# Case Reports and Reviews

Case Report



# From Discrete Patching to Continuous Deformation: Viscoelastic Boundary Control in Infected Distal Tibial Nonunion


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## Abstract

*Infected nonunion of the distal tibia represents a dual failure mode: a stochastic biological void (infection, necrosis, and bone loss) and a geometric boundary deficit (a soft-tissue envelope that cannot be closed). Conventional reconstruction often treats the soft-tissue problem as an additive filling task, typically combining a vascularized flap with split-thickness skin grafting (STSG) or negative-pressure wound therapy (NPWT). We report a resource-sparing alternative framed as viscoelastic boundary control. A middle-aged woman presented with an infected, draining nonunion of the distal third tibia. After radical debridement to bleeding bone and culture-guided antibiotics, structural continuity was restored using autologous mid-shaft fibular corticocancellous struts. A distally based medial hemisoleus flap, pivoting on distal posterior tibial perforators, provided reliable vascular coverage. Instead of STSG or NPWT, stepwise bedside dermatotraction was applied using reinforced adjustable ties constructed with doubled-suture NICE knots, tightened in 1-3 mm increments under vigilant perfusion monitoring. Progressive approximation culminated in delayed primary closure with complete epithelialization, preserved flap viability, and satisfactory cosmesis. This case illustrates how converting a spatial deficit into a time-domain problem can exploit skin stress relaxation and creep to achieve a topologically continuous closure, potentially reducing donor-site morbidity and interface complexity in biologically compromised distal tibial reconstruction.*


## Introduction: The Topology of Defect

The distal tibia constitutes a hostile boundary condition for reconstruction: limited soft-tissue coverage, relatively tenuous vascularity, and high mechanical demand. When infection supervenes, tissue loss may exceed regenerative capacity, creating a state of biological bankruptcy in which both union and coverage become unreliable [1]. Standard reconstruction often follows a modular logic: eradicate infection, stabilize the bone, then fill the soft-tissue deficit. For distal-third defects, the distally based medial hemisoleus flap (a Type II Mathes-Nahai muscle flap supplied by distal perforators of the posterior tibial artery) offers a reproducible arc of rotation and dependable perfusion [2-6]. Muscle flaps are frequently covered with STSG; although effective, a graft introduces a secondary interface and donor-site morbidity, and yields a discontinuous cutaneous surface.

This report explores a geometric alternative. Rather than asking which material can be imported to patch a defect, we ask whether the boundary itself can be reshaped. By combining a reliable vascular carrier (distally based medial hemisoleus flap) with a titratable tension-control interface (stepwise dermatotraction using adjustable NICE-knot constructs), a spatial deficit can be converted into a temporal problem. The approach exploits viscoelastic skin properties (stress relaxation and creep) to enable delayed primary closure, aiming to replace discrete patching with continuous deformation.

## Case Presentation: Resetting The System State

A middle-aged woman presented with an infected, draining nonunion of the distal third tibia (Figure 1). After assessment and planning, reconstruction was conceptualized as a staged system reset with four phases.

**Phase 1:** Entropy reduction (infection control): Radical debridement was performed down to bleeding bone, with excision of necrotic tissue and acquisition of multiple deep cultures. Antibiotics were subsequently tailored to culture sensitivities.

**Phase 2:** Structural determinism (bony continuity): Autologous mid-shaft fibular


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***Figure 1***. *Preoperative appearance of infected distal-third tibial non-union with draining ulceration and soft-tissue deficit.*

corticocancellous struts were harvested and used to bridge the tibial defect, re-establishing a load-bearing pathway. Fixation strategy was selected to maintain stability while minimizing additional soft-tissue insult.

**Phase 3:** Vascular state control (coverage): A distally based medial hemisoleus flap was designed with handheld Doppler confirmation of distal posterior tibial perforators and rotated to cover the distal tibia as a dependable vascular module (Figure 2A).

**Phase 4:** Viscoelastic closure (boundary control): Instead of immediate STSG (a static patch), a dynamic dermatotraction protocol was initiated after flap inset. Reinforced adjustable ties were constructed at approximately 1.5-2.0 cm intervals using doubled-suture NICE-knot loops. At each daily dressing, ties were tightened by approximately 1-3 mm, with immediate relaxation if any sign of venous congestion or ischemia was observed (Figure 2B). This protocol aimed to induce controlled creep and stress relaxation while preserving perfusion.

## Postoperative course and outcomes

The flap remained viable throughout the tightening period. Progressive approximation culminated in complete epithelial closure without STSG or NPWT (Figure 4). Post-reconstruction radiographs demonstrated maintained fixation and progressive consolidation (Figure 5). The patient regained independent ambulation and reported satisfaction with the cosmetic result.

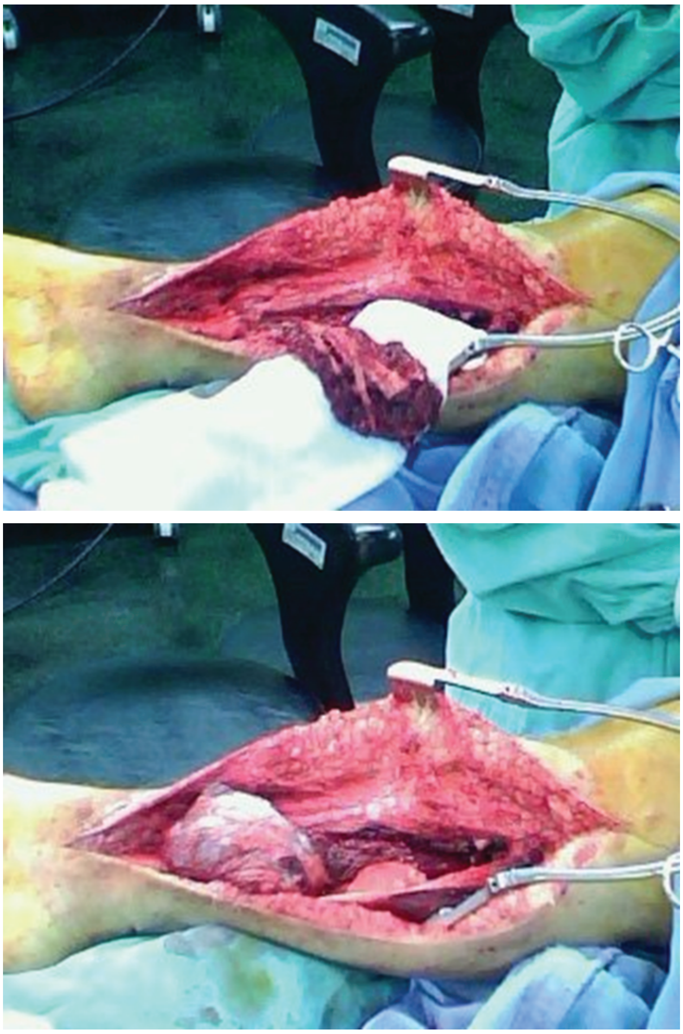

***Figure 2***. *Intraoperative views of the distally based medial hemisoleus flap and the dermatotraction setup. (A) The flap rotated to cover the distal tibia. (B) After flap inset, wound edges were gradually approximated using reinforced adjustable ties constructed with doubled-suture NICE-knot loops (daily 1–3 mm increments under perfusion monitoring).*

## Discussion: A First-Principles Analysis

### The hemisoleus flap as a deterministic vascular module

The distal tibia is prone to biological uncertainty due to limited soft-tissue stock and variable local perfusion. The distally based medial hemisoleus flap provides a reproducible solution by relying on consistent distal perforators of the posterior tibial artery, thereby importing a block of well-perfused tissue into a compromised bed [2-7]. In this sense, the flap functions as a reliability component: it does not merely cover exposed structures, but also supports local immune surveillance and tissue oxygenation after infection control.

### Dermatotraction converts space into time

The key conceptual shift in this case is the rejection of immediate skin grafting as the default closure endpoint. A soft-tissue defect can be described as a spatial deficit (delta x). The conventional solution (STSG) adds external material to fill delta x, at the cost of donor-site morbidity and an additional graft-host interface. By contrast, viscoelastic boundary

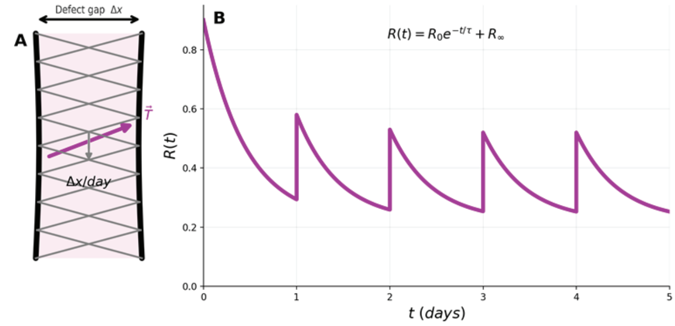


***Figure 3**. Schematic illustrating the viscoelastic boundary control applied in this case. (A) Vector interaction model: the clinical defect is abstracted as a geometric variable, Δx; the applied tension vector, T, drives a daily boundary displacement (Δx/day). (B) System response dynamics: the resistive force follows the analytical solution R(t) = $R_0$ e^{-t/τ} + R∞, where R(t) is the resistive force, $R_0$ is the peak tension after tightening, τ is the relaxation time constant, and R∞ is the residual equilibrium stress. The strategy leverages exponential decay (e^{-t/τ}) to reset the system state daily, enabling incremental closure without exceeding an ischemic threshold (R_crit).*

***Figure 4**. Clinical outcome after viscoelastic boundary control. Postoperative appearance demonstrating progressive approximation and complete epithelialization / delayed primary closure of the distal tibial soft-tissue defect following distally based medial hemisoleus flap coverage and stepwise dermatotraction using adjustable NICE-knot constructs, without STSG or NPWT. (Left) Local wound appearance. (Right) Patient's standing/functional status at follow-up.*

control leverages the skin's stress relaxation and creep under low, sustained tension to reduce delta x over time. In practical terms, closure becomes a function of tension and time. Through stepwise adjustments, time is traded for space, allowing the wound to reach delayed primary closure without importing an inferior surface layer.

External evidence supports the feasibility of this strategy. Dermatotraction techniques (including the shoelace method) have been reported as effective options for delayed primary closure, reducing or eliminating the need for skin grafting in selected situations [9-11]. A meta-analysis of fasciotomy-

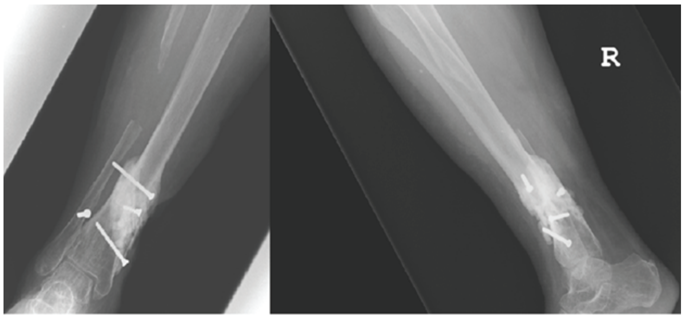


***Figure 5**. Post-reconstruction radiographs (anteroposterior and lateral) showing fixation and progressive consolidation after fibular strut grafting.*

wound closure techniques reported high primary-closure success with dynamic dermatotraction, while NPWT showed low complication rates but lower primary-closure success in comparison [19].

## The NICE knot as a control interface

Standard closure sutures are effectively binary: tension is set at the time of tying and then left to biology. In contrast, adjustable doubled-suture NICE-knot constructs can be treated as a titratable actuator that enables incremental control of the tension vector while maintaining security [12]. This enables a simple bedside feedback loop: tighten, assess perfusion, and wait. Conceptually, this transforms closure from a single high-stakes event into a controllable algorithm parameterized by small daily increments and perfusion-based stopping rules.

## Mechanistic plausibility: low strain, avoid ischemia

Although the present report is clinical and descriptive, mechanistic literature supports the plausibility of gentle mechanical tension promoting a pro-granulation and pro-angiogenic phenotype. Cyclic mechanical stretch can increase VEGF and FGF-2 expression in vascular smooth muscle cells [15], and mechanotransduction pathways such as YAP/TAZ interact with VEGF signaling to regulate sprouting angiogenesis and vascular barrier maturation [16,17]. Broader reviews of endothelial responses to mechanical stretch further support the concept that deformation cues can influence vascular biology [18]. These observations are consistent with the operating principle used here: apply low, incremental strain to induce viscoelastic deformation while avoiding capillary occlusion and flap ischemia.

## Limitations

Limitations include the single-patient design, absence of quantitative perfusion monitoring, and lack of formal biomechanical measurement of applied tension. Accordingly, the framework proposed here should be interpreted as a conceptual model supported by a single instantiation rather than comparative evidence. Future work could parameterize dermatotraction protocols (increment size, frequency, and perfusion thresholds) and evaluate outcomes against STSG- or NPWT-based pathways.

## Conclusion

In infected distal tibial nonunion, reliability requires simultaneous control of infection, structural continuity, and the soft-tissue boundary. This case demonstrates that, after radical debridement and culture-guided antibiotics, autologous fibular strut grafting combined with a distally based medial hemisoleus flap can be followed by stepwise, low-strain dermatotraction using adjustable NICE-knot ties to achieve delayed primary closure without STSG or NPWT. By exploiting skin viscoelasticity, the method replaces discrete patching with continuous deformation and may reduce resource use, preserve flap monitoring, and improve cutaneous continuity in carefully selected patients.

## Ethics, funding, and conflicts of interest

**Ethics and consent:** Written informed consent for publication of de-identified clinical details and images was obtained from the patient.

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**Conflicts of interest**: The author declares no conflicts of interest.

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