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PILOT STUDY

Peripheral Nerve

Pilot Study: Innovative Minimally Invasive Tarsal Tunnel Release for Diabetic Foot Ulcer Patients Minimizing Drawbacks

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Background: Diabetic foot ulcers are challenging to manage due to the multifactorial nature of the disease, with diabetic neuropathy being a primary contributing factor. Tarsal tunnel release has shown promise in restoring sensation, reducing ulcer recurrence through improved sensation, and enhancing microcirculation to promote ulcer healing. However, existing open and endoscopic techniques have notable limitations. This study introduces a novel minimally invasive tarsal tunnel release technique designed to address these shortcomings.
Methods: A retrospective cohort study was conducted at Sengkang General Hospital, a tertiary care center. The control group comprised 22 consecutive patients who underwent open tarsal tunnel release, whereas the treatment group included 34 consecutive patients treated with the novel minimally invasive approach. All patients were followed up for a minimum of 3 months.
Results: Both groups demonstrated comparable efficacy in improving sensation (100% versus 95.5%) and 2-point discrimination (88.2% versus 86.4%; $P = 0.19$, $P = 0.83$, respectively). However, the treatment group exhibited significantly shorter wound lengths (2.3 ± 0.26 versus 5.8 ± 0.72 cm; $P < 0.0001$) and a faster wound healing duration (15 ± 5 versus 24 ± 17 d; $P = 0.0052$). Additionally, the treatment group experienced no major wound complications compared with a 13.6% complication rate in the control group ($P = 0.029$).
Conclusions: This minimally invasive novel technique demonstrates similar efficacy in improving sensation while addressing the limitations of existing open and endoscopic methods. It offers significant advantages in terms of reduced wound size, faster healing, and lower complication rates. *(Plast Reconstr Surg Glob Open 2025;13:e6719; doi: 10.1097/GOX.0000000000006719; Published online 21 April 2025.)*

INTRODUCTION

Diabetic foot ulcers (DFUs) are a common and serious complication of diabetes mellitus, with a prevalence of 4%–10% and a lifetime risk estimated at 15%.[1] The treatment of DFUs is particularly challenging due to their multifactorial nature, with diabetic neuropathy being a significant contributing factor.

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Pathophysiology of Diabetic Neuropathy

Diabetic neuropathy often manifests in a glove-and-stocking distribution, characterized by gradual sensory loss in the feet. This sensory impairment increases the risk of repetitive microtrauma, which can contribute to the development of DFUs. One proposed explanation for this phenomenon is the "double crush" hypothesis. According to this theory, metabolic disturbances in diabetes, such as elevated intraneural osmolarity caused by hyperglycemia, lead to nerve edema. Additionally, the intraneural accumulation of advanced glycation end products triggers

Limitations regarding long-term follow-up inherently exist in this article type.

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an inflammatory response that impairs nerve gliding. These pathological changes heighten the susceptibility of peripheral nerves to compression, particularly in regions of anatomical narrowing, such as the carpal tunnel in the wrist and the tarsal tunnel in the ankle.[2] Supporting this hypothesis, the prevalence of carpal tunnel syndrome is significantly higher in individuals with diabetes, estimated at approximately 14% compared with 3% in the general population.[3] Similarly, the posterior tibial nerve within the tarsal tunnel is another site prone to chronic compression due to the aforementioned metabolic abnormalities, leading to tarsal tunnel syndrome.[4]

Tarsal Tunnel Release Surgery and Current Limitations

In addition to medical optimization, surgical intervention may play a role in addressing diabetic neuropathy. Tarsal tunnel release has demonstrated efficacy in improving neurological function and reducing ulcer recurrence by restoring sensation.[5] Furthermore, this procedure can enhance microcirculation in the feet postoperatively,[6] thereby promoting ulcer healing. The surgery involves decompressing the tarsal tunnel (the space between the flexor retinaculum and the medial ankle bone) as well as distal segments beneath the abductor hallucis muscle and its deep fascia, where the tibial nerve branches into the medial and lateral plantar branches.

The standard open tarsal tunnel release requires a 5–6 cm incision along the medial ankle to access the tibial nerve beneath the flexor retinaculum and abductor muscle. However, this approach carries the risk of wound complications, including delayed healing and infection, particularly in patients with diabetes with compromised wound-healing capacity. Minimally invasive techniques utilizing endoscopic release have been described[7,8]; however, these methods often necessitate the use of an intraoperative tourniquet and postoperative compression bandages to control bleeding and prevent hematoma formation. Such measures are contraindicated in patients with peripheral arterial disease (PAD), which affects approximately 50% of DFU patients.[9]

To overcome these limitations, we developed a novel minimally invasive technique for tarsal tunnel release tailored to DFU patients. This study demonstrates that the minimally invasive approach reduces complications and accelerates wound healing due to smaller incision sizes, while achieving outcomes in nerve decompression comparable to those of the traditional open procedure.

MATERIALS AND METHODS

Ethical Approval

An institutional review board (IRB) exemption (IRB Ref: 2023/2248) was granted by the Sengkang General Hospital IRB for this clinical audit. Informed consent was obtained from all patients for the publication of their photographs.

Study Design and Setting

This retrospective cohort study was conducted at Sengkang General Hospital, a single tertiary care center. All procedures were performed by a single consultant plastic surgeon. Patients presenting with DFUs were referred to the diabetic limb salvage team[10] for wound management and assessment for tarsal tunnel release as part of their treatment plan to reduce ulcer recurrence.

Takeaways

Question: Is there a novel minimally invasive tarsal tunnel release technique that has similar efficacy yet minimizes the drawbacks of traditional approaches?

Findings: This retrospective cohort study consisted of a control group of 22 patients who received open tarsal tunnel release and a treatment group of 34 patients who were treated with this novel technique. The treatment group not only experienced similar improvements in sensation and 2-point discrimination but also had a significant reduction in wound length, wound healing duration, and no complications when compared with the control group.

Meaning: This novel technique, therefore, aimed to improve on the drawbacks of traditional approaches.

Patient Selection

The inclusion criteria[11] comprised patients with:

- symptomatic diabetic neuropathy,
- a positive Tinel sign,
- adequate blood supply (no PAD or PAD successfully treated with angioplasty).

Study Groups

- Control group: Twenty-two consecutive patients underwent open tarsal tunnel release between March 1, 2022, and October 31, 2022.
- Treatment group: Thirty-four consecutive patients underwent minimally invasive tarsal tunnel release between November 1, 2022, and September 30, 2023.

Tarsal tunnel release was performed either concurrently with wound closure or after wound healing. Both groups received standardized wound care and follow-up. No patients were excluded from the study. All participants were followed up for a minimum of 3 months.

Data Collection

Patient data were collected from March 1, 2022, to December 31, 2023. The follow-up period for the control group spanned from March 2022 to February 2023, whereas for the treatment group, it spanned from November 2022 to December 2023.

Demographic and medical data collected included (Table 1):

- age, sex, and comorbidities (eg, hypertension, ischemic heart disease, kidney disease, and PAD);
- HbA1c levels (a marker of glycemic control) at the time of surgery.

Table 1. Demographics of Open Versus Minimally Invasive Approach

Demographics and Comorbidities	Open Release, n = 22	Minimal Invasive, n = 34	*P*
Age, y	55.3 ± 12.5	57.3 ± 14.1	0.5904
Sex: male	63.6% (14/22)	67.6% (23/34)	0.7597
HbA1C, %	9.7 ± 3.8	9.5 ± 3.2	0.8328
Hypertension	72.7% (16/22)	79.4% (27/34)	0.5513
Ischemic heart disease	31.8% (7/22)	23.5% (8/34)	0.4603
Chronic kidney disease	22.7% (5/22)	26.5% (9/34)	0.8014
End-stage renal failure	9.1% (2/22)	5.9% (2/34)	0.6738
PAD	45.5% (10/22)	44.1% (15/34)	0.9419

Table 2. Outcomes of Open Versus Minimally Invasive Surgery

Outcome	Open Surgery	Minimally Invasive	*P*
Subjective improvement	95.5% (21/22)	100% (34/34)	0.1919
2PD improvement	86.4% (19/22)	88.2% (30/34)	0.8283
TTR wound length, cm	5.8 ± 0.72	2.3 ± 0.26	<0.0001
Mean TTR wound healing duration, d	24 ± 17	15 ± 5	0.0052
Major TTR wound complications	13.6% (3/22)	0% (0/34)	0.0285
Mean diabetic foot wound healing duration, d*	61 ± 20 (20)	58 ± 27 (29)	0.6654
No. recurrences posttarsal tunnel release	4.5% (1/22)	2.9% (1/34)	0.74896

*Including patients who received primary closure, skin grafting, and local flap.
TTR, tarsal tunnel release.

Fig. 1. A photograph showing the traditional wound length and site on a patient who underwent open tarsal tunnel release.

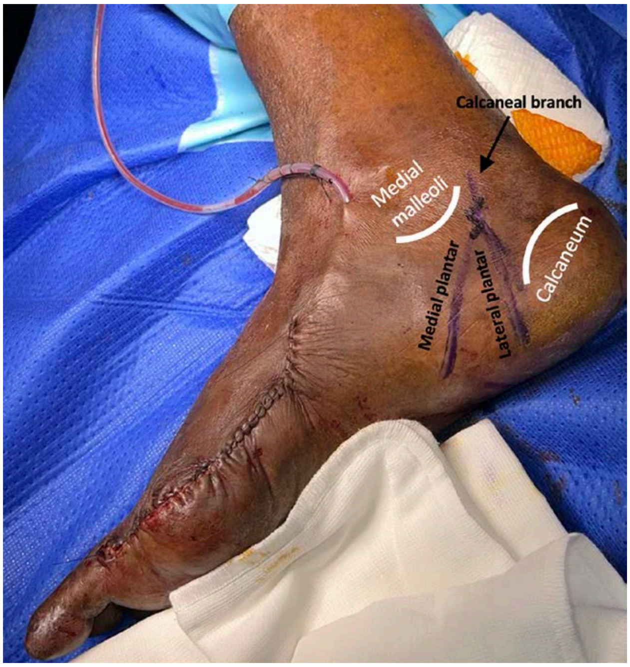

Fig. 2. A photograph showing medial and lateral branches, and the main trunk of posterior tibial nerve marked out. A zigzag incision was made between the calcaneum and medial malleolus.

Clinical outcomes measured included (Table 2):

- subjective improvement in foot sensation,
- improvement in 2-point discrimination (2PD),
- tarsal tunnel release wound length,
- major wound complications (eg, dehiscence, infection),
- wound healing duration,
- recurrence rates.

2PD Measurement

Three points on the plantar surface were tested for 2PD: the heads of the first and fifth metatarsals and the calcaneum. The mean 2PD score was calculated from these 3 readings. Measurements were obtained preoperatively and postoperatively during follow-up. (**See table, Supplemental Digital Content 1**, which displays the 2PD data, **http://links.lww.com/PRSGO/D973**.)

Statistical Analysis

Comparative analyses were performed between patients undergoing open versus minimally invasive tarsal tunnel release. Statistical significance was evaluated using the Fisher exact test for categorical data and paired *t* tests for continuous variables, with significance defined as *P* less than 0.05. Analyses were conducted using SPSS software.

Fig. 3. A photograph showing the flexor retinaculum after the initial incision.

Surgery

Concurrent DFU Closures

For patients undergoing tarsal tunnel release, concurrent DFU closures were performed using primary wound closure, skin grafting, or local flaps. In cases requiring free flap reconstruction, tarsal tunnel release was performed after the DFUs had healed.

Open Approach

The open tarsal tunnel release technique followed established protocols described by Hollis Caffee,[12] Wieman and Patel,[13] and Siemionow et al.[14] A 5–6 cm curvilinear incision was made along the medial ankle to expose the flexor retinaculum. The tibial nerve and its medial and lateral plantar branches were decompressed by releasing the 3 medial ankle tunnels.

Careful dissection was carried out to release the septum and fascia encasing these tunnels while avoiding injury to critical structures such as the posterior tibial artery, vein, and tibial nerve. After decompression, the incision was closed in layers, and a 10- to 12-French Blake drain was placed in situ to facilitate postoperative drainage (Fig. 1).

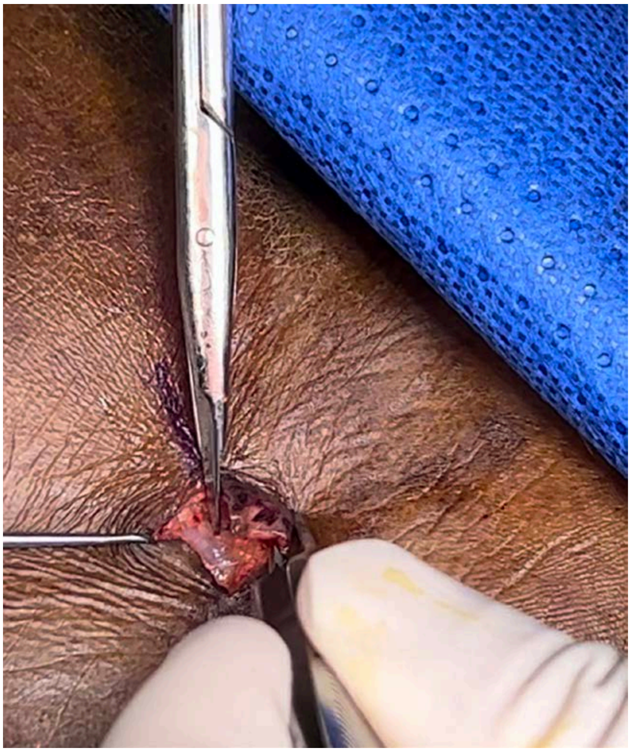

Fig. 4. A photograph showing the tibial venae comitans exposed after the flexor retinaculum is incised through with monopolar.

Minimally Invasive Tarsal Tunnel Release Approach

This minimally invasive procedure was performed under regional block or general anesthesia.

1. Preoperative mapping: Ultrasound evaluation of the posterior tibial neurovascular bundle was conducted to map the location and branching directions of the main trunk, as well as the medial and lateral plantar neurovascular bundles.
2. Incision and initial exposure: A 2 cm zigzag incision was marked at the trifurcation site of the posterior tibial neurovascular bundles, located between the calcaneum and the medial malleolus (Fig. 2). The incision was made down to the flexor retinaculum, followed by sharp dissection using tenotomy scissors to define the retinaculum, which was then incised (Fig. 3). The most superficial structure encountered was the tibial vena comitans (Fig. 4). Subsequent dissection exposed the branching main vena comitans, consistent with preoperative ultrasound findings.
3. Tunnel dilation: A No. 1 Hegar dilator, lubricated with gel, was inserted beneath the flexor retinaculum with the curvature directed superficially to minimize the risk of venous injury. The dilator was advanced approximately 5 cm along the direction of the neurovascular bundles, as determined by the preoperative ultrasound. Serial dilations were performed using progressively larger Hegar dilators (sizes 2–9) with lubrication gel (Fig. 5). This process was repeated for the main tibial neurovascular trunk and its medial and lateral branches.

Fig. 5. Photographs demonstrating serial dilation of the medial plantar tunnels with Hegar dilators, sizes 1–9.

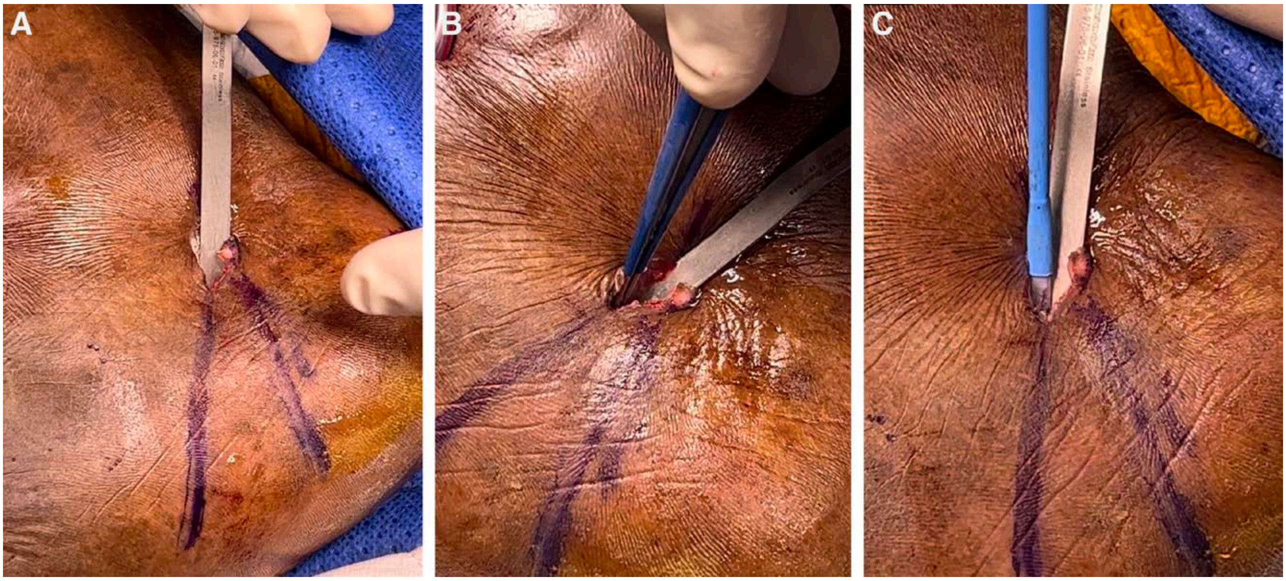

Fig. 6. Photographs showing the malleable retractor placed within the medial plantar tunnel to protect the neurovascular bundle underneath (A), bipolar diathermy of the retinaculum above to decompress the tunnel (B), monopolar diathermy of the remaining tough fibrous retinaculum that could not be diathermized through with bipolar (C).

4. Tissue release and hemostasis: The tunnels were released using a combination of monopolar and bipolar cautery to minimize bleeding, whereas the underlying neurovascular bundles were protected with a malleable retractor (Figs. 6, 7). Adequacy of the release was confirmed by inserting a size 10 Hegar dilator (Fig. 8).
5. Drain and wound closure: An 8-French Blake drain was inserted to prevent fluid accumulation. The skin edges were refashioned, and the wound was closed in layers (Fig. 9).

RESULTS

A total of 22 patients underwent open tarsal tunnel release, whereas 34 patients underwent the minimally invasive approach. The mean follow-up duration was 6 months for both the control (range: 3–10 mo) and treatment (range: 3–11 mo) groups, with a minimum follow-up period of 3 months for each group. There were no statistically significant differences in patient demographics or comorbidities between the 2 groups (Table 1).

In the control group, DFUs were managed using 2 primary closures, 3 skin grafts, and 15 local flaps,

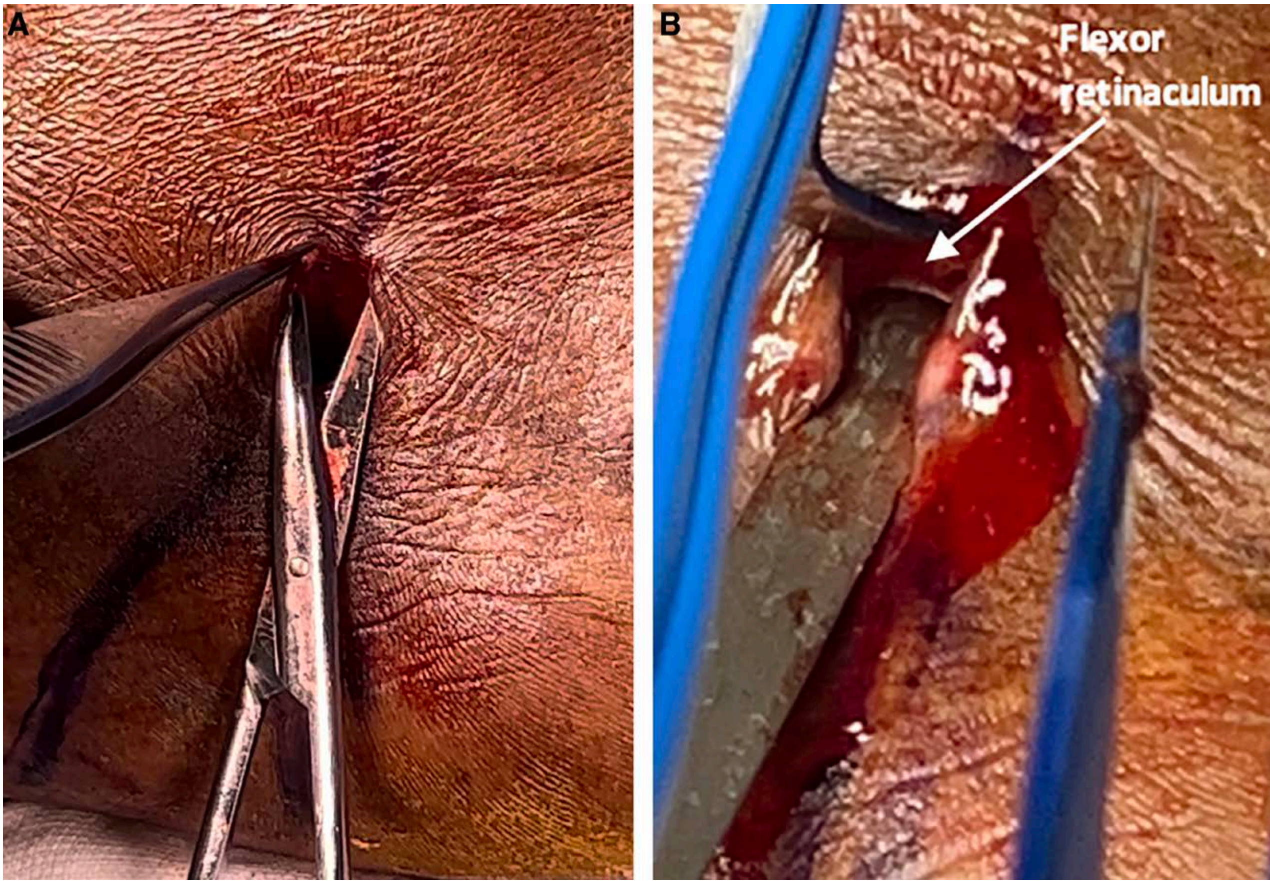

Fig. 7. Photographs showing the dissection of the tunnel of the posterior tibial main trunk (A) and intact flexor retinaculum before bipolar diathermy to release the tunnel (B).

Fig. 8. Photographs showing verification of the main tarsal tunnel release with a size 10 Hegar dilator.

Fig. 9. A photograph illustrating the final wound size after closure.

performed concurrently with the open tarsal tunnel releases. Additionally, 2 patients underwent open tarsal tunnel release after free flap reconstruction and wound healing. In the minimally invasive group, DFUs were managed with 1 primary closure, 6 skin grafts, and 22 local flaps. Furthermore, 5 patients received minimally invasive tarsal tunnel release following free flap reconstruction. The proportions of wound management procedures were not significantly different between the 2 groups (Table 3).

Both groups demonstrated comparable efficacy in improving foot sensation and 2PD (100% versus 95.5% and 88.2% versus 86.4%, respectively; P = 0.19 and P = 0.83). Wound length: The treatment group had significantly shorter wound lengths (2.3 ± 0.26 versus 5.8 ± 0.72 cm in the control group; P < 0.0001). Wound healing duration: Wound healing was significantly faster in the treatment group (15 ± 5 versus 24 ± 17 d; P = 0.0052). Wound complications: The treatment group experienced no major wound complications, compared with 13.6% in the control group (P = 0.0285). There were no significant differences between the 2 groups in DFU healing durations (61 ± 20 versus 58 ± 27 d; P = 0.6654) or recurrence rates (4.5% versus 2.9%; P = 0.74896) (Table 2).

DISCUSSION

Tarsal tunnel release has been shown to improve plantar sensation in patients with diabetic neuropathy with a positive Tinel sign.[15] Additionally, Trignano et al[6] demonstrated enhanced peripheral microcirculation through pre- and postoperative transcutaneous oximetry measurements. These improvements in neurological function and vascular supply have the potential to minimize ulcer recurrence, reduce the incidence of new ulcer formation, lower amputation rates, and enhance ulcer healing.[11,16]

Current open techniques result in a 5–6 cm wound, which poses challenges for DFU patients due to their compromised wound-healing capacity. Such large wounds require longer healing times and are prone to higher rates of complications. The endoscopic approach was developed to reduce wound size, but it introduces other limitations. The lack of intraoperative hemostasis necessitates the use of a tourniquet and postoperative compression bandages to minimize hematoma formation. However, this approach is contraindicated in patients with PAD—a condition present in up to 50% of DFU patients[9]—due to the prolonged arterial flow occlusion caused by external compression. These limitations restrict the utility of both the open and endoscopic techniques for treating and preventing DFUs.

Our novel minimally invasive technique addresses these deficiencies by reducing wound size to approximately 2 cm and eliminating the need for external compression to achieve hemostasis. To overcome the challenges of limited visualization, preoperative ultrasound mapping is utilized to accurately locate and define the neurovascular bundle and its branching directions. Key technical details—such as curving the instruments against the fascia, gradual dilation with lubrication, and careful use of bipolar and monopolar electrocautery—ensure adequate release of the tunnel while protecting the neurovascular

Table 3. Diabetic Foot Wound Management

Wound Management	Open Surgery	Minimally Invasive	P
Primary closure	9.1 % (2/22)	2.9% (1/34)	0.31732
Skin grafting	13.6% (3/22)	17.6% (6/34)	0.68916
Local flap	68.2% (15/22)	64.7% (22/34)	0.78716
Free flap	9.1% (2/22)	14.7% (5/34)	0.53526

bundle with a malleable retractor. Additionally, this technique has been successfully performed in 15 patients with PAD who had undergone prior angioplasty, a group for whom endoscopic release is contraindicated.

Our study demonstrates that sensory improvement following the minimally invasive tarsal tunnel release is equivalent to that of the open approach, confirming the adequacy of tunnel decompression for the posterior tibial nerve and its medial and lateral branches. Moreover, the smaller wound size in the minimally invasive group resulted in significantly faster wound healing and lower complication rates compared with the open release group.

However, this novel technique is not without limitations. The study is constrained by a relatively small patient cohort and a short follow-up duration, which may limit the generalizability of the findings. Temporal bias is also a concern due to the sequential design of the 2 patient groups. Additionally, although the procedure relies on preoperative ultrasound and intraoperative safeguards to protect the neurovascular bundle, the risk of inadvertent injury remains. Furthermore, incomplete release is a potential risk due to the reduced visibility compared with open surgery. The technique is also contraindicated in cases of tarsal tunnel syndrome caused by space-occupying lesions (eg, lipomas) or altered anatomy (eg, posttraumatic fractures), as these conditions require more extensive surgical exposure.

CONCLUSIONS

DFUs are notoriously complex to treat and carry significant risks of morbidity and mortality if not properly managed. The “double crush” theory challenges the traditional view that diabetic neuropathy is irreversible by highlighting the role of peripheral nerve compression, compounded by the metabolic effects of diabetes. This paradigm shift provides an opportunity for surgical interventions, such as tarsal tunnel release, to complement medical optimization.

Although current open and endoscopic techniques have their limitations, our novel minimally invasive tarsal tunnel release addresses many of these drawbacks. By minimizing wound size, avoiding external compression, and maintaining efficacy in sensory improvement, this technique offers a promising alternative for managing DFUs. These advancements may encourage broader acceptance of this approach, offering new hope for patients with diabetic neuropathy and DFUs.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

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