A Minimally Invasive Full Endoscopic Approach to Tibial Nerve Neurolysis in Diabetic Foot Neuropathy: An Alternative to Open Procedures

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Background: Dellon et al. have reported that chronic nerve compression of the tibial nerve inside the tarsal tunnel, caused by diabetes mellitus, can be relieved following open decompression surgery. However, the large skin incision resulting from Dellon's procedure may cause wound healing problems. The authors report the possibility of a minimally invasive full endoscopic procedure.
Methods: Operations were performed under local anesthesia without a pneumatic tourniquet. An anesthetic agent was applied at the proximal part of the flexor retinaculum of the foot, and a hypodermic needle was advanced into the tarsal tunnel. Tarsal tunnel pressure and blood circulation of the tibial nerve using indocyanine green assessment were measured preoperatively. One 1-cm portal skin incision was made at the anesthetized area and the Universal Subcutaneous Endoscope system was inserted into the tarsal tunnel. The flexor retinaculum, tibial nerve, blood vessels, and abductor hallucis muscle fascia were identified under endoscopic observation. After decompression of the tarsal tunnel, the authors measured tarsal tunnel pressure and blood circulation of the tibial nerve for analysis of the effectiveness of the endoscopic decompression during the procedure.
Results: Fourteen operations were compiled and analyzed. Postoperative clinical status was improved based on the preoperative modified Toronto Clinical Neuropathy Score. The mean tarsal tunnel pressure dropped to 4.5 mmHg during surgery from the initial preoperative 49.4 mmHg in resting position. Endoscopic indocyanine green assessment showed more than 30 percent improvement of the vascularity surrounding the tibial nerve.
Conclusion: The authors' minimally invasive full endoscopic procedure is a viable alternative approach for tarsal tunnel syndrome patients with diabetic foot neuropathy. (*Plast. Reconstr. Surg.* 148: 592, 2021.)
CLINICAL QUESTION/LEVEL OF EVIDENCE: Therapeutic, IV.

Diabetic neuropathy has been considered an irreversible and progressive polyneuropathy disease; however, nerve decompression in diabetic patients who have undergone open neurolysis of the tibial nerve has resulted in relief from pain and eventual sensory recovery. Some researchers have suggested possible recovery from diabetic neuropathy,[1–3] including entrapment neuropathy of the tibial nerve with tarsal tunnel syndrome, because systemic diseases such as diabetes also cause tarsal tunnel syndrome. Other researchers[4–10] state that there is not enough evidence to support decompression of the diseased nerve. The International Working Group on the Diabetic Foot 2019 Prevention Guideline suggests not using nerve decompression procedures

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because there is no evidence to support an ulcer prevention effect from nerve decompression.[10] Another reason for no recommendation of tibial nerve decompression procedures is the possibility of surgical complications of wound healing after making a long invasive incision of the ankle. This lack of recommendation for tibial nerve decompression procedures is despite the many positive articles published by Dellon and Aszmann et al.[1–3] We compiled and analyzed the clinical results of our alternative full endoscopic surgical approach to verify the efficacy of this minimally invasive procedure for treatment of tibial nerve neurolysis in diabetic foot neuropathy with tarsal tunnel syndrome.

PATIENTS AND METHODS

We have retrospectively compiled, examined, and analyzed our results from all 14 feet that received treatment for diabetic foot neuropathy with tarsal tunnel syndrome using full endoscopic neurolysis with the Universal Subcutaneous Endoscope system (Tact Medical, Inc., Tokyo, Japan) since March of 2015 (Fig. 1).

The operation was performed using techniques first introduced by Yoshida et al.[11] for treatment of idiopathic, hemodialysis-related tarsal tunnel syndrome. [**See Video 1 (online)**, which shows surgical anatomy, criteria, and techniques with some schema. The Universal Subcutaneous Endoscope system and a push knife are inserted into the tarsal tunnel. Video shows the Universal Subcutaneous Endoscope system for the right foot. Video shows measuring of tarsal tunnel pressure before and after surgery using a continuous infusion technique.] Unlike the more common two-portal endoscopic carpal tunnel release approach, our approach is based on the one-portal technique for endoscopic carpal tunnel release surgery as first reported by Okutsu et al. in 1987.[12]

Written informed consent was obtained from all participating patients in this treatment. This study was performed in accordance with the World Medical Association Declaration of Helsinki and the confirmation of the ethics guideline for clinical studies in Saga University Hospital.

We inject 10 ml of 1.5% lidocaine into the tarsal tunnel and wait 5 minutes. We then measure tarsal tunnel pressure preoperatively and postoperatively using a continuous infusion technique. This technique can be used to both confirm diagnoses and for postoperative evaluation of decompression following the Universal Subcutaneous Endoscope system procedure.[13–15]

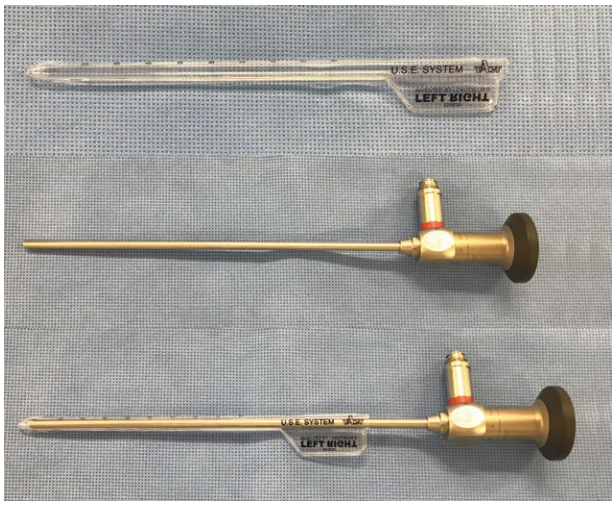

Fig. 1. Photograph shows the Universal Subcutaneous Endoscope system. (*Above*) Transparent closed sheath without an open slot. (*Center*) Standard 30-degree, 4-mm oblique viewing arthroscope. (*Below*) Universal Subcutaneous Endoscope system. Our endoscopic procedure was applied using the Universal Subcutaneous Endoscope (*U.S.E.*) system. The Universal Subcutaneous Endoscope system consists of a standard 30-degree, 4-mm oblique viewing arthroscope and a tapered 6- to 8-mm-diameter transparent closed sheath (Universal Subcutaneous Endoscope sheath). Dr. Okutsu developed the system and has used it since 1986 in various types of subcutaneous surgical treatments such as carpal tunnel syndrome.

To evaluate whether our procedure effectively decompresses the tibial nerve, we measure tarsal tunnel pressure preoperatively and postoperatively in the resting position. We also evaluate quantitative assessment of the perfusion around the tibial nerve by measuring indocyanine green intensity to see whether it can be used to predict postoperative outcomes.

RESULTS

Preoperative complaints of tingling, positive Tinel-like signs, sensory disturbance, and abnormal motor nerve conduction velocity occurred in all 14 cases. We evaluated the results at 3 months, 6 months, and 1 year.

A modified Toronto Clinical Neuropathy Score[16] was applied to measure changes that occurred before and after surgery for all cases. Preoperative mean score rates were 17.57 ± 1.26 of 33; 2.28 for foot pain, 2.42 for numbness, 2.42 for tingling, 0 for weakness and ataxia, 0.07 for upper limb symptoms, 2.53 for pinprick test, 2.5 for temperature test, 2.57 for light touch test, 2.78 for vibration test, and 0 for position sense test.

One-year postoperative mean score rates were 7.25 ± 0.52 of 33; 1.07 for foot pain, 1.0 for numbness, 0.85 for tingling, 0 for weakness and ataxia, 0.07 for upper limb symptoms, 1.14 for pinprick test, 0.92 for temperature test, 0.92 for light touch test, 1.28 for vibration test, and 0 for position sense test. There were statistically significant differences between the preoperative and 1-year postoperative Toronto Clinical Neuropathy Score mean rates with a value of $p = 0.001$ in Wilcoxon signed rank test. Postoperatively, all 14 feet showed improved rating scores (Table 1).

Preoperative tarsal tunnel pressure was measured at 5 minutes after administration of the local anesthetic agent (1% lidocaine 10 ml with epinephrine) into the tarsal tunnel, and postoperative measurement was performed immediately after tarsal tunnel release. Preoperative and postoperative tarsal tunnel pressures in resting position for 12 feet had a preoperative mean of 49.4 ± 46.4 mmHg (range, 16 to 187 mmHg) and there was a 4.5 ± 6.5 mmHg (range, 1 to 25 mmHg) pressure immediately after surgery. There were statistically significant differences between the preoperative and postoperative tarsal tunnel pressure measurement results with a value of $p < 0.01$ according to the Wilcoxon signed rank test.

Table 1. Clinical Features of the 14 Cases and Results

Characteristic	Value (%)
No. of feet	14
Male sex	12 (85.7)
Age, yr	56.6 ± 0.1
Diabetes mellitus	
Type 1	0 (0)
Type 2	14 (100)
Preoperative mean mTCNS score (of 33 points)	
Symptom scores*	17.57 ± 1.26
Pain of foot	2.28
Numbness of foot	2.42
Tingling of foot	2.42
Weakness and ataxia of foot	0
Upper limb symptoms	0.07
Sensory test score†	
Pinprick test	2.53
Temperature test	2.5
Light touch test	2.57
Vibration test	2.78
Position sense test	0
Postoperative mean mTCNS score at 1 yr	7.25 ± 0.52
Symptom scores*	
Pain of foot	1.07
Numbness of foot	1.0
Tingling of foot	0.85
Weakness and ataxia of foot	0
Upper limb symptoms	0.07
Sensory test score†	
Pinprick test	1.14
Temperature test	0.92
Light touch test	0.92
Vibration test	1.28
Position sense test	0
Preoperative TT pressure in 12 feet, mmHg	
Mean ± SD	49.4 ± 46.4
Range	16–187
Postoperative TT pressure in 12 feet, mmHg	
Mean	4.5 ± 6.5
Range	1–25

mTCNS, Modified Toronto Clinical Neuropathy Score; TT, tarsal tunnel.

*Symptom scores are thus graded as follows: 0 = absent; 1 = present, but no interference with sense of well-being or activities of daily living; 2 = present and interferes with sense of well-being but not with activities of daily living; 3 = present and interferes with both sense of well-being and activities of daily living.

†Sensory test scores are graded as follows: 0 = normal; 1 = reduced at the toes only; 2 = reduced to a level above the toes, but only up to the ankles; and 3 = reduced to a level above the ankles and/or absent at the toes.

Endoscopic indocyanine green assessment showed more than 30 percent improvement of the vascularity around the tibial nerve in the tarsal tunnel for three feet using Vision Sense (Heiwa Medical Instruments Co. Ltd., Yamaguchi, Japan). [**See Video 2 (online)**, which shows quantitative assessment of perfusion around the tibial nerve by measuring indocyanine green intensity.]

We had one postoperative case with hematoma formation in a hemodialysis patient. It required no further surgical treatment and there was no recurrence in this series during the 1-year follow-up period.

DISCUSSION

According to World Health Organization estimates, the global prevalence of diabetes has increased from 153 million people in 1980 to 347 million in 2008.[17] The number of diabetic patients in Asian countries, including Japan, has also increased. In 2016, 20 million Japanese (16 percent) were diagnosed with diabetes mellitus. Diabetic patients may suffer from several complications, and neuropathy is one of the most common, affecting up to 60 percent of people with diabetes.[17–21] It is debilitating and expensive to treat, and diabetic neuropathy has long been considered an irreversible and progressive disease.[22] Some researchers suggest that there is the possibility of a cure for diabetic neuropathy[1–3,23–33] by means of nerve decompression, whereas others argue there is not enough evidence to support nerve decompression procedure for the diabetic population with neuropathy.[4–9]

Tarsal tunnel syndrome is an entrapment neuropathy caused by compression of the tibial nerve in the tarsal tunnel, which is roofed by the flexor retinaculum of the foot.[34] The clinical symptoms include pain at the medial malleolus radiating to the sole as paresthesia, dysesthesia, and/or hyperesthesia in the distribution area of the tibial nerve.[35]

Normal tarsal tunnel pressure is difficult to determine. With the foot and ankle held in mild

plantar flexion and neutral eversion-inversion position, mean tarsal tunnel pressure was a minimal (2 ± 1 mmHg) in an anatomical study of 10 fresh cadavers. When the foot and ankle were positioned in full eversion, mean tarsal tunnel pressure increased 32 mmHg.[36] Rosson et al. and Barker et al. reported that pronation and plantar flexion of the intact foot would have higher pressure levels than the intact foot in other positions. Furthermore, pronation and plantar flexion significantly increased pressure in the tarsal tunnel to levels sufficient to cause chronic nerve compression.[37,38] According to other carpal canal pressure measurement results, in patients suffering from carpal tunnel syndrome, the preoperative mean pressure in the carpal canal with the wrist in resting position was 43 mmHg. Postoperatively, carpal canal pressure in the same resting position was 6.2 mmHg.[15] Preoperative mean tarsal tunnel pressure in our study was 49.4 mmHg and dropped to 4.5 mmHg, postoperatively. We believe that normal tarsal tunnel pressure in resting position changes during the surgical procedure similar to how carpal canal pressure measurement results in resting changes during surgery.

The International Working Group on the Diabetic Foot 2019 Prevention Guideline suggests clinicians not use a nerve decompression procedure because of a lack of evidence to support the procedure's ulcer prevention effect.[10] Reasons for the Guideline's suggestion include the surgical complications of wound healing from the standard skin incision made at the medial ankle. In contrast, inserting the 10-cm Universal Subcutaneous Endoscope sheath from the 1-cm portal allows us to visually confirm a sufficient length of tibial nerve decompression from the proximal part of the flexor retinaculum to the abductor hallucis muscle fascia and to observe restored intranerve blood circulation during the operation while verifying complete decompression of the nerve. The closed transparent sheath characteristic of our method is used without a pneumatic tourniquet, and this enables us to observe the nerve and vessels without blood obscuring the magnified field of vision.[12,37–42] Interference bleeding during the endoscopic procedure is avoided and postoperative perineural adhesion is usually prevented.[11] It is imperative that a clear field of vision be secured throughout surgery because insufficient release and perineural scar formation may lead to poor postoperative results.

Our one-portal technique has the benefit of leaving only a 1-cm scar on the medial malleolus area. Furthermore, there is no scar in any weight-bearing area and the small incision requires only a short recovery period. A two-portal endoscopically assisted procedure that uses a retractor to create observation space in the tarsal tunnel has been reported.[43,44] This procedure, however, requires two skin incisions, and this may lead to complications described in the International Working Group on the Diabetic Foot 2019 guidelines.

Our indocyanine green assessment is an original concept with more than 30 percent improved results as related to clinical symptoms. This minimally invasive full endoscopic tibial nerve neurolysis technique for treatment of tarsal tunnel syndrome with diabetic foot neuropath avoids nerve and/or vessel damage during release of the flexor retinaculum of the foot and a part of the abductor hallucis muscle fascia and can be considered as a viable alternative to standard open decompression procedure.

The greater long-term economic benefits generated by our one-portal technique, as compared to open or two-portal procedures, should also be noted. It could be a potential benefit that is more cost-effective than current prevention strategies that often include extended hospital stays.

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REFERENCES

1. Dellon AL. Treatment of symptomatic diabetic neuropathy by surgical decompression of multiple peripheral nerves. *Plast Reconstr Surg.* 1992;89:689–697; discussion 698–699.
2. Aszmann OC, Kress KM, Dellon AL. Results of decompression of peripheral nerves in diabetics: A prospective, blinded study. *Plast Reconstr Surg.* 2000;106:816–822.
3. Aszmann O, Tassler PL, Dellon AL. Changing the natural history of diabetic neuropathy: Incidence of ulcer/amputation in the contralateral limb of patients with a unilateral nerve decompression procedure. *Ann Plast Surg.* 2004;53:517–522.
4. Chaudhry V, Russell J, Belzberg A. Decompressive surgery of lower limbs for symmetrical diabetic peripheral neuropathy. *Cochrane Database Syst Rev.* 2008;3:CD006152.
5. Dyck PJ, Engelstad JK, Giannini C, Lais AC, Minnerath SR, Karnes JL. Resistance to axonal degeneration after nerve compression in experimental diabetes. *Proc Natl Acad Sci USA.* 1989;86:2103–2106.
6. Jaramillo J, Simard-Duquesne N, Dvornik D. Resistance of the diabetic rat nerve to ischemic inactivation. *Can J Physiol Pharmacol.* 1985;63:773–777.
7. Seneviratne KN, Peiris OA. The effects of hypoxia on the excitability of the isolated peripheral nerves of alloxan-diabetic rats. *J Neurol Neurosurg Psychiatry* 1969;32:462–469.
8. Steiness I. Vibratory perception in diabetics during arrested blood flow to the limb. *Acta Med Scand.* 1959;163:195–205.
9. Steiness I. Influence of diabetic status on vibratory perception during ischaemia. *Acta Med Scand.* 1961;170:319–338.

10. International Working Group on the Diabetic Foot. WGDF2019 prevention guideline. Available at: https://iwgdfguidelines.org/wp-content/uploads/2019/05/IWGDF-Guidelines-2019.pdf#search=%27IWGDF2019%27. Accessed March 10, 2020.
11. Yoshida A, Okutsu I, Hamanaka I. Endoscopic tarsal tunnel syndrome surgery using the Universal Subcutaneous Endoscope system. *Asia Pac J Sports Med Arthrosc Rehabil Technol.* 2016;3:1–5.
12. Okutsu I, Ninomiya S, Natsuyama M, et al. Subcutaneous operation and examination under the universal endoscope (in Japanese). *Nihon Seikeigeka Gakkai Zasshi* 1987;61:491–498.
13. Hamanaka I, Okutsu I, Shimizu K, Takatori Y, Ninomiya S. Evaluation of carpal canal pressure in carpal tunnel syndrome. *J Hand Surg Am.* 1995;20:848–854.
14. Okutsu I, Ninomiya S, Yoshida A, Hamanaka I, Kitajima I. Measurement of carpal canal and median nerve pressure in patients with carpal tunnel syndrome. *Tech Hand Up Extrem Surg.* 2004;8:124–128.
15. Okutsu I, Ninomiya S, Hamanaka I, Kuroshima N, Inanami H. Measurement of pressure in the carpal canal before and after endoscopic management of carpal tunnel syndrome. *J Bone Joint Surg Am.* 1989;71:679–683.
16. Bril V, Tomioka S, Buchanan RA, Perkins BA; mTCNS Study Group. Reliability and validity of the modified Toronto Clinical Neuropathy Score in diabetic sensorimotor polyneuropathy. *Diabet Med.* 2009;26:240–246.
17. Danaei G, Finucane MM, Lu Y, et al.; Global Burden of Metabolic Risk Factors of Chronic Diseases Collaborating Group (Blood Glucose). National, regional, and global trends in fasting plasma glucose and diabetes prevalence since 1980: Systematic analysis of health examination surveys and epidemiological studies with 370 country-years and 2.7 million participants. *Lancet* 2011;378:31–40.
18. Young MJ, Boulton AJ, MacLeod AF, Williams DR, Sonksen PH. A multicentre study of the prevalence of diabetic peripheral neuropathy in the United Kingdom hospital clinic population. *Diabetologia* 1993;36:150–154.
19. Kumar S, Ashe HA, Parnell LN, et al. The prevalence of foot ulceration and its correlates in type 2 diabetic patients: A population-based study. *Diabet Med.* 1994;11:480–484.
20. Polydefkis M, Griffin JW, McArthur J. New insights into diabetic polyneuropathy. *JAMA* 2003;290:1371–1376.
21. Dyck PJ, Kratz KM, Karnes JL, et al. The prevalence by staged severity of various types of diabetic neuropathy, retinopathy, and nephropathy in a population-based cohort: The Rochester Diabetic Neuropathy Study. *Neurology* 1993;43:817–824.
22. Coppini DV, Spruce MC, Thomas P, Masding MG. Established diabetic neuropathy seems irreversible despite improvements in metabolic and vascular risk markers: A retrospective case-control study in a hospital patient cohort. *Diabet Med.* 2006;23:1016–1020.
23. Biddinger KR, Amend KJ. The role of surgical decompression for diabetic neuropathy. *Foot Ankle Clin.* 2004;9:239–254.
24. Hollis C. Treatment of diabetic neuropathy by decompression of the posterior tibial nerve. *Plast Reconstr Surg.* 2000;106:813–815.
25. Tambwekar DS. Extended neurolysis of the posterior tibial nerve to improve sensation in diabetic neuropathic feet. *Plast Reconstr Surg.* 2001;108:1452–1453.
26. Wieman TJ, Patel VG. Treatment of hyperesthetic neuropathic pain in diabetics: Decompression of the tarsal tunnel. *Ann Surg.* 1995;221:660–664; discussion 664–665.
27. Wood WA, Wood MA. Decompression of peripheral nerves for diabetic neuropathy in the lower extremity. *J Foot Ankle Surg.* 2003;42:268–275.
28. Karagoz H, Yuksel F, Ulkur E, Celikoz B. Early and late results of nerve decompression procedures in diabetic neuropathy: A series from Turkiye. *J Reconstr Microsurg.* 2008;24:95–101.
29. Siemionow M, Alghoul M, Molski M, Agaoglu G. Clinical outcome of peripheral nerve decompression in diabetic and nondiabetic peripheral neuropathy. *Ann Plast Surg.* 2006;57:385–390.
30. Valdivia JM, Dellon AL, Weinand ME, Maloney CT Jr. Surgical treatment of peripheral neuropathy: Outcomes from 100 consecutive decompressions. *J Am Podiatr Med Assoc.* 2005;95:451–454.
31. Dellon AL, Muse VL, Nickerson DS, et al. Prevention of ulceration, amputation, and reduction of hospitalization: Outcomes of a prospective multicenter trial of tibial neurolysis in patients with diabetic neuropathy. *J Reconstr Microsurg.* 2012;28:241–246.
32. Dellon AL, Muse VL, Scott ND, et al. A positive Tinel sign as predictor of pain relief or sensory recovery after decompression of chronic tibial nerve compression in patients with diabetic neuropathy. *J Reconstr Microsurg.* 2012;28:235–240.
33. Knobloch K, Gohritz G, Vogt PM. Surgical decompression of the lower leg in painful diabetic polyneuropathy (in German). *Oper Orthop Traumatol.* 2012;24:74–79.
34. Lam SJ. A tarsal-tunnel syndrome. *Lancet* 1962;2:1354–1355.
35. Edwards WG, Lincoln CR, Bassett FH III, Goldner JL. The tarsal tunnel syndrome: Diagnosis and treatment. *JAMA* 1969;207:716–720.
36. Trepman E, Kadel NJ, Chisholm K, Razzano L. Effect of foot and ankle position on tarsal tunnel compartment pressure. *Foot Ankle Int.* 1999;20:721–726.
37. Rosson GD, Larson AR, Williams EH, Dellon AL. Release of medial ankle compartments reduces pressure upon tibial nerve branches in patients with diabetic neuropathy. *Plast Reconstr Surg.*2009;124:1202–1210.
38. Barker AR, Rosson GD, Dellon AL. Pressure changes in the medial and lateral plantar, and tarsal tunnels related to ankle position: A cadaver study. *Foot Ankle Int.* 2007;28:250–254.
39. Okutsu I, Ninomiya S, Takatori Y, Ugawa Y. Endoscopic management of carpal tunnel syndrome. *Arthroscopy* 1989;5:11–18.
40. Okutsu I. The world's first endoscopic management of carpal tunnel syndrome: Eleven years clinical experience. In Roth JH, Richards RS, eds. *Proceedings of the 7th Congress of the International Federation of Societies for Surgery of the Hand (IFSSH).* Bologna, Italy: Monduzzi Editore; 1998:123–129.
41. Okutsu I, Hamanaka I, Ninomiya S, Takatori Y, Shimizu K, Ugawa Y. Results of endoscopic management of carpal-tunnel syndrome in long-term haemodialysis versus idiopathic patients. *Nephrol Dial Transplant.* 1993;8:1110–1114.
42. Okutsu I. How I developed the world's first evidence-based endoscopic management of carpal tunnel syndrome. *Hand Surg.* 2010;15:149–155.
43. Krishnan KG, Pinzer T, Schackert G. A novel endoscopic technique in treating single nerve entrapment syndromes with special attention to ulnar nerve transposition and tarsal tunnel release: Clinical application. *Neurosurgery* 2006;59(Suppl 1):ONS89–ONS100; discussion ONS89–ONS100.
44. Day FN III, Naples JJ. Tarsal tunnel syndrome: An endoscopic approach with 4- to 28-month follow-up. *J Foot Ankle Surg.* 1994;33:244–248.