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Effect of Achilles Tendon Lengthening on Neuropathic Plantar Ulcers*

A Randomized Clinical Trial

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Background: Limited ankle dorsiflexion has been implicated as a contributing factor to plantar ulceration of the forefoot in diabetes mellitus. The purpose of this study was to compare outcomes for patients with diabetes mellitus and a neuropathic plantar ulcer treated with a total-contact cast with and without an Achilles tendon lengthening. Our primary hypothesis was that the Achilles tendon lengthening would lead to a lower rate of ulcer recurrence.

Methods: Sixty-four subjects were randomized into two treatment groups, immobilization in a total-contact cast alone or combined with percutaneous Achilles tendon lengthening, with measurements made before and after treatment, at the seven-month follow-up examination, and at the final follow-up evaluation (a mean [and standard deviation] of 2.1 ± 0.7 years after initial healing). There were thirty-three subjects in the total-contact cast group and thirty-one subjects in the Achilles tendon lengthening group. There were no significant differences in age, body-mass index, or duration of diabetes between the groups. Outcome measures were time to healing of the ulcer, ulcer recurrence rate, range of dorsiflexion of the ankle, peak torque (strength) of the plantar flexor muscles, and peak plantar pressures on the forefoot.

Results: Twenty-nine (88%) of thirty-three ulcers in the total-contact cast group and all thirty ulcers (100%) in the Achilles tendon lengthening group healed after a mean duration (and standard deviation) of 41 ± 28 days and 58 ± 47 days, respectively ($p > 0.05$). (One patient in the Achilles tendon lengthening group died before treatment was completed.) In the first seven months of follow-up, sixteen (59%) of the twenty-seven patients in the total-contact cast group who were available for follow-up and four (15%) of the twenty-seven patients in the Achilles tendon lengthening group who were available for follow-up had an ulcer recurrence ($p = 0.001$). At the time of the two-year follow-up, twenty-one (81%) of the twenty-six patients in the total-contact cast group and ten (38%) of the twenty-six patients in the Achilles tendon lengthening group had ulcer recurrence ($p = 0.002$). Compared with the group treated with the total-contact cast, the group treated with Achilles tendon lengthening had increased dorsiflexion and it remained increased at seven months ($p < 0.001$). Plantar flexor peak torque also decreased after Achilles tendon lengthening ($p < 0.004$), but it returned to baseline after seven months. Peak plantar pressures on the forefoot during barefoot walking were reduced ($p < 0.0002$) following Achilles tendon lengthening yet returned to baseline values within seven months after treatment.

Conclusions: All ulcers healed in the Achilles tendon lengthening group, and the risk for ulcer recurrence was 75% less at seven months and 52% less at two years than that in the total-contact cast group. Achilles tendon lengthening should be considered an effective strategy to reduce recurrence of neuropathic ulceration of the plantar aspect of the forefoot in patients with diabetes mellitus and limited ankle dorsiflexion (≤5°).

Level of Evidence: Therapeutic study, Level I-1a (randomized controlled trial [significant difference]). See Instructions to Authors for a complete description of levels of evidence.

Plantar ulcers in diabetic patients are commonly caused by high plantar pressures in the presence of sensory neuropathy and foot deformity[1,2]. Most foot ulcers (approximately 75%) occur beneath the metatarsal heads and are the result of painless trauma caused by excessive plantar pressures during normal walking[1,3]. Limited dorsiflexion of the foot on the leg, which is thought to occur primarily at the ankle joint (i.e., equinus deformity)[4-8], has been implicated as a contributing factor to excessive plantar pressures and forefoot skin breakdown. Limited ankle dorsiflexion presumably re-

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stricts the leg from rolling over the foot during the late stance phase of walking and places excessive pressure on the plantar aspect of the forefoot, contributing to recurrent skin breakdown and delayed wound-healing.

Immobilization in a total-contact cast is an effective ambulatory method to heal plantar ulcers in patients with diabetes mellitus. Numerous descriptive studies[3,9,10] and controlled clinical trials[11,12] have provided evidence that approximately 90% of these neuropathic plantar wounds heal after an average duration of six weeks. Treatment with a total-contact cast appears to be effective, in part, because it reduces the plantar pressures at the ulcer site[13,14]. Despite the documented ability of a total-contact cast to heal primary ulcers, the ulcer recurrence rate is high, ranging from 20% to 70%[15-17]. The time-period associated with the greatest likelihood of reulceration (a rate of 20% to 57%) is thought to be within the first month after the patient resumes walking without the cast[17,18].

A number of investigators have proposed that patients with recurrent ulceration and limited ankle dorsiflexion should have an Achilles tendon lengthening to increase motion, reduce stress on the forefoot, and help to prevent skin breakdown[5-8]. Descriptive studies have noted an increase of 9° to 18° of ankle dorsiflexion following surgery[6-8]. Armstrong et al. reported that the mean peak pressure (and standard deviation) on the forefoot decreased from 86 ± 9 N/cm^2 to 63 ± 13 N/cm^2 at eight weeks after an Achilles tendon lengthening in ten patients with diabetes mellitus[7]. Furthermore, Lin et al. reported that none of fifteen patients managed with an Achilles tendon lengthening had an ulcer recurrence after more than seventeen months of follow-up[6].

An Achilles tendon lengthening presumably changes the length-tension relationship in the gastrocnemius and soleus muscles and likely affects muscle performance. We could find few clinical data to indicate the effect of Achilles tendon lengthening on muscle performance. While two computer simulation studies of Achilles tendon lengthening for the treatment of equinus deformity predicted substantial weakness in the plantar flexor muscles[19,20], no controlled clinical trials have been conducted, as far as we know, to determine the effect of Achilles tendon lengthening on ulcer-healing, ankle dorsiflexion, or performance of the plantar flexor muscles.

The primary purpose of this study was to compare the effect of Achilles tendon lengthening followed by immobilization in a total-contact cast with treatment with a total-contact cast alone on the rate and duration of ulcer-healing and the number of ulcer recurrences in the first two years of follow-up. Secondary outcome measures were ankle dorsiflexion, plantar flexor muscle strength, and peak plantar pressures on the forefoot and the heel. Since use of a total-contact cast is an effective treatment for healing ulcers, we did not expect a difference between the groups with respect to the duration of healing but did expect a lower rate of ulcer recurrence in the Achilles tendon lengthening group. Furthermore, we hypothesized that ankle dorsiflexion would increase and peak plantar pressures on the forefoot during walking would decrease in the Achilles tendon lengthening group and would remain decreased over a seven-month follow-up period, whereas plantar flexor muscle strength would decline after surgery but return to baseline after seven months.

Materials and Methods

Study Design Overview

Patients were randomly assigned to participate in one of two treatment groups: Achilles tendon lengthening followed by immobilization in a total-contact cast or immobilization in a total-contact cast alone. Tests were conducted on three occasions. The first test occurred at a mean (and standard deviation) of 9.8 ± 15.8 days before treatment; the second test, or posttreatment test, at a mean of 17.3 ± 29.3 days after termination of the primary treatment and healing of the plantar ulcer; and the third test, at a mean of 7.1 ± 1.8 months after initial ulcer-healing. A seven-month follow-up was chosen because we speculated that the plantar flexor muscles would have had an adequate time to rehabilitate, and we could carefully monitor the time-period when ulcers are most likely to recur. Patients were contacted by telephone every month to question them about their health status and foot condition. Patients who reported a reulceration were seen in the clinic. We conducted a final follow-up telephone interview of all patients at an average of 2.1 ± 0.7 years after initial healing to assess for recurrence of ulcers (Fig. 1). Special precautions were not taken to blind the testers to the subject treatment group.

Inclusion Criteria

Patients were considered for inclusion in the study if they had a history of diabetes mellitus, loss of protective sensation (unable to sense the 5.07 Semmes-Weinstein monofilament on at least one location on the plantar aspect of the foot), limitation of ankle dorsiflexion to ≤5°, a palpable ankle pulse, and a recurrent or nonhealing ulcer on the forefoot (Grade II according to the Wagner scale[21]). A limitation of 5° of ankle dorsiflexion was chosen because most authors believe that ≥10° is required for normal walking ability[22]. A recurrent or nonhealing ulcer was defined as two or more occurrences of a plantar ulcer or the failure of a plantar ulcer to heal with conservative treatment (i.e., dressing changes and footwear modifications).

Exclusion Criteria

Patients were excluded from the study if they had a neurological problem complicating the rehabilitation, had a history of Charcot fractures of the hindfoot, were unable to tolerate the anesthesia required for Achilles tendon lengthening, or if it was thought that they would not benefit from an Achilles tendon lengthening (i.e., they were not able to walk). We did not exclude individuals with a Charcot deformity of the midfoot or forefoot or a partial foot amputation if they met the above inclusion criteria.

Randomization

Randomization began in 1998 and was terminated in 2002. An a priori power analysis was conducted to predict the number of subjects needed for the primary and secondary measures.

On the basis of a summary of ulcer recurrence rates ranging from 9% to 57% following treatment with a total-contact cast[17] and a 0% recurrence rate following Achilles tendon lengthening in one descriptive study[6], a 25% effect size (the percentage difference in success) was used for the power analysis. The power calculations assumed a minimum power of 0.80 and a significance level of 0.05, and they predicted that 100 patients would be required to identify group differences in the rate of ulcer recurrence[23]. Next, a power analysis was conducted for the secondary outcome measures (i.e., ankle dorsiflexion, performance of the plantar flexor muscles, and plantar pressures). Effect size was estimated conservatively at 50% of outcome variance accounted for by treatment group differences[6,7]. We also assumed that other variables in the statistical model would account for ≥25% of the variance in outcome. A sample size of sixty patients would allow detection of a 25% effect size with power of 0.80 and an alpha level at 0.05 for the secondary outcome measures[24]. Because of the ex-

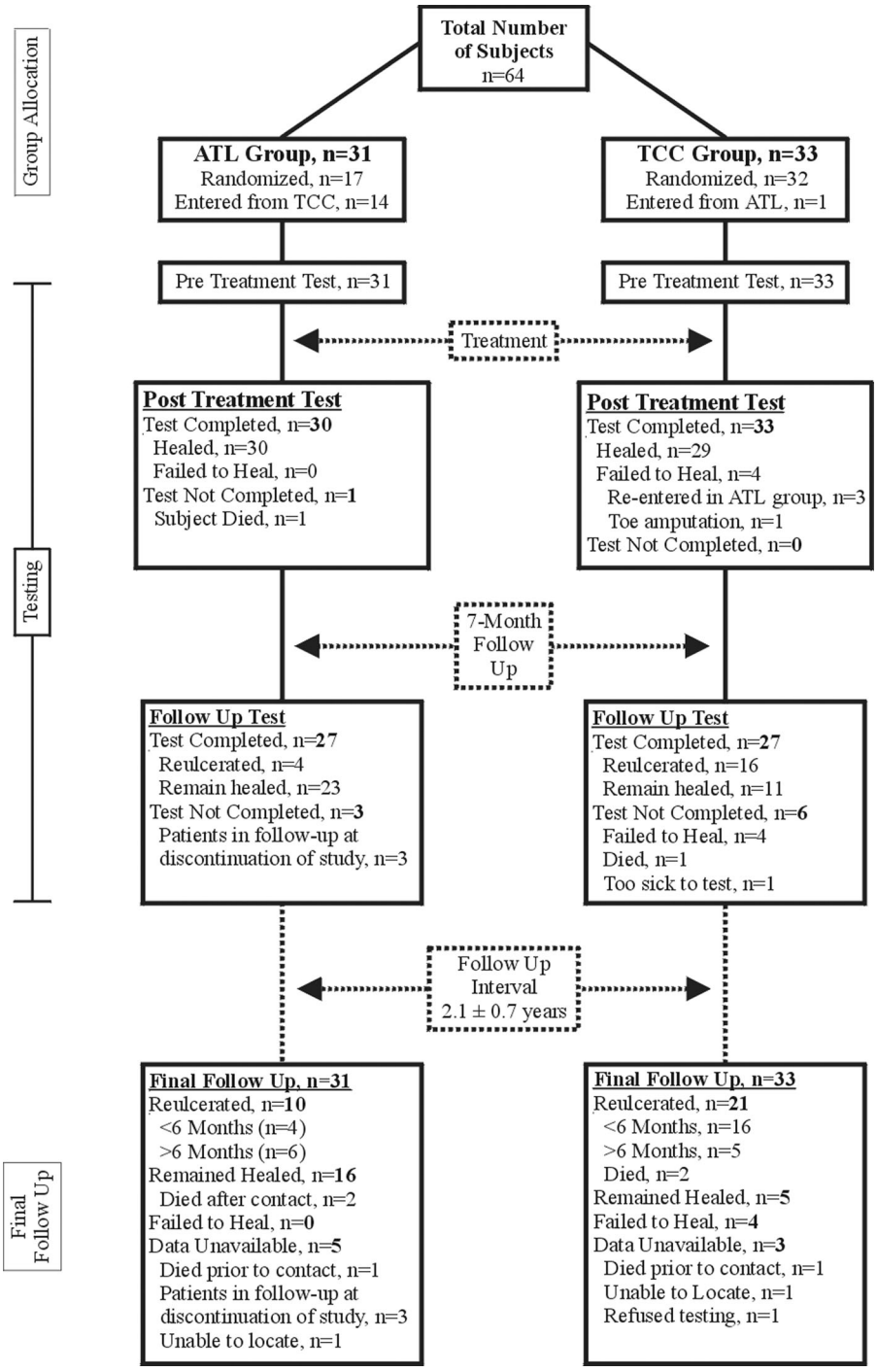

Fig. 1
Subject flow through the study. ATL = Achilles tendon lengthening, and TCC = total-contact cast.

pected effect size, additional testing and cost to the project, and inconvenience for the subjects (time and travel to a different laboratory), only a subsample of subjects was tested for secondary outcome measures. Finally, since the effect size of intervention was greater than anticipated for all outcome measures, testing was terminated in 2002 with the number of subjects described in this study.

Subjects were recruited from the Diabetic Foot Center at Barnes-Jewish Hospital associated with Washington University School of Medicine, St. Louis, Missouri. Informed consent was obtained, with use of a form approved by the institutional review board, from all subjects who agreed to participate. Subjects were randomized into the Achilles tendon lengthening group or the total-contact cast group with use of a prearranged schedule generated by a computer program. Because we anticipated a much higher rate of reulceration in the total-contact cast group compared with that in the Achilles tendon lengthening group[6], and we wanted subjects to have the opportunity to cross over to the Achilles tendon lengthening group if treatment with a total-contact cast alone was not successful, the prearranged schedule was planned to enroll two times as many subjects in the total-contact cast group as in the Achilles tendon lengthening group. Subjects who had a reulceration after treatment with a total-contact cast were then allowed to enter the Achilles tendon lengthening group. Subjects who had a reulceration in the Achilles tendon lengthening group could enter the total-contact cast group only if they lacked 5° of ankle dorsiflexion, a criterion that they were unlikely to meet. The orthopaedic surgeon (J.E.J.), who screened all patients for eligibility into the study, was blind to the prearranged schedule. Once the subject agreed to participate, he or she was referred to the patient coordinator for the study who assigned the subject to a treatment group according to the prearranged schedule and arranged all testing sessions.

Subject Characteristics

Sixty-four subjects met the study criteria and agreed to participate. Thirty-one subjects were randomly assigned to the Achilles tendon lengthening group, and thirty-three subjects were randomly assigned to the total-contact cast group (Fig. 1). Randomization methods were successful as there were no differences between the groups with respect to any subject characteristic ($p > 0.05$). Overall, the subjects had a mean age (and standard deviation) of 56 ± 10 years, and they were predominantly male (forty-nine men and fifteen women) and obese (mean body-mass index, 31.9 ± 7.3 kg). They usually had Type-2 diabetes mellitus (forty-eight had Type 2 and sixteen had Type 1), the mean duration of the diabetes was 18.4 ± 11.7 years, and the subjects had relatively poor glycemic control (mean HbA1c [glycated hemoglobin], 8.8% ± 1.8%) (Table I). The patients presented with an average of 3.7 ± 4.0 previous ulcers. Methods of sensory testing followed a previously described reliable technique[4,25]. All subjects had severe peripheral neuropathy and lacked protective sensation as evidenced by a history of a plantar ulcer and the inability to sense the 5.07 Semmes-Weinstein monofilament on at least one location on the plantar aspect of the foot[25]. Table II contains a description of the foot deformities and comorbidities. There were no differences between groups ($p > 0.05$) for any of these characteristics.

Methods of Treatment

All necrotic tissue and callus surrounding the ulcer were sharply débrided. The ulcer was covered with a dry gauze dressing. The subjects who were randomized to the Achilles tendon lengthening group were placed supine on the operating table, and intravenous sedation was administered. After sterile preparation, local anesthesia was injected along the subcutaneous border of the Achilles tendon as a field block. Three hemisections were made in the Achilles tendon with use of the Hoke triple hemisection technique[26]. Then the surgeon firmly pushed on the plantar aspect of the forefoot, dorsiflexing the ankle in a controlled manner to allow the Achilles tendon to lengthen along the course of its weakened fibers until the foot could be brought

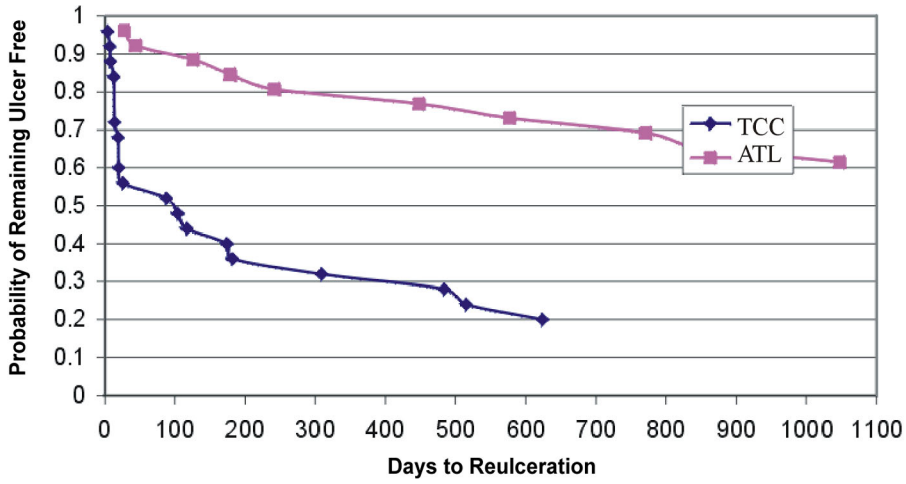

Fig. 2

The Kaplan-Meier survivor probability curve for each group. The curves separately indicate the probability of remaining ulcer-free over time. The subjects in the total-contact cast group (TCC) were much more likely to have an ulcer recurrence than were those in the Achilles tendon lengthening group (ATL), especially in the first weeks after initial healing. Day 0 indicates initial healing of the ulcer.

TABLE I Subject Characteristics

	Group Treated with Achilles Tendon Lengthening	Group Treated with Total-Contact Cast Alone
Age* *(yr)*	56.6 ± 9.2	56.2 ± 10.1
No. of patients	31	33
Male/female†	26/5	23/10
Type-1/type-2 diabetes mellitus *(no. of patients)*	5/26	11/22
Duration of diabetes mellitus* *(yr)*	17.1 ± 10.8	19.6 ± 12.6
Body-mass index*	33.3 ± 7.8	30.5 ± 6.8
HbA1c*† *(%)*	8.8 ± 1.9	8.8 ± 1.7
No. of previous ulcers*	3.7 ± 4.4	3.3 ± 4.0
Ulcer length* *(mm)*	14.3 ± 9.2	15.1 ± 12.0
Ulcer width* *(mm)*	11.3 ± 8.0	12.7 ± 11.9

*The values are given as the mean and the standard deviation. No significant difference ($p > 0.05$) between groups was found with use of the t test between two independent means. †No significant difference ($p > 0.05$) between groups was found with use of chi-square analysis. ‡HbA1c = glycated hemoglobin.

into 10° of dorsiflexion. Excessive force that might cause complete transection or overlengthening of the tendon was carefully avoided. No sutures were used to close the three tenotomy sites, and a dry gauze dressing (4 by 4 in [10 by 10 cm]) was applied and held in place with a sterile cotton wrap.

After the Achilles tendon lengthening, a total-contact cast was applied as described previously[27], except that the distal end of the toe box was left open and a standard rocker cast shoe was used rather than a walking heel. The cast was applied to the leg with the ankle joint in a neutral position. The cast was initially changed after one week and was subsequently changed every two to three weeks for at least six weeks or until the forefoot ulcer had completely healed. The patient was allowed partial weight-bearing immediately after application of the total-contact cast and progressed to full weight-bearing after the first week but was asked to limit his or her activities as much as possible. After application of the cast, the involved foot was placed in a padded diabetic pressure-relief walking boot (DH Pressure Relief Walker; Royce Medical, Camarillo, California) for one to four weeks until the subject felt stable enough to walk with the extra-depth shoes with custom-molded inserts that were prescribed according to published recommendations[28].

Subjects who were randomly assigned to the total-contact cast group were treated with a total-contact cast with use of methods identical to those used in the Achilles tendon lengthening group except that the patients were allowed full weight-bearing immediately after the initial application of the cast. The ankle was positioned as close to neutral as possible, and the cast was changed every two to three weeks until the plantar ulcer was healed. Subjects then were instructed to wear the extra-depth shoes with custom-molded inserts[28].

After treatment, all subjects were instructed in a home-exercise program by a physical therapist with use of a Thera-Band (Hygenic, Akron, Ohio) to provide resistance to the musculature around the ankle. The exercise program included use of a red Thera-Band, progressing to a green one to resist ankle plantar flexion, dorsiflexion, inversion, and eversion movements. Exercises were completed in three sets with ten repetitions in each set, one time per day, for three, four, or five days per week[29].

Primary Outcome Measures

The primary intent of the Achilles tendon lengthening is to decrease the rate of ulcer recurrence. Therefore, primary outcome measures were related to ulcer-healing. Ulcers were considered healed when they showed complete epithelialization with no drainage. Ulcers were evaluated in each group every seven to fourteen days by the physician as the casts were changed. Ulcer-healing (yes or no) and the time to healing (days) were recorded for each subject. Subjects were considered to have an ulcer recurrence if the ulcer reopened (a break in epithelial tissue and drainage) in any location on the forefoot. If the subjects noticed any skin breakdown, they were instructed to contact the patient coordinator to schedule an appointment in the clinic. Subjects also were contacted by telephone every month for the first seven months after the treatment and were asked about their health status and foot condition, including the incidence of skin breakdown. Attempts also were made to contact all subjects by telephone for a final follow-up evaluation regarding ulcer recurrence in 2002. Ulcer recurrence (yes or no) and, for those who had ulcer recurrence, the time (days) from initial ulcer-healing to ulcer recurrence were recorded.

TABLE II Foot Deformities and Comorbidities

	Group Treated with Achilles Tendon Lengthening (n = 31)	Group Treated with Total-Contact Cast Alone (n = 33)
Foot deformities on involved side *(no. of patients)*		
Transmetatarsal amputation	3 (10%)	2 (6%)
Toe and/or ray resection	9 (29%)	6 (18%)
Hammer or claw toe or toes	22 (71%)	24 (73%)
Hallux valgus	6 (19%)	7 (21%)
Comorbid conditions *(no. of patients)*		
Myocardial infarction	10 (32%)	9 (27%)
Cardiac artery bypass graft	6 (19%)	5 (15%)
Congestive heart failure	5 (16%)	6 (18%)
Hypertension	18 (58%)	18 (55%)
Retinopathy	10 (32%)	11 (33%)
Lower extremity revascularization	1 (3%)	3 (9%)
Renal failure	6 (19%)	4 (12%)

Secondary Outcome Measures

The range of dorsiflexion was measured with the subject prone and with use of a standard goniometer by methods described elsewhere[25]. The arms of the goniometer were aligned parallel to the lateral aspect of the leg and the plantar aspect of the foot. The reliability of this test in a similar population has been established (intraclass correlation coefficient [formula 2,1]) = 0.96)[25].

Concentric peak torque of the plantar flexor muscles was measured as an indicator of muscle strength with use of an isokinetic dynamometer (Kin-Com; Chattecx, Hixon, Tennessee) according to methods with established reliability[30,31]. Briefly, the subject was positioned on the dynamometer in the supine position with the foot strapped to the ankle apparatus and with the knee stabilized at 10° of flexion[30]. The testing speed was 60°/sec, which is comparable with the angular velocity of the ankle during the stance phase of walking[31]. Subjects were allowed three, four, or five submaximal practice contractions to become acquainted with the resistance and speed of movement. The foot was then placed in a position of maximum dorsiflexion, and the patient was instructed to push as hard and as fast as possible through the full available range of motion. Subjects were allowed to rest between each of the three repetitions. The maximum peak torque of the three trials was recorded as the peak torque.

Peak plantar pressures on the forefoot during barefoot walking were measured with use of the EMED platform system (Novel Electronics, Minneapolis, Minnesota) for both feet. Data were collected at a sampling rate of 50 Hz as the subject walked barefoot for at least three trials at a self-selected speed across a walkway with the EMED pressure platform embedded in the walkway. The location and magnitude of forefoot and hindfoot peak pressures for both feet were obtained with use of a mean of the three trials to enhance the reliability of the measures[32]. The subjects walked over the platform barefoot to determine the effects of surgery apart from the effects of any foot-wear. Walking speed was recorded by measuring the time required for the subject to walk a known distance.

Statistical Methods

A Fisher exact test was used to determine the significance of differences between groups with respect to the number of ulcers healed and ulcer recurrence rates. A t test was used to determine the significance of differences in the time to healing. Kaplan-Meier survival curves and Cox regression were used to evaluate the data on reulceration for the two groups. A two (group) by three (times of testing) repeated-measures analysis of variance was used to determine differences in each of the secondary measures. Follow-up t tests with use of the error terms from the analysis of variance were used for post hoc comparison on variables found to have a significant group-by-time interaction. The alpha level for all analyses was set at 0.05.

Results

Primary Outcome Measures

Number of Ulcers Healed and Time to Healing

Twenty-nine (88%) of the thirty-three ulcers in the total-contact cast group and all thirty ulcers (100%) in the Achilles tendon lengthening group healed after a mean duration of 40.8 ± 28.1 days and 57.5 ± 47.0 days, respectively. There were no differences in the number of ulcers to heal ($p = 0.12$) or the time to healing ($p = 0.14$) between the groups. Overall, 50% of the ulcers healed in forty-five days, and 85% of the ulcers healed in sixty-three days.

Ulcer Recurrence Rates

Reulceration rates were significantly higher in the total-contact cast group than in the Achilles tendon lengthening group. In the first seven months of follow-up, sixteen (59%) of the twenty-seven patients in the total-contact cast group who were available

for follow-up and four (15%) of the twenty-seven patients in the Achilles tendon lengthening group who were available for follow-up had recurrence of the plantar ulcers on the forefoot ($p = 0.001$). The risk ratio for reulceration during the first seven months after healing in the total-contact cast group compared with the Achilles tendon lengthening group was 4.0 (95% confidence interval, 1.8 to 8.9). At the time of the long-term follow-up evaluation (a mean of 2.1 ± 0.7 years; range, 1.3 to 3.9 years after the initial healing), twenty-one (81%) of the twenty-six patients in the total-contact cast group and ten (38%) of the twenty-six patients in the Achilles tendon lengthening group had recurrence of the plantar ulcers on the forefoot ($p = 0.002$). The risk ratio for reulceration during the 2.1 years after healing in the total-contact cast group compared with the Achilles tendon lengthening group was 2.1 (95% confidence interval, 1.7 to 9.6). Patients in the total-contact cast group also had reulceration much sooner than did those in the Achilles tendon lengthening group (the mean time to reulceration after healing was 131.2 ± 189.9 days and 431.0 ± 364.4 days, respectively; $p = 0.03$). The Kaplan-Meier survivor probability curve for each group (Fig. 2) indicates the probability of being ulcer-free over time. As illustrated in the curve, subjects were much more likely to have an ulcer recurrence in the total-contact cast group than in the Achilles tendon lengthening group, especially in the first weeks after initial healing.

Secondary Outcome Measures (**Table III**)

The range of dorsiflexion for both groups was severely limited prior to treatment (mean, –4.1° ± 7.0° in the Achilles tendon lengthening group and –1.1° ± 7.0° in the total-contact cast group, measured with knee extended). Dorsiflexion with the knee extended and with the knee flexed increased 15.2° and 11.4°, respectively, following treatment with Achilles tendon lengthening (postoperative compared with preoperative dorsiflexion, $p < 0.001$). Dorsiflexion remained essentially the same seven months after treatment in the Achilles tendon lengthening group compared with the posttreatment value ($p > 0.05$). Dorsiflexion in the total-contact cast group measured with the knee extended or flexed changed ≤1.0° across the testing sessions ($p > 0.05$). There were no differences in pretreatment measurements between the groups with respect to any of the secondary measures ($p > 0.05$).

Patients in the Achilles tendon lengthening group showed a 32% decrease in peak torque (strength) of the plan-

TABLE III Results for Ankle Motion, Strength, and Plantar Pressures During Walking

Outcome Variable	Pretreatment Examination*	Posttreatment Examination*	Seven Months After Treatment*	P Value†
Range of dorsiflexion with knee in extension *(deg)*				
Achilles tendon lengthening (n = 17)	–4.1 ± 7.0	11.1 ± 4.1	10.8 ± 4.9	<0.001
Total-contact cast (n = 19)	–1.1 ± 7.0	0.1 ± 3.9	–0.2 ± 5.2	
Range of dorsiflexion with knee in flexion *(deg)*				
Achilles tendon lengthening (n = 17)	3.0 ± 7.0	14.4 ± 4.5	13.9 ± 5.8	<0.001
Total-contact cast (n = 19)	6.5 ± 7.0	6.0 ± 4.8	6.7 ± 5.7	
Peak torque (strength) of plantar flexors *(Nm)*				
Achilles tendon lengthening (n = 15)	35.4 ± 13.2	23.9 ± 13.2	34.4 ± 15.5	<0.001
Total-contact cast (n = 14)	38.2 ± 13.1	42.0 ± 13.6	41.7 ± 16.3	
Peak plantar pressure on forefoot *(N/cm^2)*				
Achilles tendon lengthening (n = 13)	89.24 ± 17.66	64.72 ± 30.67	88.78 ± 28.16	0.005
Total-contact cast (n = 11)	82.56 ± 23.70	86.52 ± 20.03	96.97 ± 16.81	
Peak plantar pressure on hindfoot *(N/cm^2)*				
Achilles tendon lengthening (n = 12)	52.17 ± 22.89	70.06 ± 28.55	70.62 ± 28.05	0.018
Total-contact cast (n = 11)	51.77 ± 30.17	49.00 ± 23.74	55.77 ± 30.70	
Peak plantar pressure on forefoot in uninvolved foot *(N/cm^2)*				
Achilles tendon lengthening (n = 12)	87.86 ± 17.54	84.36 ± 23.64	86.54 ± 29.40	0.848
Total-contact cast (n = 11)	92.80 ± 15.40	91.52 ± 20.13	89.14 ± 18.05	
Peak plantar pressure on hindfoot in uninvolved foot *(N/cm^2)*				
Achilles tendon lengthening (n = 11)	55.15 ± 24.53	59.58 ± 19.39	60.82 ± 19.82	0.380
Total-contact cast (n = 11)	57.74 ± 31.77	55.09 ± 22.70	65.58 ± 31.37	

*Values are given as the mean and the standard deviation. †Group × time interaction.

tar flexor muscles following surgery ($p < 0.004$), but the peak torque returned to the pretreatment level seven months after surgery ($p < 0.001$). Patients in the total-contact cast group showed no significant changes in peak torque of the plantar flexors across the testing times ($p > 0.05$).

Patients in the Achilles tendon lengthening group showed a 32% decrease in peak plantar pressures on the forefoot during barefoot walking on the involved foot following surgery ($p = 0.0002$), but the peak plantar pressure returned to the pretreatment level seven months after surgery ($p = 0.0004$). Patients in the total-contact cast group showed no significant change in peak plantar pressures on the forefoot after treatment, but there was an increase in peak pressure on the forefoot from pretreatment to the seven-month follow-up evaluation (mean, 83 ± 24 N/cm^2 to 97 ± 17 N/cm^2, $p = 0.02$). Peak plantar pressures on the hindfoot for subjects in the Achilles tendon lengthening group increased 34% after treatment ($p = 0.007$) and remained at this increased level at the seven-month follow-up evaluation. Peak plantar pressures on the hindfoot of the subjects in the total-contact cast group did not change over time ($p > 0.05$). Peak plantar pressures on the forefoot or the heel of the uninvolved foot showed no significant differences between groups or across time ($p > 0.05$). Walking speed, which may affect plantar pressures, was not significantly different between the groups or across the testing times.

Complications and Other Outcomes

Four (13%) of the thirty-one patients in the Achilles tendon lengthening group had a heel ulcer develop following treatment. Six (18%) of the thirty-three patients in the total-contact cast group and four (13%) in the Achilles tendon lengthening group had development of superficial abrasions as a result of treatment with the cast; all healed once treatment with the cast was complete. Three patients in the total-contact cast group were intolerant of the cast, refused application of an additional cast, and had immobilization of the foot and ankle with a removable pressure-relief walking boot. No patient had a superficial infection develop from the Achilles tendon lengthening, but one patient had a deep infection that required sharp débridement and antibiotic therapy. Two patients (6.5%) in the Achilles tendon lengthening group reported that they fell during the time that the leg was immobilized in a total-contact cast, but neither was injured. No patient required a major amputation (transmetatarsal or transtibial amputation), but one patient in the total-contact cast group required a toe amputation. Three people (9%) in the total-contact cast group and three (10%) in the Achilles tendon lengthening group died during the course of the five-year study. One of the patients in the Achilles tendon lengthening group died during the treatment phase. The reported cause of death was a myocardial infarction.

Discussion

Primary Outcome Measures

The results support our primary hypothesis that Achilles tendon lengthening helps to reduce ulcer recurrence rates compared with treatment with a total-contact cast alone. Risk reduction for ulcer recurrence after short-term (seven-month) and long-term (2.1-year) follow-up in the Achilles tendon lengthening group was 75% and 53%, respectively, compared with the total-contact cast group. The time-period of greatest risk for ulcer recurrence in the total-contact cast group was the initial three weeks after treatment (Fig. 2). The patients in the Achilles tendon lengthening group did not show this dramatic recurrence of ulceration.

We believe that a primary reason for the lower rate of early recurrence in the Achilles tendon lengthening group was that peak pressures on the forefoot were substantially reduced (27%) after the procedure. During barefoot walking, the patients demonstrated plantar pressures on the forefoot before and after the tenotomy (mean, 89 ± 18 N/cm^2 to 65 ± 31 N/cm^2, Table III) that were almost identical to those reported by Armstrong et al. (mean, 86 ± 9 N/cm^2 to 63 ± 13 N/cm^2)[7]. The lower forefoot pressures may allow the ulcer to heal more thoroughly. These forefoot pressures do not remain decreased, however. Within seven months after surgery, the forefoot pressures returned to the pretreatment level. Perhaps the slow increase of peak pressures on the forefoot back to the baseline level allowed the initial ulcer to heal and adapt to higher pressures more completely than if high pressures were resumed immediately during walking after the initial healing.

Our data indicated that the peak pressures on the forefoot appeared to be related more to plantar flexor muscle strength than to ankle dorsiflexion. Dorsiflexion increased dramatically after the Achilles tendon lengthening and remained increased for seven months. Plantar flexor muscle strength decreased after surgery but returned to baseline level in seven months, similar to the peak pressures on the forefoot. Therefore, the peak pressures on the forefoot appeared to be more related to the vigor of push-off generated from the plantar flexor muscles than to the amount of ankle dorsiflexion.

Patients in the total-contact cast group had a higher rate of ulcer recurrence (59% at seven months and 81% at 2.1 years) than we had anticipated. Apelqvist et al. reported that after one, three, and five years of observation, 34%, 61%, and 70%, respectively, of the patients with a previous ulcer had development of a new foot ulcer[15]. Reiber et al. reported reulceration rates of only 14% to 17% over a two-year follow-up period for patients with diabetes and a history of ulcer, but none of the patients had severe foot deformity and only about 58% had loss of protective sensation[33]. We may have seen a high rate of ulcer recurrence in our total-contact cast group because this patient population had a mean of three or four previous ulcers and all had peripheral neuropathy, loss of protective sensation, multiple comorbidities, and a severe limitation of ankle dorsiflexion. These problems would place them at high risk for recurrent skin breakdown.

The present study provides additional evidence that treatment with a total-contact cast is a rapid and effective method for healing plantar ulcers[3,9-12], but an important limitation of the method is the high rate of reulceration. Patients

clearly require a slow progression from immobilization in a total-contact cost to walking in appropriate foot-wear. Patients may benefit from a padded pressure-relief walker boot as a transition from the total-contact cast to foot-wear. Although the walker boot was used in the Achilles tendon lengthening group after initial healing to help to provide stability secondary to the weak plantar flexor muscles, perhaps it also provided extended protection to the plantar aspect of the foot. This discrepancy in postoperative protocol between the groups is a confounding factor in the interpretation of the results of this study. Additional research is needed to determine the optimal progression and rehabilitation for patients who transition from a total-contact cast to therapeutic foot-wear.

Secondary Outcome Measures

Ankle dorsiflexion increased an average of 15° after the Achilles tendon lengthening compared with an increase of 9° reported by Armstrong et al.[7] and 19° reported by Lin et al.[6]. Each study described an end point in the range of dorsiflexion of approximately 10°, which is the goal of surgery. Interestingly, we found that the mean amount of dorsiflexion did not change in the first seven months after surgery. Inclusion of ankle range-of-motion and strengthening exercises may have helped to maintain this increased dorsiflexion over the seven-month follow-up period.

The Achilles tendon lengthening resulted in a substantial decrease (32%) in the plantar flexor strength after surgery and immobilization, but strength returned to baseline after seven months. There are few other quantitative data in the literature describing the effects of surgery on the performance of the plantar flexor muscles in the adult population, although postoperative weakness of the plantar flexor muscles has been observed in pediatric patients[34,35]. The finding of reduced plantar flexor torque is consistent with computer simulations of the procedure[19,20]. Despite the reduction in plantar flexor muscle strength after surgery, strength returned to a baseline level after seven months. The improvement in plantar flexor peak torque may be related to the return to walking and the progressive resistance exercise program. We do not know how compliant subjects were with this home exercise program. Perhaps greater improvements could be made with a more structured and/or supervised exercise program. More research is needed to determine the ability of patients with diabetes and peripheral neuropathy to increase muscle strength with use of a progressive resistance exercise program.

Somewhat surprisingly, the total-contact cast group showed no changes in the range of dorsiflexion or plantar flexor muscle strength after immobilization. A number of possible reasons may explain the maintenance of ankle range of motion and strength in this group. First, the patients remained weight-bearing throughout the duration of immobilization. In addition, the negative effects of immobilization may have been offset by the positive effects of ulcer-healing and reduced edema in the leg. During initial testing, all subjects had an open plantar ulcer. Although none of them complained of pain during testing, they may have been reluctant to perform maximally resisted plantar flexion. Furthermore, the cast was changed every one to three weeks, and subjects were encouraged to move the ankles. Although it was not measured, reduction of edema during cast changes often was apparent because the cast had become loose. The finding of little change in the range of motion of the ankle joint following treatment with a total-contact cast for the treatment of neuropathic plantar ulcers is consistent with a report from Diamond et al.[36]. A reduction in ankle range of motion and strength does not appear to be a common complication of treatment with a total-contact cast.

The Achilles tendon lengthening procedure resulted in a 34% increase in peak pressures on the heel, which likely was related to the postoperative skin breakdown at the heel that occurred in four subjects after the procedure. Clearly, Achilles tendon lengthening causes an increase in ankle dorsiflexion with reduced strength in the plantar flexor muscles to control the motion, and weight is shifted from the forefoot to the heel during standing and walking. Usually this shift in weight-bearing is uneventful since the heel has a good fat pad for protection of skin breakdown, but four patients in the Achilles tendon lengthening group had skin breakdown under the heel. Of these four patients, none showed excessive increases in ankle dorsiflexion (9° to 12°), and only one showed an unusually large increase (65%) in heel pressures. Patients should be cautioned to watch for skin irritation of the heel following Achilles tendon lengthening.

In conclusion, Achilles tendon lengthening should be considered as an adjunct to treatment with a total-contact cast in patients with a neuropathic plantar ulcer of the forefoot and limited ankle dorsiflexion (≤5°) to decrease the rate of ulcer recurrence. ■

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