Long-Term Results of Tibialis Anterior Tendon Transfer for Relapsed Idiopathic Clubfoot Treated with the Ponseti Method

A Follow-up of Thirty-seven to Fifty-five Years

Joshua B. Holt, MD, David E. Oji, MD, H. John Yack, PhD, PT, and Jose A. Morcuende, MD, PhD

Investigation performed at The Ponseti Clubfoot Treatment Center, Department of Orthopaedic Surgery and Rehabilitation, University of Iowa Hospitals and Clinics, Iowa City, Iowa

Background: Relapse of idiopathic clubfoot deformity after treatment can be effectively managed with repeat casting and tibialis anterior tendon transfer during early childhood. We evaluated the long-term effects on adult foot function after tibialis anterior tendon transfer for relapsed idiopathic clubfoot deformity during childhood.

Methods: Thirty-five patients (sixty clubfeet) in whom idiopathic clubfoot was treated with the Ponseti method from 1950 to 1967 were followed. At an average age of forty-seven years (range, thirty-seven to fifty-five years), the patients underwent a detailed musculoskeletal examination, radiographic evaluation, pedobarographic analysis, and surface electromyography (EMG). They also completed three quality-of-life patient questionnaires.

Results: Fourteen patients (twenty-five clubfeet, 42%) had required repeat casting and tibialis anterior tendon transfer in childhood for relapsed clubfoot deformity after initial casting and served as the study group. Twenty-one patients (thirty-five clubfeet, 58%) were successfully treated with initial casting without relapse (the reference group). No patient in either group had subsequent relapse or required additional operative intervention associated with clubfoot deformity. The mean ankle dorsiflexion was similar between the groups. Radiographically, the tendon transfer group showed a smaller mean anteroposterior talocalcaneal angle and slightly more talar flattening than the reference group with no associated clinical differences. Peak pressures, total force distribution, and surface EMG results were not significantly different between the groups. Outcome questionnaires demonstrated no significant difference between the groups.

Conclusions: Tibialis anterior tendon transfer is very effective at preventing additional relapse of deformity without affecting long-term foot function of patients with idiopathic clubfoot.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

Peer Review: This article was reviewed by the Editor-in-Chief and one Deputy Editor, and it underwent blinded review by two or more outside experts. The Deputy Editor reviewed each revision of the article, and it underwent a final review by the Editor-in-Chief prior to publication. Final corrections and clarifications occurred during one or more exchanges between the author(s) and copyeditors.

Idiopathic congenital talipes equinovarus (clubfoot) remains a common congenital problem, with an incidence of one to seven per 1000 live births[1]. Successful outcomes including a plantigrade, painless, well-aligned foot with good mobility have been reported in long-term follow-up studies after initial treatment with the Ponseti method of serial manipulations and application of casts and a brace regimen[2,3]. However, relapse of dynamic supination deformity during walking and progressive heel varus malalignment remains a major concern, with the reported prevalence ranging from 7%

Disclosure: None of the authors received payments or services, either directly or indirectly (i.e., via his or her institution), from a third party in support of any aspect of this work. None of the authors, or their institution(s), have had any financial relationship, in the thirty-six months prior to submission of this work, with any entity in the biomedical arena that could be perceived to influence or have the potential to influence what is written in this work. Also, no author has had any other relationships, or has engaged in any other activities, that could be perceived to influence or have the potential to influence what is written in this work. The complete **Disclosures of Potential Conflicts of Interest** submitted by authors are always provided with the online version of the article.

to 56%[4,5]. Relapses are commonly the result of inadequate, short-term use of foot abduction bracing and nonadherence to bracing recommendations[4-6]. Multiple surgical approaches to the relapsed clubfoot have been described, including posteromedial soft-tissue release[7], midfoot or hindfoot osteotomies[8-10], resection arthrodesis[11,12], tibial osteotomies[13,14], and various manipulations with use of Ilizarov frame techniques[15]. Relapses can usually be corrected with additional manipulations and serial application of plaster casts, followed by appropriate bracing. However, this becomes increasingly difficult as the child becomes older and will no longer tolerate the brace (usually after three years old). To prevent future relapses, a tibialis anterior tendon transfer to the lateral aspect of the foot can be performed to maintain the improved positioning accomplished through repeated casting[4,16,17]. While this treatment algorithm is known to be effective in the short to medium term, we evaluated the long-term outcomes of tibialis anterior tendon transfer on foot function of adult patients who had been treated for relapsed idiopathic clubfoot during childhood.

Materials and Methods

We conducted a retrospective review of prospectively collected data on all patients treated for idiopathic clubfoot with the Ponseti method at the University of Iowa from 1950 to 1967. All aspects of treatment including manipulation, casting, tenotomies, and tendon transfers were performed by Dr. Ignacio Ponseti. The decision to proceed with tibialis anterior tendon transfer was based on clinical factors, including the severity of the relapse, amount of dynamic supination deformity and varus heel malalignment, and anticipated difficulties with bracing compliance due to the patient's age. Approval was obtained from our institutional review board and consent was obtained from all participants. Patients with congenital anomalies, neuromuscular disease, previous surgery, or prior treatment for clubfoot other than up to three plaster casts were excluded. The medical records of 126 patients who met the inclusion criteria were evaluated. Using available demographic information and online people search engines (WhitePages, Intelius, and USSearch), we were able to find the current telephone number and/or address of eighty-nine (71%) of these patients while we could not locate thirty-seven. Contact was attempted via telephone and/or letter. Of these patients, thirty-five (sixty clubfeet) presented for follow-up clinical examination and completed questionnaires; thus, the follow-up rate was 28%. The remaining fifty-four patients either never replied to contact attempts (thirteen) or were unwilling to return for evaluation because of travel expense, time requirement, or other general health limitations (forty-one).

Of the thirty-five patients for whom follow-up data were obtained, fourteen (40%) underwent tibialis anterior tendon transfer for clubfoot relapse and served as the study group. The remaining twenty-one patients (60%) did not undergo a tibialis anterior tendon transfer and served as the reference group. Eleven of the fourteen patients in the study group had bilateral tibialis anterior tendon transfer for bilateral clubfoot, one with bilateral clubfoot had a unilateral transfer, and two with a unilateral clubfoot had a unilateral transfer.

The tibialis anterior tendon was transferred to the third cuneiform in twenty-two feet, the second cuneiform in two, and the cuboid in one. Percutaneous Achilles tendon lengthening was performed in ten feet because passive dorsiflexion was <10° intraoperatively. Plantar fasciotomy was performed in three feet. The operatively treated lower limb was immobilized in a toe-to-groin plaster cast for six weeks. No additional therapy or bracing was performed thereafter. The procedure technique has been described previously[4]. The mean number of relapses prior to tibialis anterior tendon transfer was 1.4 (range, one to five), with six patients having had four or five relapses. The average age at the time of the tendon transfer was five years (range, sixteen months to eight years).

Of the twenty-one patients in the reference group, fourteen (67%) had bilateral and seven (33%) had unilateral clubfoot. All thirty-five patients returned for a follow-up examination specifically for this study, at an average age of forty-seven years (range, thirty-seven to fifty-five years). The average duration from the time of tibial anterior transfer to the time of final follow-up was forty-three years.

Foot Function Questionnaires

Patients completed three questionnaires: the American Academy of Orthopaedic Surgeons (AAOS) Foot and Ankle Outcomes Questionnaire[18,19], the Laaveg-Ponseti questionnaire[3], and the Foot Function Index (FFI)[20,21]. The AAOS questionnaire evaluates foot and ankle conditions and improvements. The Laaveg-Ponseti questionnaire evaluates occupation, education, pain, function, and satisfaction with the treatment and combines these results with objective measures of motion and gait mechanics. The FFI evaluates pain, disability, and activity limitation and determines the impact of foot pathology on those functions[18,21].

Physical Examination

The senior author (J.A.M.) performed a physical examination on all patients. Examination included measurement of height, weight, foot length and width, and calf circumference. Feet were inspected for tenderness to palpation or manipulation and presence and location of soft-tissue calluses. Manual assessment of the motor strength of the muscles of the foot and ankle was performed with a standard 0-to-5 scale[22]. Patients were assessed for the number of single-legged toe-ups they could perform[23]. The test was stopped on development of pain or fatigue or completion of forty toe-ups. Gait was assessed to identify limping, back-kneeing, and the ability to walk on the toes and heels.

Ankle plantar flexion-dorsiflexion, heel varus-valgus, and forefoot inversion-eversion were measured manually and at specific levels of torque with use of the validated Iowa ankle range of motion device (see Appendix)[24,25].

Radiographic Evaluation

Standing anteroposterior, lateral, and hindfoot radiographs were obtained for all patients. On the anteroposterior radiographs, the talocalcaneal angle, calcaneus-fifth metatarsal angle, and talus-first metatarsal angle were assessed by two independent observers (D.E.O. and J.A.M.). On the lateral radiographs, the talocalcaneal, talus-first metatarsal, calcaneus-first metatarsal, and first-fifth metatarsal angles were evaluated and the talocalcaneal index was calculated. Hindfoot radiographs were assessed for calcaneal varus-valgus alignment with use of the technique advocated by Saltzman and el-Khoury[26].

Wedging of the navicular and flattening of the trochlea of the talus were evaluated, with severity assessed on a scale of none (0), minimal (1), moderate (2), and severe (3). Degenerative changes were analyzed at the ankle, subtalar, talonavicular, calcaneocuboid, navicular-cuneiform, and Lisfranc joints. Osteoarthritic changes were assessed with use of an adapted form of criteria described by Kellgren and Lawrence[27].

Pedobarographic Analysis

Pedobarographic analysis was performed with a pedobarograph pressure sensor while patients walked freely across the room. Measurements were analyzed on a per foot basis. Two measurements were obtained for each foot, one at a self-selected pace and one at 3 mph (4.8 kph). For analysis, the foot was divided into five anatomical regions: heel, midfoot, forefoot, lateral toes, and great toe. For each region, plantar pressure profiles were characterized with use of the following outcome variables: total area of peak pressure (cm^2), peak pressure (N/cm^2), total force (N), pressure time integral (Ns/cm^2), and force time integral (Ns).

Surface Electromyography

Surface electromyographic (EMG) patterns were obtained from the tibialis anterior, lateral gastrocnemius, and peroneus longus muscles as subjects walked

TABLE I Physical Characteristics

Physical Characteristics	Tibialis Anterior Tendon Transfer (N = 14 Patients)	Reference (N = 21 Patients)	P Value
Male *(no.)*	10	13	0.72
White race *(no.)*	14	21	
Age at follow-up* *(yr)*	47.4 ± 6	47.1 ± 4.1	0.83
Height* *(cm)*	171.3 ± 11.7	168.8 ± 10.2	0.55
Weight* *(kg)*	87.9 ± 16.2	90.5 ± 16.3	0.67
Foot length* *(cm)*	25.1 ± 1.63	24.6 ± 1.75	0.31
Foot width* *(cm)*	9.86 ± 0.65	9.65 ± 0.48	0.24
Calf circumference* *(cm)*	36.8 ± 4.13	37.5 ± 3.20	0.51

*The values are given as the mean and standard deviation.

along a 10-m walkway for a total of thirty seconds. Foot-switch data were used to define the gait cycle, and EMG data were time-normalized and ensemble-averaged over ten cycles to obtain representative averages.

Statistical Analysis

Continuous data are expressed as the mean and standard deviation. Differences between groups with regard to radiographic data, physical examination data, and results of the functional questionnaires were analyzed with use of a paired t test. Pearson correlation coefficients were used to determine significant relationships between variables. Categorical data (e.g., the ability to perform toe-ups) were analyzed with use of the chi-square test. The nonparametric Wilcoxon signed-rank test was used to compare pedobarographic results between groups.

Source of Funding

No external funding was received for this study.

Results

No patient in the tendon transfer group had had a relapse or had required additional treatments for clubfoot at time of final follow-up. Three patients in this group did have additional foot/ankle procedures for secondary etiologies including trauma (one), excision of a Morton neuroma (one), and changes related to rheumatoid arthritis (one). There were no significant differences between the transfer and reference groups with regard to the mean number of casts required during the initial treatment (5.8 compared with 5.4, p = 0.37) or the percentage of feet treated with Achilles tenotomy (76% [nineteen] of twenty-five compared with 66% [twenty-three] of thirty-five, p = 0.22).

Sex, race, age, height, weight, foot length, foot width, and calf circumference did not differ significantly between the transfer and reference groups (p ≥ 0.24 for all) (Table I). Five patients (seven feet) in the reference group had a relapse of deformity and required repeat casting.

Foot Function Questionnaires

Questionnaire results (see Appendix) demonstrated no significant differences between the tendon transfer and reference groups with regard to the foot and ankle and shoe scores on the AAOS Foot and Ankle Outcomes Questionnaire or pain, disability, or function scores determined on the FFI (p ≥ 0.18 for all).

The Laaveg-Ponseti functional ratings were similar (p = 0.5) in the two groups (80.6 ± 12.16 in the tendon transfer group compared with 79.8 ± 11.2 in the reference group). The percentage of patients reporting to be "very satisfied" with the treatment was higher in the tendon transfer group than the

TABLE II Foot Range of Motion

	Range of Motion* *(deg)*		
	Tibialis Anterior Tendon Transfer (N = 25 Feet)	Reference (N = 35 Feet)	P Value
Ankle dorsiflexion	3.4 ± 6.7	4.8 ± 7.7	0.51
Ankle plantar flexion	42 ± 13.2	43.7 ± 16.9	0.71
Forefoot eversion	17.6 ± 10.9	14.3 ± 8.4	0.22
Forefoot inversion	16.7 ± 10.3	21.2 ± 11.5	0.15

*The values are given as the mean and standard deviation.

TABLE III Passive Ankle Dorsiflexion Measured with the Iowa Ankle Range of Motion Device

	Passive Ankle Dorsiflexion* *(deg)*		
Torque *(Nm)*	Tibialis Anterior Tendon Transfer (N = 25 Feet)	Reference (N = 35 Feet)	P Value
10	10.5 ± 8.0	10.3 ± 7.0	0.89
15	14.7 ± 8.6	15.8 ± 6.8	0.96
20	20.9 ± 9.5	19.2 ± 6.1	0.54
25	23.0 ± 7.0	22.3 ± 6.3	0.71
Max.	22.0 ± 7.2	23.6 ± 5.9	0.44

*The values are given as the mean and standard deviation.

reference group (86% [twelve] compared with 62% [thirteen]). The percentages of patients reporting "no limitation" or "occasional limitation" in activities requiring use of the involved limb were similar in the two groups (79% [eleven] in the tendon transfer group and 81% [seventeen] in the reference group). Pain was also similar between groups, with 71% [ten] of the patients with a tibialis anterior tendon transfer reporting "no pain" or "occasional mild foot pain" compared with 81% [seventeen] of the reference group. Average and worst foot pain were rated slightly higher by the tendon transfer group (3.2 and 6.7 of 10, respectively) when compared with the reference group (1.8 and 4.3 of 10, respectively). Neither difference reached significance. Four patients in the tendon transfer group compared with one patient in the reference group were taking nonsteroidal anti-inflammatory drugs (NSAIDs) for foot pain. Only one patient in the tendon transfer group was taking them on a daily basis.

Physical Examination

Passive ankle plantar flexion-dorsiflexion and forefoot inversion-eversion did not differ significantly between the groups (Table II). There were no significant differences in passive ankle dorsiflexion between the two groups at any level of applied torque (Table III).

The tibialis anterior tendon transfer and reference groups did not differ with respect to areas of focal tenderness to palpation. In the tendon transfer group, six feet had focal tenderness to palpation in the plantar fascia (two feet), in the Achilles tendon (two), in the third cuneiform (one), or dorsolateral near the sinus tarsi (one). Similar results were found in the reference group, with focal tenderness to palpation at the anterolateral aspect of the ankle (two), at the Achilles tendon (two), at the first metatarsal (two), and between the third and fourth metatarsals at the site of a prior Morton neuroma resection (one).

The most common symptom in both groups was pain along the body of the Achilles tendon (at the location of the prior tenotomy). However, no patient reporting Achilles tendon pain had radiographic evidence of Achilles tendon calcification. The groups were similar with regard to callus formation over the heads of the first and fifth metatarsals. There was no significant difference in the location of calluses between the two groups, with neither group having a unique area of callus formation.

Motor strength of the tibialis anterior and peroneal muscles was comparable between the two groups (see Appendix). Two feet in the tendon transfer group had tibialis anterior strength of 3 of 5 and 4 of 5. One of these patients had had a previous ankle fusion secondary to rheumatoid arthritis, and the other had osteophytes at the first metatarsophalangeal joint causing pain with resisted dorsiflexion. Five feet in the tendon transfer group had decreased peroneal muscle strength, measuring 3 of 5 in one foot and 4 of 5 in four. In the reference group, two feet had decreased peroneal strength. The patient in the tendon transfer group with 3 of 5 strength of both the tibialis anterior and the peronei had substantial osteophytosis at the first metatarsophalangeal joint and was limited by pain. The patients who had undergone a tibialis anterior tendon transfer completed a significantly greater number of single-legged toe-ups than the reference patients (average, twenty-nine compared with twenty, $p < 0.01$). No correlation was found between the number of toe-ups performed and prior Achilles tenotomy.

Three patients in the tendon transfer group were unable to toe walk. However, one patient had severe osteophyte formation at the first metatarsophalangeal joint, another had had a prior ankle fusion due to complications from rheumatoid arthritis, and the third did not attempt to toe walk because of pain from previous ankle trauma. One patient from the reference group could not toe walk. Six patients in the tendon transfer group were unable to heel walk compared with four in the reference group. The patient with a history of rheumatoid arthritis and associated ankle fusion walked with a grossly antalgic gait pattern, whereas all remaining patients in both study groups demonstrated a grossly normal gait pattern.

Radiographic Evaluation

The patients who underwent tibialis anterior tendon transfer had a significantly smaller ($p = 0.048$) anteroposterior talocalcaneal angle compared with the reference patients (11.04 ± 3.7 compared with 13.13 ± 3.8) (Table IV). The number of patients with moderate to severe talar flattening was significantly higher in the tendon transfer group ($p = 0.03$) than in the reference group

Fig. 1
Talar flattening (grade 2) is shown in the top radiograph whereas the bottom radiograph shows no flattening (grade 0).

(eight compared with three) (Fig. 1 and Appendix). The two groups did not differ significantly with regard to the prevalence of other commonly reported radiographic abnormalities in patients with clubfoot, including an abnormal lateral talocalcaneal angle and navicular wedging.

Osteoarthritic changes were evaluated radiographically with use of an adapted form of the criteria defined by Kellgren and Lawrence[27]. The talonavicular and navicular-cuneiform joints (Fig. 2) showed the greatest degree of degenerative change in both groups. With the exception of more moderate

Fig. 2
Degenerative changes in the talonavicular and navicular-cuneiform joints. The radiograph on the left shows moderate osteophyte formation, and the radiograph on the right shows severe talonavicular joint-space narrowing and degeneration.

TABLE IV Radiographic Measurements

	Tibialis Anterior Tendon Transfer* (N = 25 Feet)	Reference* (N = 35 Feet)	P Value
Anteroposterior radiograph			
Talocalcaneal angle	11.04 ± 3.7	13.12 ± 3.8	0.048
Calcaneus-fifth metatarsal angle	0.63 ± 12.7	1.42 ± 10.1	0.81
Talus-first metatarsal angle	1 ± 10.1	2.15 ± 9.62	0.68
Lateral radiograph			
Talocalcaneal angle	28.91 ± 5.7	30.64 ± 7.2	0.38
Talus-first metatarsal angle	2.62 ± 3.2	4.1 ± 4.8	0.24
Calcaneus-first metatarsal angle	148.19 ± 6.4	146 ± 9.5	0.38
First-fifth metatarsal angle	12.91 ± 2.9	13.6 ± 3.2	0.42
Talocalcaneal index	40.1 ± 5.7	43.8 ± 8.4	0.09
Hindfoot radiograph			
Mean apparent moment arm† *(mm)*	−3.9 ± 6.3	−2.8 ± 5	0.52

*The values are given as the mean and standard deviation, with all angles given in degrees. †Normal moment arm = −3.2, as reported by Saltzman and el-Khoury[26].

to severe osteophytes in the navicular-cuneiform joint in the tendon transfer group (p = 0.024), degenerative changes and osteophyte formation were similar between the two groups. Three patients in the tendon transfer group and one in the reference group had radiographic evidence of degenerative change at the first metatarsophalangeal joint. One patient in the reference group had osteoarthritic changes at the first distal interphalangeal joint. One patient in the reference group had navicular displacement.

Six patients (nine feet) had painless Achilles tendon calcification on radiography (see Appendix). All nine feet had previously undergone Achilles tenotomy, five feet had had a prior tibialis anterior tendon transfer, and four feet had not undergone a prior tibialis anterior tendon transfer. In the tendon transfer group, one patient with bilateral clubfoot had unilateral calcification and two with bilateral clubfoot had bilateral calcification. Of the patients who had not undergone tendon transfer, one had bilateral calcification and bilateral clubfoot, another had unilateral calcification and bilateral clubfoot, and the third patient had unilateral calcification and unilateral clubfoot.

Two patients had previously undergone fusion of the subtalar and calcaneocuboid or ankle joint for reasons other than clubfoot (rheumatoid arthritis and trauma); therefore, their radiographs were excluded from analysis.

Pedobarographic Analysis

Pedobarographic data showed no significant difference between the two groups (see Appendix). Additionally, comparison of medial and lateral foot surface pressures showed no difference between the tendon transfer and reference groups (Fig. 3).

Surface Electromyography Analysis

Patients in the tendon transfer group showed no difference in muscle firing times when compared either with the reference group or healthy college-age students[28] (Fig. 4). The mean tibialis anterior and gastrocnemius muscle amplitudes were slightly decreased in the tendon transfer group

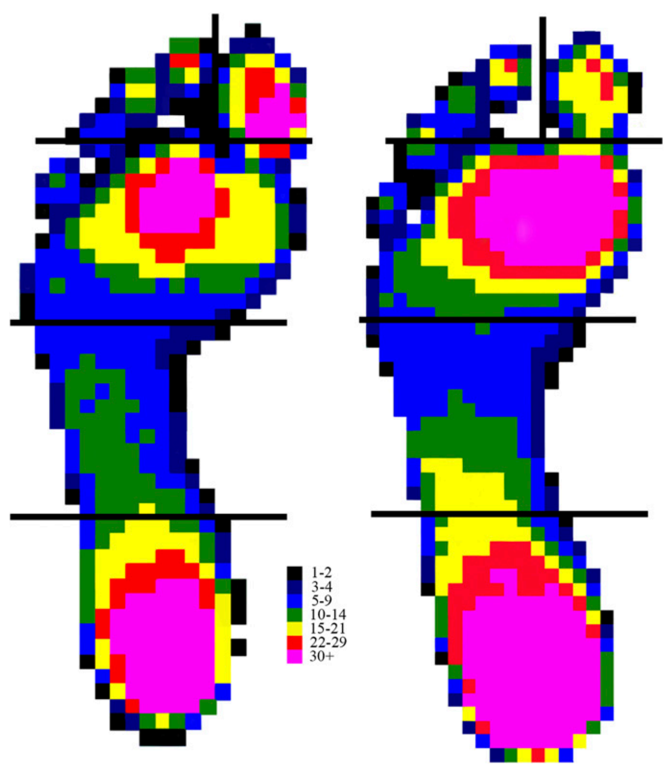

Fig. 3

Pedobarographic images demonstrating average pressure recordings in five regions of the foot in the reference group (left Image) and the tendon transfer group (right image). The color coding is based on absolute average peak pressure measurement (in N/cm²).

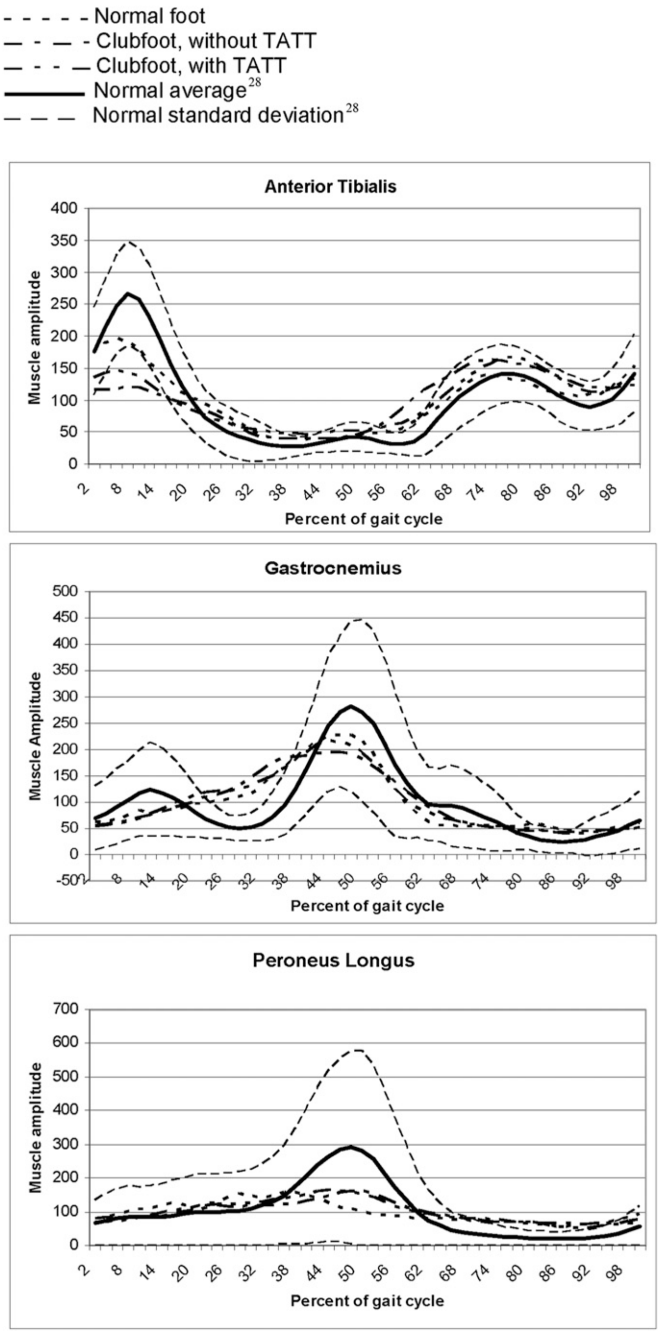

Fig. 4

EMG data from the tibialis anterior, gastrocnemius, and peroneus longus muscles. Zero on the x axis represents initial heel strike. Stance phase is 0% to 60% of the gait cycle. TATT = tibialis anterior tendon transfer.

compared with those of the healthy subjects (p = 0.45 and 0.36, respectively).

Discussion

Since tibialis anterior tendon transfer was initially described for the treatment of clubfoot relapse by Garceau and Manning in 1947[29] and Ponseti and Smoley[4] in 1963, the procedure has become an important treatment in the management of clubfeet[17,30-35]. Medium-term follow-up studies have shown tibialis anterior tendon transfer to correct residual dynamic supination deformity and maintain clinical improvements in dorsiflexion and eversion[36-38]. Our study provides information regarding the long-term outcomes of tibialis anterior tendon transfer in the treatment of clubfoot relapse[2,3]. First, the results establish the effectiveness of the procedure as no patient who underwent tibialis anterior tendon transfer had subsequent relapse or required additional casting or operative intervention for clubfoot. To our knowledge, this is the first long-term evaluation of foot function after tibialis anterior tendon transfer, and it demonstrated no delayed or recurrent adverse outcomes and showed maintenance of foot function into the fifth decade of life.

Few differences were noted between the tendon transfer and reference groups. Those who had undergone tibialis anterior tendon transfer had greater talar flattening, a smaller anteroposterior talocalcaneal angle, and more moderate to severe osteophytes at the navicular-cuneiform joint, findings that were distinctly different from those of prior reports demonstrating a normal anteroposterior talocalcaneal angle and smaller lateral talocalcaneal angle after tibialis anterior tendon transfer[3,39]. However, the smaller anteroposterior talocalcaneal angle noted in our patients who had been treated with tibialis anterior tendon transfer resulted in no clinically detectable differences between the groups as demonstrated by similar outcomes measured with questionnaires.

We postulate that the increased number of toe-ups performed by the tendon transfer group resulted from improved muscle balance in the lower extremity through enhanced eccentric muscle contraction leading to improved complement to the gastrocnemius-soleus during heel rise, confirming the results of previous reports[40].

Radiographic evidence of degenerative change—i.e., navicular-cuneiform osteophyte formation and talar flattening—was more severe in the tendon transfer group than in the reference group. However, neither radiographic evidence of moderate to severe osteoarthritic change nor greater talar flattening was associated with increased pain, greater medication use, or difficulty walking. Conversely, those clinical symptoms were highly associated with the patients' medical history. Six patients (nine feet) had painless Achilles tendon calcifications, with no history of extraskeletal calcifications, hypercalcemia, hyperphosphatemia, dystrophic calcification, or fibrodysplasia ossificans. Some of our patients had prior radiographs available from when they participated in the studies by Laaveg and Ponseti in 1980[3] and Cooper and Dietz in 1995[2], and these radiographs did not show calcifications in any of them, suggesting that calcification occurred several decades after the index procedure. Subgroup analysis demonstrated no significant difference in subjective measures between patients with and those without Achilles tendon calcification. Mean ankle dorsiflexion did not differ significantly between patients with calcification and those without it, and only a nonsignificant decrease in ankle plantar flexion was found in the patients with calcification.

No differences in pedobarographic findings were found between the patients who had undergone tibialis anterior tendon transfer and those who had not. Specifically, lateral and medial pressure readings of the foot demonstrated no difference between groups, demonstrating that the tendon transfer effectively balances the forces on the foot and prevents equinus deformity and walking on the lateral surface of the foot.

Previous data have shown surface electromyography to be an important tool in evaluating the sequence and amplitude of individual muscles during the gait cycle[41,42]. Although there is "cross talk" between muscles of interest, these low signals from adjacent muscles during the gait cycle can be effectively minimized through filters and processing of the received data[43]. The obtained surface EMG data demonstrated a non-significant decrease in muscle firing amplitudes in patients with a prior tibialis anterior tendon transfer when compared with healthy young adults[28]. This difference was most pronounced in the tibialis anterior and gastrocnemius muscles early in the gait cycle. This amplitude difference is likely due to the slightly shorter arc of dorsiflexion seen after tibialis anterior tendon transfer when compared with normalized data. As a result, there is a smaller angle of heel strike and decreased eccentric contraction of the muscle. Although EMG abnormalities have been demonstrated preoperatively in patients with clubfoot[44], functional surface EMG data have not been validated as a reliable tool for assessing muscle strength or gait after tibialis anterior tendon transfer for clubfoot.

The present study had several limitations, particularly the 28% patient follow-up rate. Although retrospectively reviewed, the data in the current study were collected prospectively at the time of final follow-up. Consequently, complete data were generally available for all patients who presented for evaluation. A few study patients had foot/ankle pain and dysfunction related to concomitant etiologies. Secondary outcomes in these patients were assumed to be sequelae of these other etiologies. However, it is impossible to discount or attempt to quantify the contribution that the corrected clubfoot deformity may have made to the long-term outcomes in these patients. Physical examination was performed by a single examiner at the time of final follow-up, leading to the possibility of bias in outcomes. A final limitation was the small study size.

In conclusion, this study with a follow-up of nearly fifty years demonstrates that repeated serial manipulation and casting followed by tibialis anterior tendon transfer for the treatment of relapsed idiopathic clubfoot are very effective at preventing additional relapses without affecting long-term foot function. The results of this study suggest that radiographic changes commonly observed in a corrected clubfoot do not correlate with long-term functional outcomes.

Appendix

eA Tables showing questionnaire results, motor strength as assessed manually, osteoarthritic changes seen on radiographs, and pedobarographic results as well as figures demonstrating the Iowa ankle range of motion device and the radiographic appearance of Achilles tendon calcification are available with the online version of this article as a data supplement at jbjs.org. ■

Joshua B. Holt, MD
David E. Oji, MD
H. John Yack, PhD, PT
Jose A. Morcuende, MD, PhD
Ponseti Clubfoot Treatment Center (J.B.H., D.E.O., and J.A.M.) and Orthopaedic Gait Analysis Laboratory (H.J.Y.),
Department of Orthopaedic Surgery and Rehabilitation,
University of Iowa Hospitals and Clinics,
200 Hawkins Drive, 01008 JPP,
Iowa City, IA 52242.
E-mail address for J.B. Holt: joshua-holt@uiowa.edu

References

1. Wynne-Davies R. Genetic and environmental factors in the etiology of talipes equinovarus. Clin Orthop Relat Res. 1972 May;84:9-13.

2. Cooper DM, Dietz FR. Treatment of idiopathic clubfoot. A thirty-year follow-up note. J Bone Joint Surg Am. 1995 Oct;77(10):1477-89.

3. Laaveg SJ, Ponseti IV. Long-term results of treatment of congenital club foot. J Bone Joint Surg Am. 1980 Jan;62(1):23-31.

4. Ponseti IV, Smoley EN. Congenital club foot: the results of treatment. J Bone Joint Surg Am. 1963 Mar;45(2):261-75.

5. Dobbs MB, Rudzki JR, Purcell DB, Walton T, Porter KR, Gurnett CA. Factors predictive of outcome after use of the Ponseti method for the treatment of idiopathic clubfeet. J Bone Joint Surg Am. 2004 Jan;86(1):22-7.

6. Morcuende JA, Dolan LA, Dietz FR, Ponseti IV. Radical reduction in the rate of extensive corrective surgery for clubfoot using the Ponseti method. Pediatrics. 2004 Feb;113(2):376-80.

7. Blakeslee TJ, DeValentine SJ. Management of the resistant idiopathic clubfoot: the Kaiser experience from 1980-1990. J Foot Ankle Surg. 1995 Mar-Apr;34(2):167-76.

8. Dwyer FC. The treatment of relapsed club foot by the insertion of a wedge into the calcaneum. J Bone Joint Surg Br. 1963;45(1):67-75.

9. Lourenco AF, Dias LS, Zoellick DM, Sodre H. Treatment of residual adduction deformity in clubfoot: the double osteotomy. J Pediatr Orthop. 2001 Nov-Dec;21(6):713-8.

10. Wilcox PG, Weiner DS. The Akron midtarsal dome osteotomy in the treatment of rigid pes cavus: a preliminary review. J Pediatr Orthop. 1985 May-Jun;5(3):333-8.

11. Evans D. Relapsed clubfoot. J Bone Joint Surg Br. 1961;43:722-33.

12. Wei SY, Sullivan RJ, Davidson RS. Talo-navicular arthrodesis for residual midfoot deformities of a previously corrected clubfoot. Foot Ankle Int. 2000 Jun;21(6):482-5.

13. Napiontek M, Nazar J. Tibial osteotomy as a salvage procedure in the treatment of congenital talipes equinovarus. J Pediatr Orthop. 1994 Nov-Dec;14(6):763-7.

14. Lloyd-Roberts GC, Swann M, Catterall A. Medial rotational osteotomy for severe residual deformity in club foot. A preliminary report on a new method of treatment. J Bone Joint Surg Br. 1974 Feb;56(1):37-43.

15. Hosny GA. Correction of foot deformities by the Ilizarov method without corrective osteotomies or soft tissue release. J Pediatr Orthop B. 2002 Apr;11(2):121-8.

16. Hui JH, Goh JC, Lee EH. Biomechanical study of tibialis anterior tendon transfer. Clin Orthop Relat Res. 1998 Apr;(349):249-55.

17. Ponseti IV. Congenital clubfoot. Fundamentals of treatment. New York: Oxford University Press; 1996.

18. Saltzman CL, Mueller C, Zwior-Maron K, Hoffman RD. A primer on lower extremity outcome measurement instruments. Iowa Orthop J. 1998;18:101-11.

19. Johanson NA, Liang MH, Daltroy L, Rudicel S, Richmond J. American Academy of Orthopaedic Surgeons lower limb outcomes assessment instruments. Reliability, validity, and sensitivity to change. J Bone Joint Surg Am. 2004 May;86(5):902-9.

20. SooHoo NF, Samimi DB, Vyas RM, Botzler T. Evaluation of the validity of the Foot Function Index in measuring outcomes in patients with foot and ankle disorders. Foot Ankle Int. 2006 Jan;27(1):38-42.

21. Budiman-Mak E, Conrad KJ, Roach KE. The Foot Function Index: a measure of foot pain and disability. J Clin Epidemiol. 1991;44(6):561-70.

22. Daniels L, Worthingham C. Muscle testing: technique of manual examination. 4th ed. Philadelphia: W.B. Saunders; 1980.

23. Lunsford BR, Perry J. The standing heel-rise test for ankle plantar flexion: criterion for normal. Phys Ther. 1995 Aug;75(8):694-8.

24. Wilken J, Rao S, Estin M, Saltzman CL, Yack HJ. A new device for assessing ankle dorsiflexion motion: reliability and validity. J Orthop Sports Phys Ther. 2011 Apr;41(4):274-80. Epub 2011 Apr 01.

25. Hicks JH. The mechanics of the foot. I. The joints. J Anat. 1953 Oct;87(4):345-57.

26. Saltzman CL, el-Khoury GY. The hindfoot alignment view. Foot Ankle Int. 1995 Sep;16(9):572-6.

27. Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. Ann Rheum Dis. 1957 Dec;16(4):494-502.

28. Winter DA, Yack HJ. EMG profiles during normal human walking: stride-to-stride and inter-subject variability. Electroencephalogr Clin Neurophysiol. 1987 Nov;67(5):402-11.

29. Garceau GJ, Manning KR. Transposition of the anterior tibial tendon in the treatment of recurrent congenital club-foot. J Bone Joint Surg Am. 1947 Oct;29(4):1044-8.

30. Ricciardi-Pollini PT, Ippolito E, Tudisco C, Farsetti P. Congenital clubfoot: results of treatment of 54 cases. Foot Ankle. 1984 Nov-Dec;5(3):107-17.

31. Garceau GJ, Palmer RM. Transfer of the anterior tibial tendon for recurrent club foot. A long-term follow-up. J Bone Joint Surg Am. 1967 Mar;49(2):207-31.

32. Ponseti IV. Treatment of congenital club foot. J Bone Joint Surg Am. 1992 Mar;74(3):448-54.

33. Singer M, Fripp AT. Tibialis anterior transfer in congenital club foot. J Bone Joint Surg Br. 1958 May;40(2):252-5.

34. Garceau GJ. Anterior tibial tendon transfer for recurrent clubfoot. Clin Orthop Relat Res. 1972 May;84:61-5.

35. Ponseti IV, Campos J. Observations on pathogenesis and treatment of congenital clubfoot. Clin Orthop Relat Res. 1972 May;84(84):50-60.

36. Ezra E, Hayek S, Gilai AN, Khermosh O, Wientroub S. Tibialis anterior tendon transfer for residual dynamic supination deformity in treated club feet. J Pediatr Orthop B. 2000 Jun;9(3):207-11.

37. Kuo KN, Hennigan SP, Hastings ME. Anterior tibial tendon transfer in residual dynamic clubfoot deformity. J Pediatr Orthop. 2001 Jan-Feb;21(1):35-41.

38. Farsetti P, Caterini R, Mancini F, Potenza V, Ippolito E. Anterior tibial tendon transfer in relapsing congenital clubfoot: long-term follow-up study of two series treated with a different protocol. J Pediatr Orthop. 2006 Jan-Feb;26(1):83-90.

39. Ponseti IV. Relapsing clubfoot: causes, prevention, and treatment. Iowa Orthop J. 2002;22:55-6.

40. Thompson GH, Hoyen HA, Barthel T. Tibialis anterior tendon transfer after clubfoot surgery. Clin Orthop Relat Res. 2009 May;467(5):1306-13. Epub 2009 Feb 26.

41. De Luca CJ. The use of surface electromyography in biomechanics. J Appl Biomech. 1997 May;13(2):135-63.

42. Perry J, Easterday CS, Antonelli DJ. Surface versus intramuscular electrodes for electromyography of superficial and deep muscles. Phys Ther. 1981 Jan;61(1):7-15.

43. De Luca CJ, Merletti R. Surface myoelectric signal cross-talk among muscles of the leg. Electroencephalogr Clin Neurophysiol. 1988 Jun;69(6):568-75.

44. Thometz J, Sathoff L, Liu XC, Jacobson R, Tassone JC. Electromyography nerve conduction velocity evaluation of children with clubfeet. Am J Orthop (Belle Mead NJ). 2011 Feb;40(2):84-6.