We studied a cohort of 26 diabetic patients with chronic ulceration under the first metatarsal head treated by a modified Jones extensor hallucis longus and a flexor hallucis longus transfer. If the first metatarsal was still plantar flexed following these two transfers, a peroneus longus to the peroneus brevis tendon transfer was also performed. Finally, if ankle dorsiflexion was < 5° with the knee extended, a Strayer-type gastrocnemius recession was performed.

The mean duration of chronic ulceration despite a minimum of six months’ conservative care was 16.2 months (6 to 31). A total of 23 of the 26 patients were available for follow-up at a mean of 39.6 months (12 to 61) after surgery. All except one achieved complete ulcer healing at a mean of 4.4 weeks (2 to 8) after surgery, and there was no recurrence of ulceration under the first metatarsal.

We believe that tendon balancing using modified Jones extensor hallucis longus and flexor hallucis longus transfers, associated in selected cases with a peroneus longus to brevis transfer and/or Strayer procedure, can promote rapid and sustained healing of chronic diabetic ulcers under the first metatarsal head.
approved by the institutional ethics committee. In cooperation with our diabetologist, glycemic control was optimised as soon as the patients entered the conservative phase of ulcer treatment.

The inclusion criteria for the study were the presence of a unilateral chronic ulcer under the first metatarsal head (Fig. 1) (a chronic ulcer was defined as one that failed to heal after a minimum of six months’ treatment by a team specifically trained in foot care, with at least two ulcer dressing changes per week and habitual use of specific extra-depth shoes with a customised insole having a void under the first metatarsal head to reduce local pressure), diabetes, and no medical contraindications to anaesthesia. Exclusion criteria included the presence of plantar ulcers not located under the first metatarsal head, bilateral foot ulceration (we did not include bilateral ulceration because of the possible effects this might have on weight-bearing pressures, for example a patient who was operated upon bilaterally would probably be less able to walk during the first post-operative weeks, and this could be a confounding factor to ulcer healing), peripheral vascular disease associated with a transcutaneous oxygen tension (TcPO₂) on the dorsum of the foot < 25 mmHg, active infection as determined by abnormal blood studies (C-reactive protein (CRP), erythrocyte sedimentation rate (ESR), and blood cell count) or local signs of infection, such as cellulitis or suppuration, a prior history of ipsilateral partial foot amputation, inability to comply with follow-up, and medical contraindications to surgery and/or anaesthesia.

Patients were considered to have peripheral neuropathy if they were unable to feel the touch of a 5.07/10-gauge nylon monofilament at four of ten sites on the plantar aspect of the foot, which is a validated test for the detection of a foot at risk of neuropathic ulceration due to loss of protective sensation.23,24

Patient demographics are presented in Table I. The mean TcPO₂ on the dorsum of the involved foot was 43.8 mmHg (31 to 55). The mean duration of a chronic non-healing ulcer despite appropriate conservative treatment was 16.2 months (6 to 31), and the mean pre-operative ulcer size was 2.0 cm (1.0 to 3.5) for the greatest diameter and 1.7 cm (0.5 to 3.0) for the smallest. According to the modified Wagner-Meggitt depth-ischaemia classification described by Brodsky,25 there were 12 patients with grade 1A ulceration and 14 with 2A (depth classification: grade 1, superficial ulceration, not infected; grade 2, deep ulceration exposing a tendon or joint (with or without superficial infection); and ischaemia classification: A, not ischaemic). Because of our exclusion criteria, there were no 2A ulcers with an associated infection or with joint exposure, which implies complete loss of the flexor tendons under the first metatarsal head, making FHL transfer impossible. The mean age at the time of surgery was 56.2 years (29 to 80).

**Operative technique.** A single pre-operative dose of intravenous prophylactic antibiotic (cefuroxime 1.5 g) was administered one hour prior to operation. A 3 cm incision was made on the distal and dorsal aspects of the first metatarsal (Fig 2). A modified Jones EHL transfer was performed and the freed distal tendon of EHL was attached to the dorsal aspect of the neck of the first metatarsal under slight tension, using a fully threaded 2.8 mm diameter titanium suture anchor and a no. 2 polyester suture (FAS-TaK II Suture Anchor and no. 2 FiberWire; Arthrex Swiss Ltd, St Gall, Switzerland). Arthrodesis of the interphalangeal joint in the neutral position was then performed by excising the articular cartilage through an L-shaped dorsal incision (Fig. 2b) and fixed with a 3.5 mm cortical screw passing from distal to proximal through a 5 mm horizontal incision at the tip of the first toe. The FHL transfer was performed through a 2 cm incision on the medial aspect of the proximal phalanx (Fig. 3a). The tendon was transected at its attachment to the distal phalanx and fixed under the base of the proximal phalanx using the same type of titanium anchor and polyester suture.

Traditional methods of fixation involve suturing the tendon to itself after passing it through a tunnel drilled in the bone. Biomechanical studies in cadaver models have shown that suture anchors have similar or superior mechanical properties to bone tunnels.26-28

If the first metatarsal was still plantar flexed following these two procedures, a peroneus longus to peroneus brevis
tendon transfer was performed to reduce plantar flexion of the first ray.\textsuperscript{29,30} Through a 5 cm incision proximal to the tip of the lateral malleolus (Fig. 3b), the peroneus longus tendon was divided and sutured to the peroneus brevis tendon\textsuperscript{31} with no. 1 resorbable polyglactic suture (Vicryl; Ethicon, Spreitenbach, Switzerland). The rationale for the procedure is based on biomechanical studies\textsuperscript{16,18} which have shown that the peroneus longus muscle is a major contributor to increased plantar pressure beneath the first metatarsal.

Finally, if ankle dorsiflexion was $< 5^\circ$ with the knee in full extension,\textsuperscript{32} a Strayer-type gastrocnemius recession\textsuperscript{33} was performed via a 5 cm posterior-medial incision centred on the gastrocnemius indentation. An equinus deformity due to a gastrocnemius contracture is believed to be a potential cause of ulceration of the plantar aspect of the foot.\textsuperscript{8,34,35} Gastrocnemius recession is a well-documented procedure for the treatment of this condition.\textsuperscript{36-38} At the end of the operation, the ulcer under the first metatarsal head was carefully debrided and left open.

The four procedures (modified Jones procedure, FHL tendon transfer, peroneus longus tendon transfer and Strayer procedure; group I) were used in 19 of the 26 patients. Five were managed by a modified Jones procedure, FHL transfer and gastrocnemius lengthening alone (group II). Finally, two patients were treated with the two former procedures and peroneus longus transfer alone (group III).

**Post-operative care and follow-up.** The sutures were removed after three weeks. The foot was protected in an ankle-foot orthosis for six weeks and patients allowed to bear weight as tolerated. Wet-to-dry dressings were applied twice weekly until full epithelialisation of the ulcer had occurred (Fig. 4), when it was considered healed. The patients were then followed up at monthly intervals.

**Results**

The mean follow-up was 39.6 months (12 to 61). Two patients were lost to follow-up, and one died three weeks after surgery from a myocardial infarction, without any healing of the lesion. There was no wound infection or wound breakdown. Of the remaining 23 patients, all except one achieved complete healing of the ulcer, with no recurrence under the first metatarsal head. The mean time to healing of the ulcer was 4.4 weeks (2 to 8). In group II, the ulcer

| Table I. Demographic and clinical characteristics of the study population according to the surgical procedures performed. Values are means (SEM) |
| --- | --- | --- |
| **Group** | I | II | III |
| Surgical procedures | 1 + 2 + 3 | 1 + 3 | 1 + 2 |
| Number (total: 26) | 19 | 5 | 2 |
| Women/men (total: 16/10) | 11/8 | 3/2 | 2/0 |
| Age at surgery (yrs) | 55.79 (3.01) | 58.40 (4.39) | 54.00 (16.00) |
| Diabetes therapy | Oral/insulin | 6/13 | 3/2 | 2/0 |
| TcPO\textsubscript{2} at the dorsum of the foot (mmHg) | 42.89 (1.97) | 45.40 (3.14) | 48.00 (2.00) |
| Peripheral neuropathy | 19 | 5 | 2 |
| Duration of non-healing ulcer (mths) | 16.37 (1.85) | 14.20 (2.67) | 18.50 (0.50) |
| Ulcer diameter (cm) Maximum | 2.05 (0.18) | 1.90 (0.10) | 2.00 (0.50) |
| Minimum | 1.63 (0.13) | 1.90 (0.10) | 1.75 (0.75) |
| Ulcer grade (Brodsky's depth-ischaemia classification) | | | |
| 1A | 10 | 1 | 1 |
| 2A | 9 | 4 | 1 |
| Length of post-operative follow-up (mths) | 41.65 (2.44) | 30.80 (7.23) | 48 |
| Lost to follow-up | 1 | 0 | 1 |
| Died during follow-up | 1 | 0 | 0 |
| Time to healing (wks) | 4.47 (0.44) | 4.50 (0.87) | 3.00 |
| Failure to heal | 0 | 1 | 0 |
| Ulcer recurrence | | | |
| Under the first metatarsal | 0 | 0 | 0 |
| Other sites | 0 | 1 | 0 |

* surgical procedures: 1) Jones extensor hallucis longus transfer and flexor hallucis longus transfer; 2) peroneus longus to peroneus brevis transfer; 3) Strayer-type gastrocnemius recession
† TcPO\textsubscript{2}, transcutaneous oxygen tension
in a 70-year-old man failed to heal and required an extension osteotomy of the first metatarsal and a peroneus longus to brevis transfer six months later. Subsequent healing occurred eight weeks post-operatively. Finally, another patient in group II presented one year after surgery with ulceration under the second metatarsal head of the same foot.

Discussion
The presence of a chronic non-healing ulcer in a diabetic patient without peripheral vascular disease after adequate conservative treatment, including local and general medical care, should alert the clinician to an underlying anatomical abnormality causing increased local pressure. Such an ulcer under the first metatarsal head may be due to muscular imbalance between the extrinsic and intrinsic muscles of the first ray, causing an elevation of plantar pressure.\textsuperscript{15,16}

In this study we have shown that tendon balancing procedures aimed at diminishing the plantar pressure can promote rapid healing under these circumstances. The mean time to healing was 4.4 weeks after surgery, compared with a mean pre-operative duration of conservative treatment without healing of 16.2 months. The plantar ulcer failed to heal after surgery in only one of the 26 patients included in the study. There was no recurrence of ulceration under the first metatarsal head during a mean post-operative follow-up of 39.6 months.

It could be suggested that amputation of the first ray would be a more definitive surgical solution but this pro-
procedure is associated with high rates of re-ulceration and re-amputation, ranging between 12.4% and 60%.39-42

Other non-surgical forms of treatment for chronic plan- tar ulcers include negative-pressure wound therapy and off-loading foot modalities such as total-contact casts, removable cast walkers or half-shoes. Negative pressure therapy seems to promote healing in a higher proportion of large diabetic foot wounds, with faster healing rates than standard moist dressings.43,44 Although ulcer recurrence rates following this type of treatment have not been described, they could be expected to be relatively high in patients with neuropathic forefoot ulcers and increased plantar pressure.

Our patients were not treated with total-contact cast during the conservative treatment phase, but with frequent ulcer dressing and extra-deep diabetic shoes, including a customised insole with a void under the first metatarsal head. This can be seen as a weakness of our study, because a total-contact cast appears to be the most efficient way of reducing local pressure.45 However, high recurrence rates have been reported following discontinuation of treatment with a total-contact cast both in a prospective trial (59% in the first seven months and 81% at two years’ follow-up)46 and in a retro- spective study (63%).47 The costs and complication rates associated with such treatment can be high.47-49 For these reasons we agree with Laborde’s10 opinion that to consider total-contact cast as ‘the gold standard’ treatment is questionable. It is obvious that in the presence of abnormal forefoot pressure associated with structural change, every off-loading modality will have only a temporary effect on healing, and a high risk of re-ulceration when discontinued.

The ankle-foot orthosis used during post-operative care could theoretically contribute to ulcer healing. However, it was not an off-loading modality and did not function on the principle of a total-contact cast. It did not include a half-shoe, and was not patellar tendon bearing. It was a simple removable orthosis with no pressure-relief insert, and our patients were allowed to bear weight with it as tolerated. Therefore, its contribution to ulcer healing was probably very limited. Our results with respect to ulcer healing and recurrence following tendon balancing are superior to those
published with the use of total-contact cast or any other orthotic system. These findings are consistent with those of a retrospective study and a randomised clinical trial comparing the outcomes of diabetic patients with neuropathic plantar forefoot ulcer treated with total-contact cast alone or combined with lengthening of tendo-Achillis.\(^{35,46}\)

The only patient in our cohort whose ulcer did heal following surgery was initially treated by a Jones procedure, FHL tendon transfer and gastrocnemius lengthening. A peroneus longus transfer was not performed. The poor result in this patient may have been due to intra-operative underestimation of the residual plantar flexion of the first metatarsal after the Jones and FHL transfers. Intra-operative clinical evaluation of persistent first metatarsal flexion is difficult and instruments designed precisely to assess this parameter are not available.

A recent retrospective study by Laborde\(^ {10}\) including 13 plantar ulcers under the first metatarsal head, secondary to a variety of neuropathies (diabetes mellitus, alcoholism and lumbar radiculopathy), reported good results with peroneus longus (Z-type) lengthening in addition to gastrocnemius-soleus lengthening (Vulpis technique). It is not yet clear which technique is preferable for the peroneus longus tendon, as tendon lengthening or transfer to the peroneus brevis have not been compared with each other, in either biomechanical or clinical studies. To our knowledge, the study by Laborde\(^ {10}\) is the only one to report the results of peroneus longus tendon lengthening for the treatment of diabetic ulcers. We consider that the choice of technique (lengthening or transfer to the peroneus brevis) should be left to the discretion of the surgeon. Another important consideration when comparing our work with the study of Laborde\(^ {10}\) is the concept of staged treatment. He treated all patients presenting with a chronic non-healing ulcer under the first metatarsal head with gastrocnemius-soleus recession and peroneus longus lengthening. Such standardised treatment does not take into account the degree of foot deformity.

Our concept was to unload the first metatarsal by a staged protocol according to the degree of deformity of the first ray and presence of an equinus contracture, and to limit the risk of overcorrection and the potential development of a transfer lesion under the lesser metatarsal heads. Procedures that use peroneus longus tendon transfer or combined with lengthening of the tendo-Achillis have not been compared with each other, in either biomechanical or clinical studies. To our knowledge, the study by Laborde\(^ {10}\) is the only one to report the results of peroneus longus tendon lengthening for the treatment of diabetic ulcers. We consider that the choice of technique (lengthening or transfer to the peroneus brevis) should be left to the discretion of the surgeon. Another important consideration when comparing our work with the study of Laborde\(^ {10}\) is the concept of staged treatment. He treated all patients presenting with a chronic non-healing ulcer under the first metatarsal head with gastrocnemius-soleus recession and peroneus longus lengthening. Such standardised treatment does not take into account the degree of foot deformity.

Our concept was to unload the first metatarsal by a staged protocol according to the degree of deformity of the first ray and presence of an equinus contracture, and to limit the risk of overcorrection and the potential development of a transfer lesion under the lesser metatarsal heads. Procedures that use peroneus longus tendon transfer in the treatment of clawed hallux have been shown to be associated with overcorrection.\(^ {15}\) For this reason, peroneus longus transfer was performed last in our staged protocol. However, one of our patients treated by Jones, FHL transfer and a Strayer-type gastrocnemius recession (i.e., procedures implying a less powerful correction of the abnormal first metatarsal plantar flexion) developed a transfer lesion under the second metatarsal head.

All the patients in our study presented with a peripheral neuropathy, as determined by the Semmes-Weinstein test. The vast majority (24 of 26) also had an equinus contracture, which was the indication for the Strayer procedure in our protocol. This could corroborate with one histological study,\(^ {50}\) in diabetic patients with neuropathy that demonstrated structural changes in the tendo-Achillis compared with non-diabetic individuals, possibly resulting from non-enzymatic glycation expressed over many years. These structural changes could contribute to a tightening of the tendo-Achillis tendon-gastrocnemius-soleus complex, which is common in advanced diabetic neuropathy. However, there is increasing evidence that tendo-Achillis tendon lengthening alone is probably not sufficient to prevent recurrence of foot ulceration. Two clinical biomechanical studies have shown that the range of movement of the ankle accounts for only a small proportion of forefoot plantar pressure in both diabetic patients and asymptomatic subjects.\(^ {51,52}\) Lengthening of the tendo-Achillis has been shown initially to reduce plantar pressure by 27%, but it returned to very high values after eight months and persisted thereafter.\(^ {53}\) Based on these reports we only used tendo-Achillis lengthening in selected patients at the end of our staged protocol.

We believe this to be the first study to demonstrate that first ray tendon balancing by the Jones procedure and FHL transfer, associated with peroneus longus to peroneus brevis transfer and/or gastrocnemius recession in the case of persistent first ray flexion and/or equinus contracture, can successfully promote rapid ulcer healing in diabetics with chronic ulceration under the first metatarsal head. All but one of the 23 patients who completed follow-up healed their ulcer, and there was no recurrent ulceration under the first metatarsal head during a mean follow-up of 39.6 months (12 to 61). We emphasise that these findings are applicable only to a specific subset of chronic plantar ulcers in diabetic patients which have failed to respond to at least six months of conservative treatment.

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References

CHRONIC DIABETIC ULCERS UNDER THE FIRST METATARSAL HEAD TREATED BY STAGED TENDON BALANCING 493


