-operative planning was crucial, and required a careful study of the bone deficiency defect, any potential limb length difference, and the amount of deformity. This systematic evaluation allowed a clear outline of the Ilizarov device and the procedure; suddenly, we had hoped that this complicated case could progress to full recovery.^{1,2}

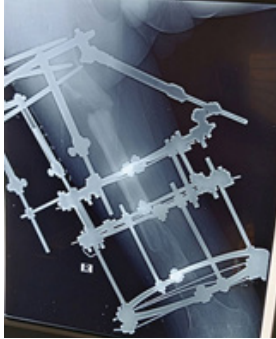


Figure 9 Gradual distraction in corticotomy site to correct the limb length discrepancy.

The surgical process: specificity and intent

October 6, 2024 was the day that the patient had a new beginning. The surgery, as planned, progressed aggressively with radical debridement to remove all necrotic (dead) bone and infected soft tissue. This is a critical step that was a must for eliminating chronic osteomyelitis. All of this was very important for infection control and debridement would also cause a considerable bone defect, and potentially induce instability in the affected limb.

After cleaning extensively, the components of the Ilizarov external fixator were sutured on. The application was detailed and required careful attention to the placement of the metallic rings and alignment of the tensioned Kirschner's wires (K-wires). The K-wires provided multiplanar stability to the femoral segments and also fixed the bone in the desired position for future alignment and healing. The surgeon performed a Corticotomy (a precise cut into the bone through the outer layer only). This careful cut spared the important periosteal and endosteal blood supply, which is vital for stimulating new viable bone.¹ This integrated approach nicely illustrates the Ilizarov method's strength; it addresses both the instability and defects of the necessary debridement for infection control, with its active and strong reconstructive properties.^{7,8}

The miracle of regeneration: distraction osteogenesis

After 5 days of rest for soft tissue healing, the slow distraction osteogenesis procedure began. The nuts and threaded rods needed to be turned at a prescribed rate of 1 mm per day by making weekly rod adjustments in order to achieve slow distraction or separation of bone. Each day the nuts were turned by 0.25 mm which meant, it was able to tolerate distraction of bone four times a day. The distraction osteogenesis procedure allows bone fragments to separate at a controlled rate which allows for new viable bone to form into the gap between the bone fragments. The measure rate is for ensuring proper blood vessel development with bone development. The rate at which distraction is occurring needs to be controlled in order for proper blood vessels and bone tissue to develop. If the rate is greater than 2 mm per day damage to the biological process will result, if too slow, bone at the distraction site may become too hardened to allow distractions to occur. The patient must maintain a specified distraction

rate so that they would be able to accommodate their existing limb length discrepancy and along with adequate new bone tissue along the fracture site. The successful bone regeneration seen in this case effectively illustrates the scientific accuracy of the Ilizarov technique, where mechanical forces have been modified in order to provoke a biological response.^{1,3}



Figure 10 Simultaneously correction of Nonunion, Osteomyelitis and limb length discrepancy by Ilizarov technique.

The healing pause: consolidation phase

Once an appropriate bone length and axial alignment was obtained, the active distraction phase ended. The Ilizarov frame remained carefully in place for the important consolidation phase, allowing the newly formed regenerate bone to mature and convert to bone as it slowly acquired the ability to bear physiological loads. The Ilizarov frame remained in place for a total of about 4.6 months (141 days) to allow adequate bone maturation and consolidation. The frame was removed on February 24, 2025, followed by the application of a cast to provide external support during the final healing process. The cast stayed on for approximately 2.1 months (65 days) and was finally removed on April 29, 2025, representing another milestone in his rehabilitation process.¹

Navigating the journey: post-operative care and managing challenges

Throughout the treatment period we implemented an extensive pin site care protocol to prevent infections which remain typical but typically manageable complications of external fixation. The medical staff followed standard procedures for treating superficial pin tract infections and conducted radiographic evaluations of healing at multiple time points. Through this method we could track bone healing status and evaluate alignment status while making frame adjustments to maintain proper healing targets. A physiotherapy program started immediately during the initial phase of the treatment. The early implementation of physiotherapy stands essential for maintaining joint flexibility while preventing stiffness and promoting progressive weight-bearing which leads to proper functional recovery alongside sufficient bone healing.

The road to full recovery: rehabilitation and functional restoration

The patient succeeded as a result of his participation in a full rehabilitation program. The program involved early mobility and progressive weight-bearing with strict supervision in the stable Ilizarov frame. The use of his limb functionally during the healing process was essential for maintaining muscle strength, joint range of motion and resulted in a better overall recovery.



Figure 11 Patient with Ilizarov apparatus in situ and overcome the limb length discrepancy.

A triumphant outcome: the final chapter

The Treatment process by Ilizarov technique was approximately 6.7 months, including radiological and clinical evaluation which demonstrated uneventful bone healing, spontaneous healing of chronic osteomyelitis, absence of limb length inequality, and absence of angular or rotational deformity. The patient then went on to return to earlier levels of functioning following complete functional recovery. The clinical case demonstrates the efficacy of the Ilizarov method in the management of complex orthopaedic conditions.^{5,9}



Figure 12 X-ray after completed treatment protocol by Ilizarov technique, No sign of Nonunion, osteomyelitis and Limb length discrepancy.

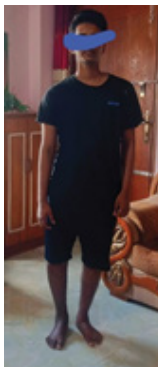


Figure 13 Patient is able to bear weight and mobilize after completing treatment by Ilizarov technique. Complete cure.

The outcomes were assessed using the ASAMI (Association for the Study and Application of the Method of Ilizarov) scale, which provides objective criteria for bone and functional results.⁷

Table 1 Patient Clinical Timeline and Key Interventions:

Event/Intervention	Date/Duration	Details
Initial Injury		Transverse fracture shaft of femur
Initial Treatment	Immediately post-injury	Closed reduction and intramedullary nailing
Complication Onset		Persistent pain, swelling, drainage, nonunion, chronic osteomyelitis
Ilizarov Frame Application	October 6, 2024	Radical debridement performed; multi-ring Ilizarov fixator applied
Latency Period		Period before distraction initiation
Distraction Phase	to	Gradual distraction osteogenesis at 1 mm/day
Total Time in External Fixator	Approx. 4.6 months (141 days)	Period the Ilizarov frame was in place
Ilizarov Apparatus Removal	February 24, 2025	Ilizarov apparatus removed
Cast Application	February 24, 2025	Cast given for external support
Cast Removal	April 29, 2025	Plaster cast removed
Total Treatment Duration	Approx. 6.7 months	From Ilizarov application to cast removal
Final Assessment		3 months post-Ilizarov application
Final Outcome	Complete Cure	Solid union, no infection, no deformity, no limb length discrepancy, excellent functional recovery

Discussion

The 20-year-old patient achieved complete functional recovery through the Ilizarov method which demonstrates its absolute necessity in complicated orthopedic cases after suffering a transverse femoral shaft fracture that resulted in nonunion alongside chronic osteomyelitis. The case strongly demonstrates the severe challenges that doctors face when treating femoral nonunions with major translation because these cases show greatly reduced healing ability. The presence of chronic osteomyelitis made the medical situation more complicated so doctors needed to perform radical debridement by removing all dead bone tissue and diseased soft tissue to treat the infection effectively. The elimination of osteomyelitis through this vital procedure leads to major bone tissue losses which simultaneously destabilizes the affected limb thus creating significant challenges for reconstruction. The patient's condition worsened after the initial interlocking intramedullary nailing failed because this outcome possibly resulted in further bone damage which made future treatment procedures more difficult.

The Ilizarov method: a definitive path to healing

Given its superior applicability for difficult situations, the Ilizarov method provides particular benefits above conventional internal fixation approaches.

Minimally Invasive approach: Unlike internal fixation techniques involving significant incisions and de-tissue, the Ilizarov method employs minimal invasive approaches to preserve soft tissue and

periosteal regions. Because these tissues might be damaged during treatment, bone healing becomes dependent on the soft tissue envelope and blood supply protection in the event of infection. Because it promotes bone development along with deformity correction by means of slow stretching of tissues without impairing blood supply, the Ilizarov technique shows more success in the therapy of difficult bone infections. Through the deployment of various wire patterns and ring sizes that may be used for one ring rather than many rings, the Ilizarov therapy offers patients several treatment options, enabling several treatment alternatives for patients because it allows for several ways of administration.^{1,4}

Directly Confronting Infection: One of the principal advantages of the Ilizarov technique is its inherent ability for the direct management of deep-seated bone infections. Its design allows for the exact introduction of K-wires through or in proximity to infected segments, thus offering effective drainage and preventing the spread of infection, while simultaneously healing the fracture. Furthermore, the frame provides relentless stability following radical debridement, a process that is critical in eradicating osteomyelitis but one that leaves behind a huge bone defect. The Ilizarov method's special capacity to provide a regenerative environment actually allows new healthy bone to grow, which actively displaces or "burns out" the dead and infected tissue—a phenomenon quite rightly referred to as "burning the infection in the fire of Ilizarov's device." This active biological removal, rather than passive containment, is an extremely fundamental aspect of its mechanism of infection control.^{8,9}

New Bone Regeneration through Distraction Osteogenesis: At the heart of the Ilizarov method lies its astounding ability of generating viable new bone through distraction osteogenesis. By applying controlled, gradual tension-stress to the bone fragments, the body's own regenerative capacity is harnessed to fill even large bone defects. This new method often eliminates the necessity for autogenous bone grafting, which is often in limited supply for large defects and is attended by the additional morbidity of a donor site. This capability was of the utmost importance in recreating the bony loss that resulted from the debridement that was necessary in this patient.

Accuracy of Correction, Deformity and Limb Length Equalization: The Ilizarov frame's masterful multiplanar adjustability allows precise, step-wise correction of complex deformities, like angulation, rotation, and translation, and precise equalization of limb length discrepancy. This multi-axial, simultaneous correction of multiple parameters is virtually impossible to achieve with any other form of fixation device, making it the revolutionary aspect of the treatment.^{2,4}

Active Healing, Functional Use and Early Weight-Bearing: The stiff yet forgiving construction provided by the circular frame and tensioned K-wires permits early mobilization and functional loading of the limb throughout the entire course of treatment. Early weight-bearing actively promotes bone healing by stimulating callus formation, and prevents disuse osteoporosis and helps to maintain necessary joint mobility, which goes a long way in allowing a firmer and more complete functional recovery. The effectiveness of the Ilizarov method is not just due to its mechanical stability but due to the very precise interaction between these mechanical forces and the deep biological reaction of the organism, like distraction osteogenesis, neovascularization (formation of new vessels), and histogenesis (construction of the tissues) of nearby soft tissues. Such advanced mechanobiology knowledge and clinical practice are the essence of its superior effectiveness.

Avoidance of Excess Loads; No Need for Bone Grafting: The intrinsic nature of the Ilizarov technique to generate new bone with or without distraction osteogenesis easily outlives the need for autogenous bone grafting and thus eliminates the associated donor site morbidity and potential complications.

In this specific case, all these advantages in particular addressed the patient's multidimensional needs. Ilizarov method provided the multi-dimensional solution to eradicate the deeply rooted infection, meticulously reconstruct the resultant bone loss, precisely correct any potential shortening or deformity, and ultimately allow for complete return to function—all within a single, overarching treatment plan.^{6,8}

Table 2 Ilizarov principles applied in case management.

The Ilizarov principle	Mechanism of action	Specific application in patient case	Outcome achieved
Distraction Osteogenesis	Controlled, gradual separation of bone fragments stimulates new bone formation under tension-stress.	Used to bridge bone defects created by debridement and achieve union at nonunion site.	Solid bone union; regeneration of viable bone.
Relative Stability & Multiplanar Fixation	Provides sufficient stability for healing while allowing micro-motion; wires inserted in multiple planes for robust construct	Enabled early weight-bearing and functional use of limb; maintained alignment during regeneration.	Enhanced bone healing; prevented joint stiffness; stable limb.
Infection Management	External nature allows direct access to the infected area; pins can bypass/traverse infection without spreading.	Facilitated radical debridement; allowed ongoing wound care; created an environment for infection eradication.	Complete eradication of chronic osteomyelitis.
Deformity Correction	Modular frame allows precise, gradual adjustments in multiple planes.	Corrected pre-existing angular/rotational deformities and restored physiological limb length.	No residual deformity; no limb length discrepancy.
Biologic Preservation	Minimally invasive approach preserves soft tissues and periosteal blood supply.	Minimized surgical trauma in an already compromised limb, promoting optimal healing conditions.	Favorable environment for bone regeneration and infection control.

Navigating the challenges: managing potential Ilizarov complications

Although the Ilizarov method is unrivaled in its advantages, it must be pointed out that it represents an intense treatment course and is further complicated by the possibility of complications. These can include pin tract infections, which are common but typically manageable; pseudoarthrosis (nonunion) at docking sites; stiffness of the knee, particularly after femoral transport; and the inherent challenge of prolonged duration treatment. However, these common complications are well-defined and well-managed through meticulous post-operative care, e.g., intensive routine pin site care, antibiotic directed therapy for infection, application of maneuvers like the accordion maneuver in case of nonunion, and aggressive physiotherapy in case of stiffness.^{2,4}

In the patient described here, the successful outcome was heavily reinforced by attentive patient management, such as strict pin site care and an active physical therapy regimen. Successful consolidation and absence of deformity or limb length disparity in this patient attest to successful management or prevention of more severe complications such as failure of distraction osteogenesis, refracture, or nonunion at the docking point, which have been reported in other series.

Broader impact: review of relevant literature

A number of studies consistently validate the superiority of the Ilizarov method in dealing with complex femoral nonunions complicated by infection. Studies consistently mention its efficacy in achieving solid bone union, effectively curing infection, and restoring functional independence. The profound influence of the Ilizarov method on orthopedic practice is also complemented by its being at the core of the development of a specific discipline, limb lengthening and reconstruction surgery (LLRS). This development emphasizes that the Ilizarov technique is not merely one of a group of techniques, but a keystone that has reshaped the very boundaries of limb preservation and reconstruction.⁴

Nevertheless, it is important to consider the practical implications of its general application. Technologically superior, the Ilizarov technique necessitates prolonged treatment phases and demands total patient compliance, like proper medication adherence and careful pin site care. Studies have indicated that this kind of operation would be less appropriate in extremely socially disadvantaged individuals, with poor mental health need control, or without solid and unifying family support. This is to recall that although technically advanced, the success of the Ilizarov technique also largely rests on non-biological factors, so proper selection of patients and extensive support programs are required for optimal gains.⁷

Outcome category	Criteria (ASAMI Scale)	Patient's result	ASAMI Classification
Bone Result	Union Status	Union achieved	Excellent
	Infection Status	No infection	Excellent
	Deformity (degrees)	<7° (No residual deformity)	Excellent
	Limb Length Discrepancy (cm)	<2.5 cm (No residual LLD)	Excellent
Functional Result	Activity Level	Active	Excellent
	Limp	No limp	Excellent
	Stiffness (Knee extension/Ankle dorsiflexion)	Loss of <15° knee extension/<15° dorsiflexion of ankle (Minimum stiffness)	Excellent
	RSD (Reflex Sympathetic Dystrophy)	No RSD	Excellent
	Pain	Insignificant pain	Excellent

Conclusion

The excellent result of this challenging case - a transverse femoral shaft fracture with nonunion and chronic osteomyelitis with full union of the bones, eradication of infection, and restitution of whole function without deformity or limb length discrepancy - is a strong endorsement of the Ilizarov method. From original trauma and disappointment of failed internal fixation to probable risk of a limb-threatening infection and finally, to complete recovery, this patient's progression demonstrates the unmatched ability of the Ilizarov technique as a reconstructive and limb salvage procedure in even the most difficult orthopedic conditions. The Ilizarov technique is not only a possibility but also in many cases the only accessible means of obtaining such a complete and successful outcome when early, less damaging techniques have failed and patients are up with serious problems including infected nonunion. Its remarkable capacity to simultaneously treat infection, bone loss, deformity, and limb length inequalities elevates it as the ideal and most appropriate treatment for such sophisticated issues. This is achieved by its unique ability to induce strong new bone formation without grafting. The favorable result in this case - the avoidance of possible amputation and restoration of complete pre-injury function - confirms the Ilizarov method's place as a cornerstone of contemporary orthopedic

reconstruction, as inspiration to victims of seemingly incurable limb trauma and as a transformer of their lives.

Acknowledgements

None.

Conflicts of interest

The authors declare that there are no conflicts of interest.

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Clinical case report: bimodal salvage of a distal femoral periprosthetic fracture and subsequent biofilm infection in a high-bmi geriatric patient

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Introduction

There is an inherent complexity in the clinical management of periprosthetic distal femur fractures (PDFF) in the elderly population due to bone quality and the presence of prosthetic devices. In the presence of significant excess weight in the patient, there is an added complexity of tissue restraints and high mechanical stress loads attributed to destabilization devices.^{1,2} The following report outlines the successful binary limb-salvage strategy for the patient who suffered a Periprosthetic supracondylar fracture in October 2024 and subsequent periprosthetic joint infection in November 2025. The report also illustrates how high tension circular fixations and CLAP were utilized effectively for preservation of the original prosthesis in 2022.^{3,4}



Figure 1 Periprosthetic supracondylar fracture of the femur without dislodgement of prosthesis.

Clinical history and timeline

Table 1 Clinical progress and applied procedure.

Date	Clinical milestone	Intervention strategy
2022	Primary TKA	Management of severe osteoarthritis
Oct 2024	Periprosthetic Fracture	Ilizarov apparatus Fixation
Oct 2024 - Mar 2025	Osteosynthesis	5-month consolidation period
March 2025	Fixator Removal	21-day posterior back slab stabilization
November 2025	PJI Presentation	DAIR with 10-day CLAP therapy
Late 2025 (Dec last week)	Follow-up	Complete resolution; TKA component retained

Phase I: Management of periprosthetic fracture

Classification

In October 2024, the patient presented with a displaced supracondylar fracture proximal to her stable TKA. The injury was classified as:

Table 2 Supracondylar Fracture (Proximal to Stable TKA) classified as below.⁵

Classification System	Grade/Type	Key diagnostic findings
Lewis & Rorabeck	Type II	Displaced fracture; Stable femoral component.
Su Classification	Type II	Fracture starts at the proximal femoral flange and moves upward.
Kim Classification	Type IB	Stable prosthesis; fracture is irreducible (cannot be set manually).

Ilizarov Osteosynthesis in Obese patient

The circular fixator was chosen for the purposes of multi-planar stability as well as early mobilization. Nevertheless, the patient's BMI caused "difficulty in application." The rings had to be large in size (220-240 mm) in order for there to be a 2 cm skin margin, which inherently decreases the axial rigidity.^{1,6,7}

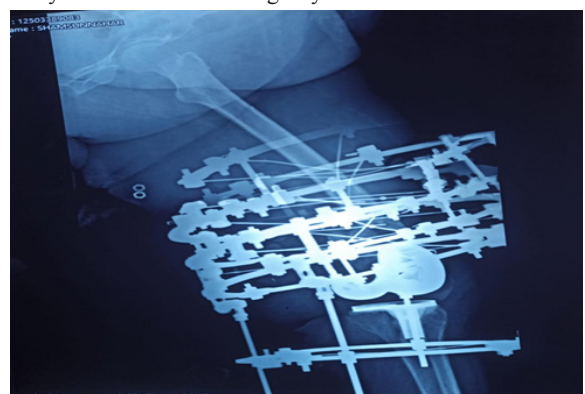


Figure 2 Periprosthetic supracondylar fracture was aligned and fixed with Ilizarov apparatus.

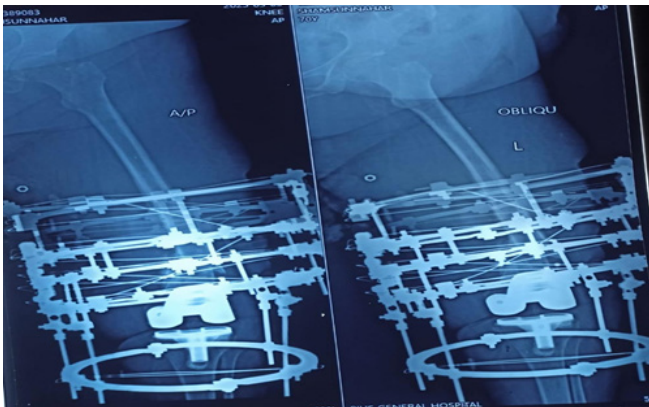


Figure 3 Multiple olive wires inserted to fixing the Periprosthetic fracture.

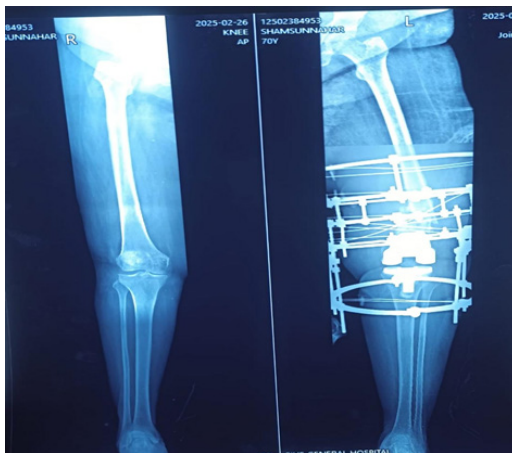


Figure 4 On X-ray stress view no limb length discrepancy.

Table 3 Olive Wire Risks of Failure in High-BMI Index Patients.^{1,6,8}

Factor	Mechanical risk to consequence	Risk to hardware
Ring Size	Decreased construct stiffness	Increased sagging and non-linear displacement
Axial Loading	Dominance of "cable" behavior	Yield failure of the wire under heavy mass
Cyclic Loading	Repetitive stress at bone-stopper interface	Metal fatigue leading to sudden wire breakage

To mitigate these effects, Russian bolts were used for tensioning purposes. The Russian bolts enable manual tensioning of high torque (1600N to 1695N), adequate to provide stiffness to prevent wire fatigue when the patient walks.^{1,2,8}

Justification of the 21-Day Back Slab

After five months of union, the frame was removed in March 2025. A posterior fixation with a back slab was then used for 21 days to offer temporary stabilization. This is an essential step in the fixation of the pin tracks because the cavities created by the 1.8 mm wires are known as "stress risers" of the bone, which tend to increase the chances of secondary fractures during the process of weight-bearing stress.^{1,6,8}

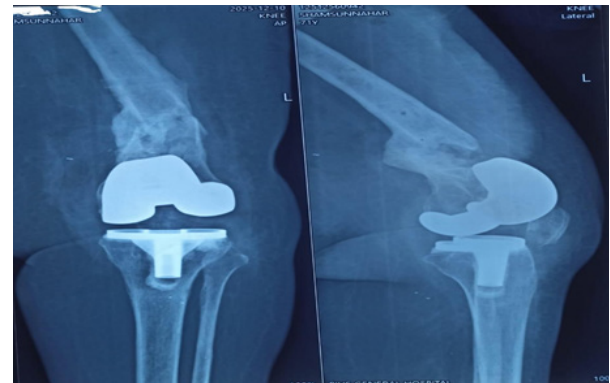


Figure 5 After demounting of the Ilizarov apparatus the Periprosthetic fracture was healed by callus formation.

Phase 2: Treatment of prosthetic joint infection

In November 2025, the patient was in the late stages of PJI. The treatment was DAIR therapy supplemented by CLAP therapy.^{9,10}



Figure 6 The CLAP therapy was applied to the Prosthetic Joint infection.



Figure 7 The negative pressure drain was used as outflow tract in CLAP therapy.

CLAP therapy dose calculation

The protocol was developed in order to keep a bactericidal dose of an antibiotic in the biofilm site itself.^{3,4,10}



Figure 8 Syringe pump is used for accurate dose calculation in inflow tract of CLAP therapy.

Carrier Solution: Gentamicin 160mg (2×80mg ampules) + 46ml 0.9 % Normal Saline.

Localised Concentration: 160 mg in 50 ml = 3.2 mg/ml = 3200 µg/ml

Perfusion rate: 2 ml/hr via intra-joint dual-lumen tubes

Daily Dose Rule/Formula: 2 mL/hr × 24 hr × 3.2 mg/mL = 153.6 mg/day

Progress and monitoring

The 10-day CLAP course showed rapid biological response:



Figure 9 Swelling and inflammation subsided after application of CLAP therapy.

Inflammatory Trends: Serum C-reactive protein (CRP) reached a ‘fast response pattern,’ lowering to a ratio of < 0.4 of its original value by day 4.

Clinical Findings: The erythema, warmth, and effusion resolved completely by the end of the 10-day perfusion phase.^{3,4}

Safety Profile: Despite the fact that the patient was elderly with significant weight, the serum gentamicin trough levels were kept below values of less than 2.0 µg/mL.¹⁰

Discussion

The success of this case emphasizes the balance of mechanical and biological salvaging techniques that must be used on the high-risk patient.

In **Phase 1**, The Ilizarov technique was chosen due to the fact that traditional internal plating has a complication rate as high as 35% in obese, osteoporotic populations, often secondary to hardware “cut-out”. A circular frame allowed axial load distribution over multiple points, providing controlled micromotion to allow for secondary bone healing.^{1,2,8}

In **Phase 2**, CLAP therapy overcame the basic inadequacies of systemic use of antibiotics. In clearing mature biofilms from implant surfaces, concentrations 100 to 1000 times the MIC are needed-levels that would be systemically toxic if given intravenously. Locally infusing 153.6 mg/day, the investigators maintained an intramedullary gradient of ≥ 500 µg/ml. In addition, Continuous Passive Motion (CPM) was incorporated during the 10-day perfusion period to allow fluid to circulate throughout the recesses of the joint to ensure complete coverage of the antibiotic on all prosthetic surfaces and to prevent arthrofibrosis.^{3,9,10}



Figure 10 On Follow up patient is able to stand by the support of Walker and there is no limb length discrepancy.

Conclusion

The patient has since made a full recovery, with the primary 2022 TKA functional. This represents that morbid obesity and advanced age are not absolute contraindications to successful limb salvage in complicated periprosthetic cases.^{1,2,10} Such a resolution was rested on three pillars:

High tension hardware constructs (> 1600N) to avoid component failure within a high-BMI setting. Transitional immobilization to protect the bone during consolidation of pin-site stress risers. Local pharmacological perfusion allows for the safe use of bactericidal concentrations not attainable by systemic methods.

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None.

Conflicts of interest

The authors declare that there are no conflicts of interest.

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From desiccated to dynamic: a 12-week multimodal rescue of the “devastated” diabetic limb

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Introduction

This report describes the successful salvage of a “threatened” lower extremity of an 18-year-old male with Type 1 Diabetes Mellitus (T1DM). Despite aggressive debridement for cellulitis and crusted scabies, the patient was left with a two-thirds tibial exposure and complete periosteal necrosis. Using the Ilizarov Tibial Transverse Transport and Console Wire Distraction as biological “pumps” for angiogenesis, we successfully induced surface granulation tissue on bare cortical bone surfaces without the use of fenestrations. This intensive preparation was then followed by a definitive Split Thickness Skin Graft (STSG) closure, resulting in 95% closure of the defect and limb salvage.

The clinical crisis

In October 2025, the patient was admitted with a life and limb-threatening infection triad:



Figure 1 Slough over the tissue on the medial aspect of leg.



Figure 2 Exposed Tibia with necrotic periosteum on the lateral aspect of leg.



Figure 3 CT angiogram shows flow reduction of lower limb vessels.

Systemic compromise: Microangiopathy caused by T1DM, arresting the natural healing cascade.¹⁻³

Parasitic infestation: Crusted scabies, compromising the skin and allowing the invasion of virulent *Streptococcus pyogenes*.

Mechanical deficit: Radically debrided necrotic periosteum, leaving the upper two-thirds of the tibia exposed, dry, and without its primary vascular supply.⁴⁻⁶

The multimodal “Biological engine”

The surgical strategy was designed to avoid primary amputation and utilize a 12-week regenerative protocol to “force” angiogenesis from the bone marrow to the cortical bone surfaces.^{4,6}

Phase I: Radical debridement

The non-viable periosteum and infected soft tissue were completely removed. The bone was debrided until punctate bleeding, referred to as the ‘chili powder sign,’ occurred. However, unlike previous methods, the cortex was left intact without fenestrations to preserve structural integrity.^{7,8}



Figure 4 Sign of Viability appears to soft tissues.

Phase II: The Ilizarov stimulation (12-week frame duration)

A circular Ilizarov frame was applied to convert the bone into a living vascular pump. This was done through two methods:



Figure 5 Granulation started after Ilizarov stimulation by TTT and Wire technique distraction.



Figure 6 Granulated wound over the medial aspect of the leg.

Tibial transverse transport (TTT): The bone flap was distracted transversely (1 mm/day). This resulted in a systemic increase in pro-angiogenic growth factors (VEGF) and endothelial progenitor cells.^{1,2,7}

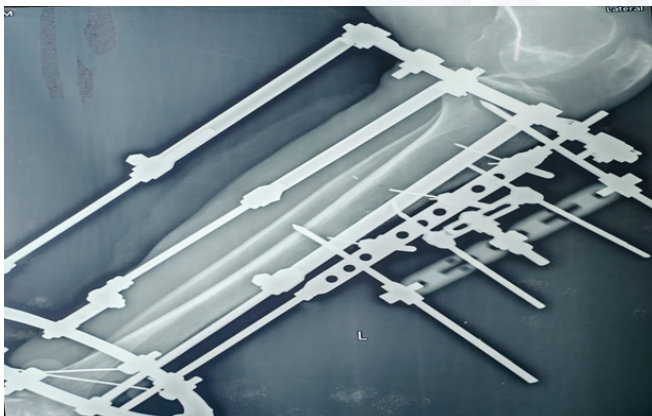


Figure 7 X-ray Shows TTT and Wire technique on the Tibia by Ilizarov technique.

Console wire distraction: Specialized wires were inserted through the exposed cortex into the second cortex. Tensioning these wires resulted in a localized stimulus, 'pushing' intraosseous blood flow through the Haversian systems to the bone surface.^{2,9}

Phase III: Synergistic NPWT

At the same time, 8 cycles of Negative Pressure Wound Therapy (-125 mmHg) were administered. This provided an external 'pull' to meet the internal 'push' from the wires, allowing small islands of granulation tissue to coalesce into a continuous moist tissue carpet.^{4,8}

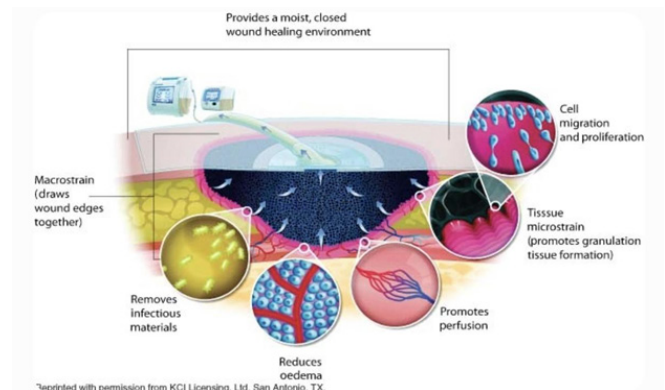


Figure 8 Process and mechanism of NPWT method.

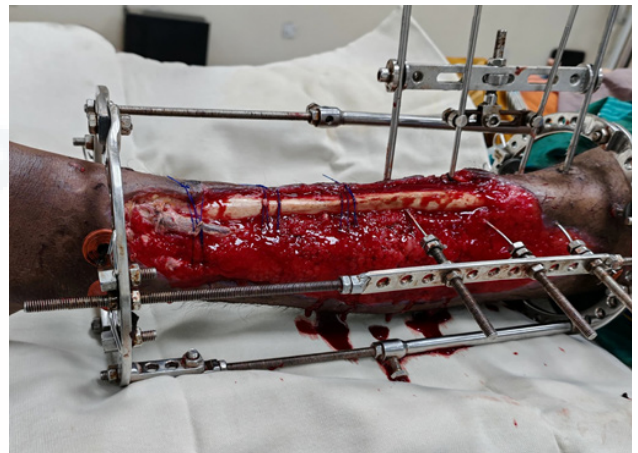


Figure 9 Granulation tissues started growing over the tibia.

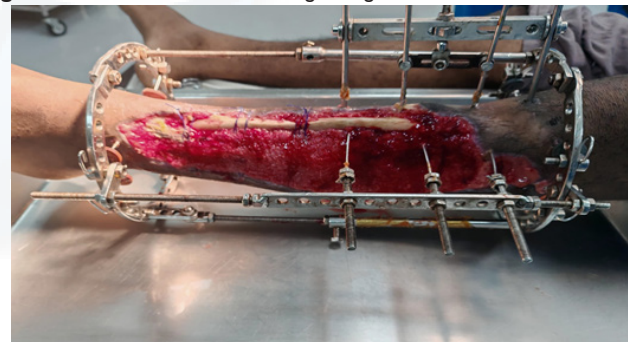


Figure 10 Gradually granulation tissue grow over the exposed tibia.

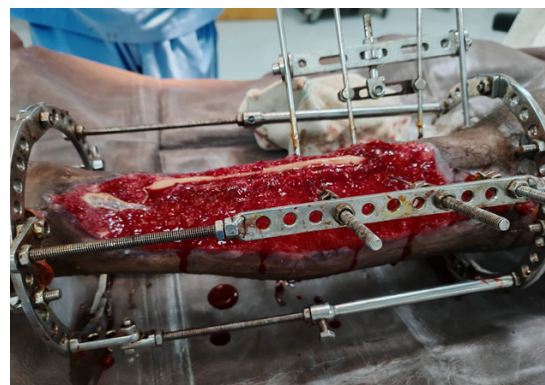


Figure 11 After giving 6th Episode of NPWT the granulation tissues growing over the tibia.

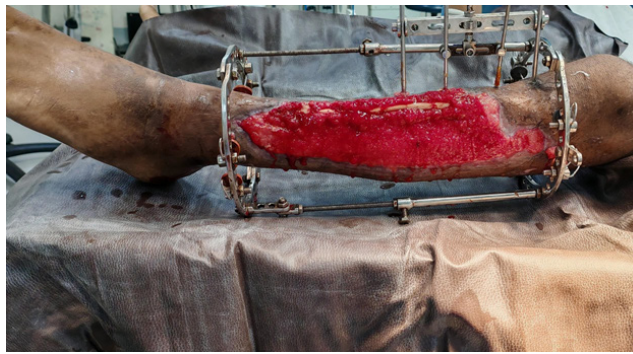


Figure 12 On 7th Episode of NPWT the Tibia almost covered with granulation.

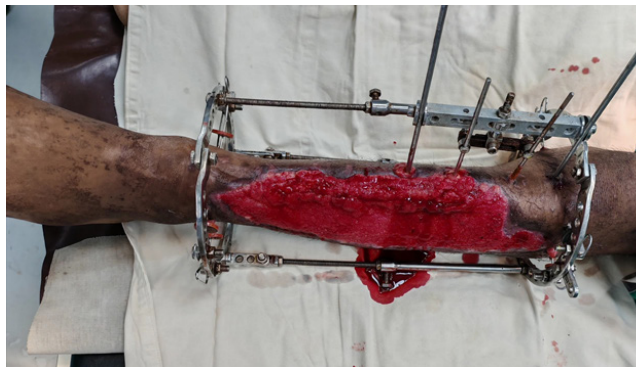


Figure 13 The tibia is fully covered with granulation after 8th Episode of NPWT.



Figure 14 The wound over medial side is healed completely.

Integrated management protocol

Parameter	Tibial transverse transport (TTT)	Console wire distraction	Split thickness skin graft (STSG)
Primary Goal	Regional Vascular Recruitment	Cortical Circulation Stimulus	Definitive Wound Closure
Biological Role	Recruits systemic progenitor cells	"Pumps" blood to bare bone	Re-establishes skin barrier
Mechanical Action	Bone flap transport (1 mm/day)	Tensioning through 1st & 2nd cortex	0.3 mm skin transplantation
Timeline	12 Weeks (Total Frame Time)	12 Weeks (Total Frame Time)	After Frame Removal
Success Marker	Reversal of local ischemia	Full coverage of denuded tibia	95% Graft "Take"

Definitive reconstruction: post-frame STSG

The Ilizarov distraction-stabilization device was removed after 12 weeks of distraction and stabilization. The bone surface that was previously “dead” was now completely covered by a high-quality reddish granulation tissue bed. A meshed Split Thickness Skin Graft (STSG) was then harvested and applied. The strong vascularization that occurred during the 12-week “pump” phase ensured successful graft adherence in spite of the metabolic problems posed by T1DM.^{2,9,10}



Figure 15 X-ray after removal of Ilizarov apparatus.

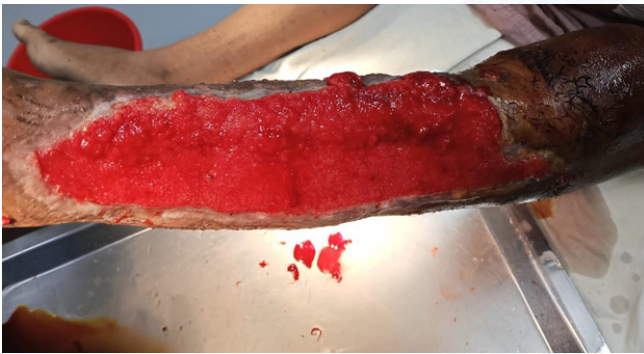


Figure 16 After proper granulation and tibia is completely covered the Ilizarov apparatus was removed.



Figure 17 After proper granulation STSG was done.

Rehabilitation and weight-bearing schedule

Weeks 1-8: Protected weight-bearing in the Ilizarov frame to encourage bone consolidation at the TTT site.

Weeks 9-12: Full weight-bearing in the Ilizarov frame to assess the stability of the newly formed soft tissue.^{2,4}

Post-Frame/Post-STSG: 2 weeks of immobilization to protect the graft, followed by a gradual return to independent ambulation with metabolic monitoring.⁸

Discussion

This case questions the need for cortical fenestration and microvascular flaps in severe tibial trauma. By stimulating the second cortex with console wires, we harnessed the *Law of Tension-Stress* to circumvent the absent periosteum. The 12-week carrying of the frame was essential. This allowed the window for distraction histogenesis—the development of new blood vessels and soft tissue—to achieve a state of biological maturity. By the time the frame was removed, the wound was no longer “diabetic and stagnant” but a living, breathing environment ready to support a skin graft on its own.^{2,5,6}

Conclusion

Limb salvage in the “devastated” diabetic limb is possible with the judicious use of mechanical forces. The combination of TTT, Console Wire Distraction, and NPWT represents a biological amplification that mandates tissue regeneration in the face of failed physiological healing.^{1,4,6} This 12-week multimodal treatment regimen represents a potent alternative to amputation, ensuring functional return for young patients with catastrophic orthopedic injuries.

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None.

Conflicts of interest

The authors declare that there are no conflicts of interest.

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Chapter 22

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Biography



Professor Dr. Md. Mofakhkharul Bari has had a brilliant academic career, securing distinction in his Secondary School Certificate (S.S.C) and Higher Secondary Certificate (H.S.C) with star marks. After completing his Higher Secondary Certificate from Dhaka College, he was admitted to

Chittagong Medical College. Awarded a Soviet Government Scholarship in 1975, he obtained his M.D. from Kiev Medical Institute (Kiev, the Soviet Queen City, the capital of Ukraine) in 1982. In 1984, he accomplished his M.S. degree in Orthopaedics from the Kiev Scientific Research Institute of Orthopaedics and Traumatology (KSRIOT).

Returning to his native land, he joined Government service in May 1986 and was posted as Consultant Orthopaedics in a 200-bedded hospital near Dhaka, Narayanganj. In February 1991, he joined the Leprosy Control Institute and Hospital, Mohakhali, Dhaka, in the Department of Orthopaedics and Reconstructive Surgery. He was subsequently awarded a Ph.D. Scholarship at the Tashkent Scientific Research Institute of Orthopaedics and Traumatology under the guidance of Professor B.M. Mirazimov, Ph.D; D.Sc, who was the Director of the Institute. In 1995, he obtained his Ph.D. from the Tashkent Scientific Research Institute of Orthopaedics and Traumatology. In 2003 and 2006, he pursued Post-Doctoral Fellowships on the Ilizarov Technique at the Kurgan Ilizarov Center, Russia.

For seven years and seven months, he worked in a 30-bedded Government Leprosy Hospital in the Department of Reconstructive Surgery with disabled patients, performing more than seven hundred surgeries for claw hand deformities, drop foot deformities, and nerve decompression including ankle and wrist arthrodesis. He also completed a Volkov-Oganesyan Fellowship in May 2003 in CITO (Central Institute of Traumatology and Orthopaedics), Moscow, and attended workshops and deformity correction courses in Miraj, India in 2003, and in Goa, India in April 2005 under Professor Dror Paley, MD, and in Tashkent in October 2005.

Professor Bari completed his Fellowship in Leprosy Reconstructive Surgery in 1997 at SLRTC (Shiefflin Leprosy Research and Training Centre), Chennai, Tamil Nadu, under a WHO Scholarship. He joined Mymensingh Medical College and Hospital in September 1999 as Assistant Professor in the Department of Orthopaedics and Traumatology, serving there for approximately five years. He has

published 66 papers in International and 52 National Journals of repute, earning tremendous admiration from the relevant professional quarters.

He has been presenting scientific papers at International and national conferences regularly, and since 2005 has been delivering lectures as a faculty member at different International conferences. He has been closely associated with Professor E.T. Sklerenko Ph.D; D.Sc of Kiev Scientific Research Institute of Orthopaedics and Traumatology; Professor B.M. Mirazimov Ph.D, D.Sc of Tashkent Scientific Research Institute of Orthopaedics and Traumatology; Professor Mirhakim Azizov (Director, Tashkent Scientific Research Institute of Orthopaedics and Traumatology); Professor O.V. Oganesyan Ph.D. D.Sc of CITO, Moscow; Professor Dror Paley, MD, FRCS of Florida, USA; Professor M. Catagny of Italy; Professor G.S. Kurlkarni of Miraj; Professor H.R. Jhunjhunwala of Mumbai; and Professor M. Shah from Bangalore, India.

In February 2004, he joined NITOR (National Institute of Traumatology and Orthopaedic Rehabilitation), Dhaka, as Associate Professor and served as Unit Chief of the Limb Lengthening, Deformity Correction and Surgical Reconstruction Unit by the Ilizarov Technique — a position he held for more than ten years until November 2013. He is the former Unit Chief of NITOR's Limb Lengthening, Deformity Correction and Surgical Reconstruction Unit.

The Kurgan Ilizarov Center in Russia — the largest Orthopaedic Institute in the world — conferred its most prestigious degree upon Professor Dr. Md. Mofakhkharul Bari as Emeritus Professor on 14th June 2013, symbolizing «the globally reputed medical scientist (Orthopaedics)». He is the first foreigner ever to be awarded this distinguished honour. He has further been recognised with the title of Honorary Emeritus Professor in acknowledgement of his exceptional and enduring contributions to the field of Orthopaedics and Traumatology. This great honour is an iconic achievement for Bangladesh and a defining milestone in the Orthopaedic arena.

He is Former Honorary Professor at NITOR, Dhaka, Bangladesh, and Now serves as Visiting Professor at both BIRDEM General Hospital and BIHS General Hospital, where he continues to advance the practice of reconstructive orthopaedic surgery. He is the Chief Consultant and Professor of the private BARI-ILIZAROV Orthopaedic Centre in Dhaka, a distinguished institution comprising 44 beds.

Professor Dr. Md. Mofakhkharul Bari has an outstanding publication record totalling 113 publications in international foreign journals, covering diverse topics in Orthopaedics and Traumatology. He has authored 8 richly textured books, now widely read as key references in multiple countries across the world. Among his most celebrated clinical achievements are deformity correction, limb lengthening, stature lengthening, osteomyelitis management, treatment of all non-unions and pseudoarthrosis, and open fractures — all applied with remarkable outcomes in Bangladesh. His work stands as an iconic milestone in the orthopaedic arena and a matter of enduring national pride.

Beyond his clinical and research pursuits, Professor Bari devotes considerable time to teaching and the mentorship of the next generation of orthopaedic surgeons. His books on the Ilizarov technique are globally reputed and widely referenced across multiple countries.

One life, but the goal
is to bring smiles to
everyone's faces.
Prof Dr. Md. Mofakhkharul Bari
is now serving in 2 hospitals.



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