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## Nonsurgical Management of Posterior Tibial Tendon Dysfunction With Orthoses and Resistive Exercise: A Randomized Controlled Trial

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**Background and Purpose.** Tibialis posterior tendinopathy can lead to debilitating dysfunction. This study examined the effectiveness of orthoses and resistance exercise in the early management of tibialis posterior tendinopathy.

**Subjects.** Thirty-six adults with stage I or II tibialis posterior tendinopathy participated in this study.

**Methods.** Participants were randomly assigned to 1 of 3 groups to complete a 12-week program of: (1) orthoses wear and stretching (O group); (2) orthoses wear, stretching, and concentric progressive resistive exercise (OC group); or (3) orthoses wear, stretching, and eccentric progressive resistive exercise (OE group). Pre-intervention and post-intervention data (Foot Functional Index, distance traveled in the 5-Minute Walk Test, and pain immediately after the 5-Minute Walk Test) were collected.

**Results.** Foot Functional Index scores (total, pain, and disability) decreased in all groups after the intervention. The OE group demonstrated the most improvement in each subcategory, and the O group demonstrated the least improvement. Pain immediately after the 5-Minute Walk Test was significantly reduced across all groups after the intervention.

**Discussion and Conclusion.** People with early stages of tibialis posterior tendinopathy benefited from a program of orthoses wear and stretching. Eccentric and concentric progressive resistive exercises further reduced pain and improved perceptions of function.



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Posterior tibial tendon dysfunction (PTTD) is a well-recognized source of pain and walking dysfunction<sup>1,2</sup> and is one of the leading causes of acquired flatfoot deformity in the adult population.<sup>3-9</sup> Descriptively, the various presentations of this condition are divided into 3 stages.<sup>1</sup> Stage I is characterized by mild swelling, medial ankle pain, normal but possibly painful heel rise, and no deformity. Stage II is characterized by progressive flattening of the arch, with an abducted midfoot indicating secondary midfoot deformity. The hindfoot is still flexible, but the tendon is functionally incompetent or ruptured, and patients are commonly unable to perform a heel rise. Stage III includes all of the signs of stage II, except that the hindfoot deformity has become fixed. In severe cases, pain may be present at the calcaneal-fibular articulation because of lateral abutment. Myerson and Corrigan<sup>10</sup> added stage IV for patients who progressed to valgus tilt of the talus in the ankle mortise, leading to lateral tibiotalar degeneration.

Despite the high prevalence of PTTD,<sup>4</sup> there are no intervention guidelines for stage I or II, and surgical repair is the only definitive treatment for stage III or IV. Factors associated with PTTD include age-related degeneration, inflammatory arthritides,<sup>11,12</sup> hypertension, diabetes mellitus, obesity, and, less frequently, acute traumatic rupture.<sup>10,12,13</sup>

Because the pathogenesis of this condition is theorized to be tendon degeneration (tendinosis),<sup>14,15</sup> rehabilitation efforts in the early stages of the disorder frequently focus on mechanically supporting the flattened arch to prevent further tendon lengthening and foot deformity.<sup>2,16,17</sup> It has been observed that a flattened arch may be accompanied by an everted calcaneus, promoting a shortened calf musculotendinous

complex. Exercises to strengthen the weakened tibialis posterior musculotendinous complex also have been strongly recommended to prevent further degeneration.<sup>16,18</sup> Lacking in the literature, however, are guidelines specifying how to most effectively strengthen the muscle in the presence of painful tendon dysfunction.

Although early reports suggested that the dysfunction arises from an inflammatory process in or around the tibialis posterior tendon (tendinitis or tenosynovitis),<sup>19</sup> recent histological studies suggested that the changes associated with PTTD are more consistent with a degenerative process. In a comparison of gross and histological findings for specimens obtained from 15 people undergoing surgical intervention for stage II PTTD, Mosier and colleagues<sup>14,15</sup> reported an absence of inflammatory infiltrates in the tendons despite the clinical appearance of tenosynovitis during surgery. Additionally, they identified disruption of the linear organization of the collagen bundles, which could reduce the tensile strength of the tendon and predispose it to further attenuation or rupture under a large load.

The development of an exercise program that strengthens the weakened tibialis posterior musculotendinous complex is essential for effectively managing the early stages of PTTD and preventing further degeneration. The specificity and intensity of training are central concepts in designing an optimal treatment paradigm. Kulig and colleagues<sup>20</sup> examined the activation of the tibialis posterior muscle during repeated movements and reported that a closed-chain resisted foot adduction exercise performed barefoot most effectively and selectively activated the tibialis posterior muscle in people with a normal arch index. In a subsequent study of people with pes

planus who were asymptomatic, the authors determined that, although the tibialis posterior muscle was preferentially recruited during the same exercise, the most effective and selective activation occurred only when subjects wore arch-supporting orthoses and shoes.<sup>21</sup> The effectiveness of this exercise for people with painful PTTD was not studied.

The intensity of a stimulus, such as exercise, requires sufficient load and frequency to trigger adaptation. The musculotendinous complex tolerates a larger load during eccentric exercise than during concentric exercise.<sup>22</sup> However, the level of muscle activation is lower during eccentric exercise,<sup>23</sup> suggesting that eccentric training may be optimal if the desired outcome is to load the tendon to promote adaptation. To test this assumption, we proposed a comparison of concentric and eccentric resistive exercises. Given the above data, it is feasible that within a 12-week period of twice-daily progressive resistive exercises, an eccentric program would allow for exercise at loads exceeding those in a concentric program and, therefore, would provide a larger load to the tendon. Furthermore, to address the everted calcaneus, which is associated with a shortened calf musculotendinous complex and flatfoot deformity, we added stretching of the calf musculature to the exercise protocol.

Recent research focusing on people with painful Achilles tendinosis determined that participation in a heavy-load eccentric calf muscle training program improved function,<sup>24,25</sup> reduced pain,<sup>25</sup> and enhanced tendon structure.<sup>26</sup> Influenced by those studies and our own positive clinical observations after the use of an adapted form of this protocol for people with PTTD, we designed a study to test the effects of

**Table 1.**  
Demographic and Anthropometric Characteristics of Participants

Group	Age, y <sup>a</sup>	Sex	Involved Side	Duration of Symptoms, mo <sup>a</sup>	Body Weight, kg <sup>a</sup>	Body Height, m <sup>a</sup>	Body Mass Index <sup>a,b</sup>	Arch Index <sup>a,c</sup>
Orthoses (n=12)	51.3 (17.2)	8 women, 4 men	5 right, 7 left	25.3 (50.3)	82.5 (18.8)	1.70 (0.07)	28.7 (6.26)	0.169 (0.035)
Orthoses and concentric exercise (n=12)	55.3 (16.4)	10 women, 2 men	9 right, 3 left	26.0 (36.2)	85.9 (22.7)	1.65 (0.14)	32.0 (9.24)	0.160 (0.027)
Orthoses and eccentric exercise (n=12)	49.4 (12.6)	10 women, 2 men	3 right, 9 left	40.5 (69.4)	80.4 (23.0)	1.67 (0.10)	28.5 (7.09)	0.169 (0.050)

<sup>a</sup> Reported as  $\bar{X}$  (SD).

<sup>b</sup> Body mass index: <18.5=underweight, 18.5–24.9=normal, 25.0–29.9=overweight, >30.0=obese.<sup>28</sup>

<sup>c</sup> Arch index: 0.193 (0.034)=normal.<sup>27</sup>

eccentric loading of the tibialis posterior tendon on pain and function in people with tibialis posterior tendinosis. We hypothesized that participation in an eccentric tibialis posterior tendon exercise program would lead to greater improvements in function and reductions in pain than would be achieved with a concentric exercise program or the use of arch-correcting orthoses alone.

**Method**  
**Participants**

Thirty-six participants were recruited from the Department of Orthopedics at the University of Southern California and Long Beach Memorial Medical Center between 2002 and 2006. Recruitment included a referral by a physician who determined, by history and physical examination, that the participants met the inclusion criteria listed below. All participants were then interviewed by one of the study investigators via telephone or in person to further screen for eligibility. To be enrolled in the study, participants had to have a current complaint of foot and ankle pain that had lasted for 3 months or more. The inclusion criteria were based on the guidelines set forth by Johnson and Strom for stage I and stage II PTTD<sup>1</sup> as discussed above: symptoms located at the medial ankle or foot, tenderness to palpation specific to the tibialis posterior tendon, foot flattening, ab-

ducted midfoot, and absence of rigid foot deformity. Foot flattening was determined with the arch index<sup>27</sup>; midfoot abduction was determined by observation of the “too-many-toes sign”<sup>1</sup>; and the presence or absence of rigid foot deformity was determined by observation of calcaneal valgus and midfoot abductus deformities, which were either rigid or flexible with passive mobilization. No participants reported pain at the lateral foot. Heel-rise performance varied among participants with regard to symptoms and ability. Because participants with both stage I and stage II PTTD were included in the study and the inability to perform a heel rise did not help with regard to classification as stage II, III, or IV, this information was used only to develop foot orthoses for each participant.

Participants were excluded if they had any of the following conditions: fixed foot deformities; previous foot surgery; or cardiovascular, neurovascular, peripheral vascular, or musculoskeletal pathology that would have limited participation in the study. Participants agreed to discontinue athletic activities and to refrain from increasing activity once enrolled in the study. All participants signed an informed consent form before enrollment. Demographic and anthropometric<sup>28</sup> information for the participants is provided in Table 1.

**Study Design**

This study was a randomized controlled trial designed to compare the effectiveness of foot orthoses in combination with eccentric or concentric resistive exercise with that of foot orthoses alone.

**Outcome Measures**

**Foot Functional Index (FFI).** The FFI consists of 23 self-reported items divided into 3 subcategories (pain, disability, and activity limitation). The pain subcategory consists of 9 items and measures foot pain in different situations, such as walking barefoot versus walking with shoes. The disability subcategory consists of 9 items and measures difficulty performing various functional activities because of foot problems, such as difficulty climbing stairs. The activity limitation subcategory consists of 5 items and measures limitations in activities because of foot problems, such as staying in bed all day. Recorded on a visual analog scale (VAS), scores range from 0 to 100 mm, with higher scores indicating worse pain. Both total and subcategory scores are calculated.<sup>29</sup> The FFI has been validated and determined to yield reliable data for people with rheumatoid arthritis<sup>29</sup> and non-traumatic foot or ankle problems.<sup>30</sup>

**5-Minute Walk Test.** The 5-Minute Walk Test measures the distance a participant can walk in a 5-minute

period as fast as tolerated. Good day-to-day test-retest reliability (the ability of a test to provide reliable results when testing is performed on 2 different days) of this test has been established for people with low back pain (intraclass correlation coefficient=.87), and moderate day-to-day test-retest reliability has been reported for people who are healthy (intraclass correlation coefficient=.60).<sup>31</sup>

**VAS.** The VAS assesses pain on a single-dimension scale with end-points marked as “no pain” and “worst pain possible.” It has been established as a reliable and valid measure of self-reported pain intensity.<sup>32</sup> In this study, the VAS was used to measure pain intensity after completion of the 5-Minute Walk Test.

### Timing of Evaluations

All tests and questionnaires were administered before and after the intervention. In addition, at the first visit, a research investigator performed a standard orthopedic lower-quadrant assessment to document structural condition, mobility, and strength (force-generating capacity); the assessment included clinical observation (foot structure, posture, and gait), palpation, manual muscle testing, heel-rise testing, and determination of the arch index with methods described by Williams and McClay.<sup>27</sup> This information was used only to determine whether participants met study inclusion or exclusion criteria and to develop foot orthoses for each participant.

### Types of Interventions

**Orthoses.** All participants received custom-made orthoses.\* The participants were asked to adhere to the protocol by wearing the orthoses during 90% of their waking hours.

**Stretching.** All participants were instructed in the performance of gastrocnemius and soleus muscle stretches to be performed 2 times per day. Each participant was issued a Slant by OPTP,<sup>†</sup> a lightweight, portable foam wedge to be used for calf muscle stretching. Participants were instructed to place the slant facing away from a wall, within a foot-length distance, and to place the shod foot of the leg to be stretched on the slant with the toes pointing up. They were instructed to lean forward until a strong but tolerable stretch was perceived in the calf muscles. This maneuver was repeated 3 times with the knee extended to target the gastrocnemius muscle and 3 times with the knee slightly flexed to more selectively isolate the soleus muscle. Stretch positions were held for 30 seconds. The lumbar spine was placed in a “neutral” position to reduce the potential risk of strain to the low back region. In addition to practice trials and verbal explanations, pictorial and written descriptions of the stretching technique were provided to each participant (Appendix). Stretching was initiated on the day of the initial evaluations, after all clinical assessments were completed.

### Progressive resistive exercise.

Previous work indicated that the tibialis posterior muscle was preferentially recruited during a resisted foot horizontal adduction exercise in people with pes planus<sup>20</sup> and that this muscle was selectively activated when people with foot flattening performed the exercise while wearing arch-supporting orthoses and shoes.<sup>21</sup> Therefore, the exercise intervention implemented in this study consisted of isolated loading of the tibialis posterior musculotendinous unit (horizontal adduction with

plantar flexion) with participants wearing both orthoses and shoes.

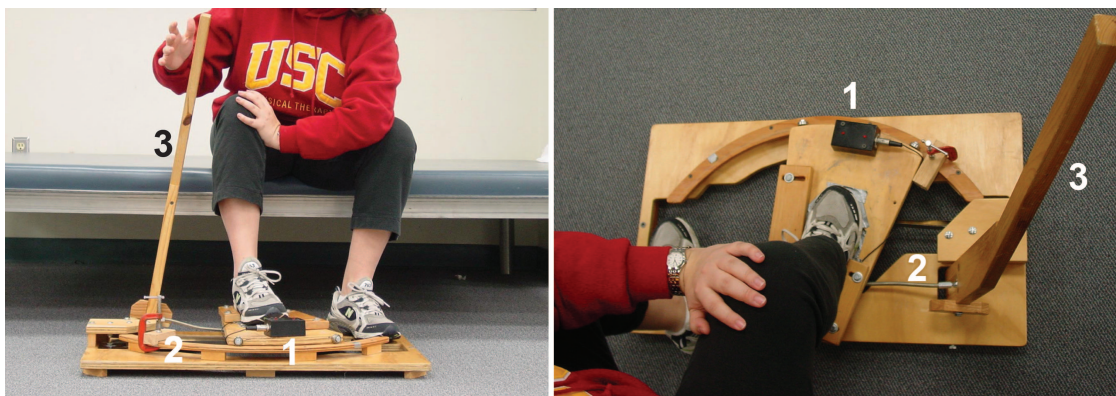
The exercise was performed with a specialized exercise unit (TibPost Loader<sup>‡</sup>) that could be adjusted to progressively load the tendon either concentrically or eccentrically, depending on group assignment (Fig. 1). The design of the TibPost Loader allowed participants in the concentric exercise group to first actively horizontally adduct the foot to an end-range position and then passively horizontally abduct back to a neutral position to eliminate an eccentric contraction. The hand lever allowed participants in the eccentric exercise group to first passively horizontally adduct the foot to an end-range position (to eliminate a concentric contraction) and then actively resist horizontal abduction back to a neutral position, providing for eccentric loading. Participants began the resistive exercise when the custom-made orthoses were delivered, approximately 1 to 2 weeks after evaluation. Resistance was provided by Conforce Constant Force springs,<sup>§</sup> starting with 0.9 kg (2 lb) and increasing in at least 0.9-kg increments on the basis of each participant's ability to perform 15 repetitions. Once the participant was able to perform 15 repetitions in 3 sets, with good technique (smooth path), a new 15-repetition maximum was established. In all cases, the addition of a 0.9-kg spring was sufficient. Interestingly, none of the participants reported pain in the tendon even when the load was at the level of the participant's maximum ability to resist the movement of the loaded footplate. A unique feature of these springs is their ability to provide constant resistance throughout their range of elongation.

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<sup>§</sup> Vulcan Spring & Mfg Co, 501 Schoolhouse Rd, Telford, PA 18969.

\* Biomechanical Service, 1050 Central Ave, Suite D, Long Beach, CA 92832.

<sup>†</sup> OPTP, PO Box 47009, Minneapolis, MN 55447-0009.



**Figure 1.**

Exercise device (TibPost Loader) designed to provide progressive, constant (throughout the range) resistance (0.9–9 kg [2–20 lb]) in the transverse plane. The hand lever (3) allows for selective application of resistance in one direction only. When the footplate is moved by the foot against the resistance of the spring (2) into horizontal adduction, the tibialis posterior tendon is recruited concentrically. Conversely, when the foot resists the motion of the footplate toward horizontal abduction, the tibialis posterior tendon is recruited eccentrically. To minimize the activity of the anterior tibialis tendon with transverse-plane motion, secondary static resistance (0.9 kg) to plantar flexion is provided. Light-emitting diodes indicate whether the foot is pressing into plantar flexion (1).

### Group Allocation

Participants were randomly assigned to 1 of 3 groups: (1) orthoses wear and calf stretching (O group); (2) orthoses wear, calf stretching, and a concentric exercise program (OC group); and (3) orthoses wear, calf stretching, and an eccentric exercise program (OE group). The intervention was performed as a home exercise program with sets and repetitions as described above. A research investigator or a practicing physical therapist met with each participant separately for 30 minutes once per week for 10 weeks to assess the quality of exercise and to modify resistance as described below. During these sessions, all stretches and exercises were performed. Participants maintained an exercise record chart with the number of stretches and resistive exercises performed daily as well as reflections on their performance (ease or difficulty; if discomfort, then location and intensity). Members of the exercise groups were provided with a TibPost Loader that they used both at home and during weekly visits for the duration of the study.

**O group.** Participants in the O group wore custom-made foot orthoses and performed the calf stretches described earlier.

**OC group.** In addition to wearing custom-made foot orthoses and performing calf stretches, participants in the OC group were instructed in a concentric exercise regimen with the TibPost Loader. The resistive exercise was performed slowly (5 seconds throughout the range of motion). A series of 3 sets of 15 repetitions were performed twice daily on the involved side. Rest periods between sets were 1 to 2 minutes long. The resistance, provided by Conforce springs, was set at 0.9 kg (2 lb) for the first week and increased within tolerance and ability by the research investigator at weekly meetings. The progression of resistance depended on participants' reports of ease or difficulty and reports of symptoms and on their ability to maintain control over 3 sets of 15 repetitions, as assessed by observation during weekly meetings. When all 45 repetitions were performed with ease, minimal or no symptoms,

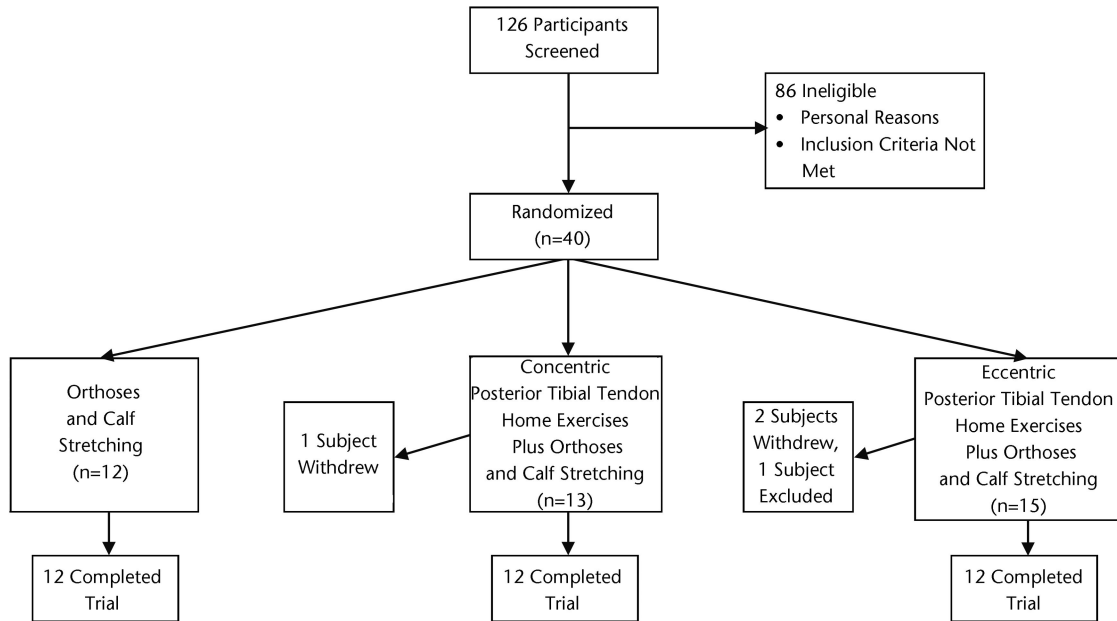
and proper control, the resistance was increased.

**OE group.** In addition to wearing custom-made foot orthoses and performing calf stretches, participants in the OE group were instructed in an eccentric exercise regimen with the TibPost Loader. All exercise parameters (ie, speed, repetitions, and rest periods) were the same as those described for the concentric intervention.

### Statistical Analyses

Exploratory analyses revealed that the data were normally distributed. Two-way analyses of variance (ANOVAs) for each dependent variable determined the influence of testing session (before and after the intervention) and treatment intervention (O, OC, and OE groups).

For variables for which randomization produced differences between groups at the initial assessment, repeated-measures analyses of covariance (ANCOVAs) with the initial scores as covariates were performed. The level of statistical significance was set at  $P < .05$ . All statistical anal-



**Figure 2.**

Diagram of the posterior tibial tendon dysfunction randomized controlled trial, showing numbers of participants screened, randomized, retained, withdrawn, and excluded.

yses were performed with SPSS for Windows software, version 15.0.<sup>||</sup>

**Results**

**Recruitment and Retention**

To achieve the estimated sample size of 36 participants (12 per treatment arm, as determined by power calculations conducted during the study design process),<sup>33</sup> we interviewed a total of 126 participants to establish their appropriateness for this research study (Fig. 2). Forty participants met the inclusion criteria and were enrolled in the study. Thirty-six participants completed the 12-week intervention and evaluations before and after the intervention. Four participants either withdrew or were excluded from the study. In brief, one elected to have surgery within the first month of beginning the intervention; the second did not return for testing after the intervention; the third began remodeling her house, an activity that was in conflict with the inclusion criteria; and the fourth

continued playing tennis, resulting in increased symptoms and subsequent application of a plaster cast by her physician to provide for rest and unloading of the foot.

**Adherence and Progression of Resistive Exercise**

For the participants who remained in the study, the self-reported adherence rate for wearing orthoses outdoors was 100%. Adherence to twice-daily stretching and resistive exercise programs ranged from 39% to 98% (average=68%). There was no difference in adherence rates among the groups. Adherence to attending weekly physical therapist visits was 90% to 100%. The initial resistance to motion was set at 0.9 kg (2 lb) and was based on symptoms and ability to perform the motion in a controlled manner. At the completion of the intervention, participants in the OC group exercised with an average resistance of ~1.7 kg (3.7 lb; range=0.9-4.5 kg [2-10 lb]), and the corresponding average for those

in the OE group was ~5.6 kg (12.5 lb; range=4.5-9 kg [10-20 lb]).

**Self-Reported Pain, Disability, and Activity Limitation**

**FFI total score.** When averaged across all groups, the mean (SD) FFI total scores significantly decreased, from 30.0 (17.7) before the intervention to 11.5 (12.8) after the intervention ( $P<.0001$ ) (Tab. 2). The FFI total scores before and after the intervention were 30.5 (19.8) and 21.2 (19.5) for the O group, 23.9 (14.2) and 13.0 (9.5) for the OC group, and 35.6 (18.2) and 10.6 (8.5) for the OE group, respectively (Tab. 2). With the initial scores as covariates, a repeated-measures ANCOVA identified differences among the groups ( $P=.042$ ) (Tab. 2).

**FFI pain subcategory.** When averaged across all groups, the mean (SD) FFI pain subcategory scores significantly decreased, from 39.7 (19.3) before the intervention to 15.0 (13.9) after the intervention ( $P<.0001$ ). The FFI pain subcategory

<sup>||</sup> SPSS Inc, 233 S Wacker Dr, Chicago, IL 60606.

## Posterior Tibial Tendon Dysfunction

**Table 2.**

Foot Functional Index Total Score and Scores for Pain, Disability, and Activity Limitation Subcategories for All Study Participants and for Each Group Before and After the 12-Week Intervention<sup>a</sup>

Group	Time Relative to Intervention	Total	Pain Subcategory	Disability Subcategory	Activity Limitation Subcategory
All participants (N=36)	Before	30.0 (24.2, 35.8)	39.7 (33.4, 46.0)	36.4 (27.7, 45.1)	13.7 (8.6, 18.8)
	After	11.5 (7.3, 15.7)	15.0 (10.5, 19.5)	11.9 (6.7, 17.1)	7.6 (3.3, 11.9)
<i>p</i> <sup>b</sup>		<.0001	<.0001	<.0001	.082
Orthoses (n=12)	Before	30.5 (19.3, 41.7)	37.5 (25.8, 49.2)	34.7 (19.4, 50.0)	18.6 (6.5, 30.7)
	After	21.2 (10.2, 32.2)	21.2 (10.2, 32.2)	19.9 (7.6, 32.2)	11.8 (2.1, 21.5)
Orthoses and concentric exercise (n=12)	Before	23.9 (15.9, 31.9)	34.8 (23.6, 46.0)	27.8 (16.6, 39.0)	9.2 (2.9, 15.5)
	After	13.0 (7.6, 18.4)	13.0 (7.6, 18.4)	10.0 (3.2, 16.9)	5.9 (-1.1, 12.9)
Orthoses and eccentric exercise (n=12)	Before	35.6 (25.3, 45.9)	46.9 (37.3, 56.5)	46.6 (29.4, 63.8)	13.2 (6.1, 20.3)
	After	10.6 (5.8, 15.4)	10.6 (5.8, 15.4)	5.9 (1.3, 10.5)	5.2 (0.1, 10.4)
<i>p</i> <sup>c</sup>		.042	.048	.036	.648

<sup>a</sup> Reported as  $\bar{X}$  (95% confidence interval [minimum, maximum]).

<sup>b</sup> *P* values for scores before the intervention versus scores after the intervention for all participants.

<sup>c</sup> *P* values for analyses of variance with the values before the intervention as covariates.

scores before and after the intervention were 37.5 (20.6) and 21.2 (19.5) for the O group, 34.8 (19.8) and 13.0 (9.5) for the OC group, and 46.9 (16.9) and 10.6 (8.5) for the OE group, respectively (Tab. 2). With the initial scores as covariates, a repeated-measures ANCOVA identified differences among the groups ( $P=.048$ ) (Tab. 2).

**FFI disability subcategory.** When averaged across all groups, the mean (SD) FFI disability subcategory scores significantly decreased, from 36.4 (26.6) before the intervention to 11.9 (15.8) after the intervention ( $P<.0001$ ) (Tab. 2). The FFI disability subcategory scores before and after the intervention were 34.7 (27.1) and 19.9 (21.7) for the O group, 27.8 (19.8) and 10.0 (12.1) for the OC group, and 46.6 (30.4) and 5.9 (8.2) for the OE group, respectively (Tab. 2). With the initial scores as covariates, a repeated-measures ANCOVA identified differences among the groups ( $P=.036$ ) (Tab. 2).

**FFI activity limitation subcategory.** When averaged across all groups, the mean (SD) FFI activity

limitation subcategory scores decreased, but insignificantly, from 13.7 (15.7) before the intervention to 7.6 (13.3) after the intervention ( $P=.082$ ) (Tab. 2). The FFI activity limitation subcategory scores before and after the intervention were 18.6 (21.4) and 11.8 (17.2) for the O group, 9.2 (11.1) and 5.9 (12.4) for the OC group, and 13.2 (12.5) and 5.2 (9.1) for the OE group, respectively (Tab. 2). A repeated-measures ANCOVA in which the covariates were the initial scores identified no difference among the groups ( $P=.648$ ).

### 5-Minute Walk Test

The data for distance walked in 5 minutes were normally distributed for all groups. A repeated-measures ANOVA identified no statistically significant difference between the testing distances walked in 5 minutes before and after the intervention ( $F_{3,33}=0.175$ ,  $P=.912$ ). On average, however, the distance decreased 3.8% for the O group. In contrast, the distance increased an average of 13.2% for the OC group and an average of 2.6% for the OE group. These between-group variations did not

reach the level of statistical significance (Tab. 3).

### Pain After 5-Minute Walk Test

When averaged across treatment groups, the mean (SD) VAS pain ratings decreased immediately after the 5-Minute Walk Test, from 26.9 (23.1) before the intervention to 6.0 (9.7) after the intervention ( $P=.0001$ ). No significant difference ( $P=.460$ ) among the treatment groups was identified (Tab. 3).

## Discussion

This is the first randomized controlled trial reporting on the effectiveness of orthoses and tibialis posterior tendon-specific exercise in the management of PTTD. In 2001, "tendinitis" cases involved a median of 10 days away from work; in comparison, all nonfatal injury and illness cases involved 6 days away from work.<sup>34</sup> In the present study, notable improvements in function and reductions in pain were documented in association with the use of custom-made orthoses. Concurrent participation in an exercise program that specifically targeted the poste-

**Table 3.**

Distance Traveled in the 5-Minute Walk Test and Pain After the 5-Minute Walk Test for All Study Participants and for Each Group Before and After the 12-Week Intervention

Parameter <sup>a</sup>	Time Relative to Intervention	$\bar{X}$ (SD)	
		5-Minute Walk Test Distance, m	Pain <sup>b</sup> After 5-Minute Walk Test, mm
All participants (N=34)	Before	441.7 (117.9)	26.9 (23.1)
	After	458.1 (119.1)	6.0 (9.7)
<i>p</i> <sup>c</sup>		.912	.0001
Orthoses (n=11)	Before	468.7 (133.4)	26.3 (21.7)
	After	451.1 (148.0)	12.2 (13.7)
Orthoses and concentric exercise (n=11)	Before	423.5 (136.6)	29.0 (26.5)
	After	479.6 (139.0)	2.6 (4.0)
Orthoses and eccentric exercise (n=12)	Before	433.7 (86.1)	25.4 (3.8)
	After	445.1 (66.3)	3.4 (6.0)
<i>p</i> <sup>d</sup>		.075	.460

<sup>a</sup> Two subjects (1 in the orthoses group and 1 in the orthoses and concentric exercise group) declined to participate in the functional test at the time of the initial evaluation because of an anticipated increase in pain.

<sup>b</sup> As determined with the visual analog scale (0 mm=no pain and 100 mm=worst pain possible).

<sup>c</sup> *P* values for scores before the intervention versus scores after the intervention for all participants.

<sup>d</sup> *P* values for analyses of variance with the values before the intervention as covariates.

rior tibial tendon furthered the gains achieved.

In the present study, we used a basic and social sciences-driven tendinopathy treatment model that emphasizes **E**ducation, **U**nloading of the faulty tendon, **R**eloading of the faulty tendon, and **P**revention of future tendon-related problems (EdUReP model).<sup>35</sup> All participants in the present study received education about their condition and calf muscle stretching as well as unloading of the tendon via the arch support provided through the custom-made orthoses. In addition, progressive reloading of the tibialis posterior tendon was initiated for participants randomly assigned to either the OE or the OC group. The loading was individualized and performance based to enable participants to progress at their own rates (as described above).

Varying the mode of resistance training (ie, eccentric versus concentric) created an opportunity for different loads in the 2 conditions. Force ca-

pabilities are typically 20% to 60% greater during eccentric actions than during isometric actions, and isometric force capabilities exceed concentric force capabilities.<sup>36</sup> Therefore, participants in the OE group had the potential to resist larger loads than those in the OC group, thus subjecting their tendons to a higher overload. The overload principle speaks to the necessity to stress biologic tissues beyond their current thresholds to increase tolerance to subsequent stresses and avoid future injuries.<sup>37</sup> Indeed, by the end of the 3-month exercise program, participants in the OE group had achieved a training load more than 3-fold greater than that of participants in the OC group (~5.6 kg [12.5 lb] and ~1.7 kg [3.7 lb], respectively).

In the present study, we provided slow, controlled reloading of the tendon within its capabilities and within the participants' pain tolerance. Exercises were performed with no pain reported. We believe that one of the factors contributing to the greater load tolerance during testing after

the intervention for the OE group than for the OC group may have been the impact of training at higher forces on remodeling of the degenerated tendon. Additional study in this area is required to determine the impact of eccentric versus concentric training on tibialis posterior tendon remodeling.

Of note is the finding that participation in the exercise program did not result in an increase in symptoms. Movement of the tibialis posterior tendon through the unique pulley system as it abruptly wraps around the medial malleolus has been implicated as a possible mechanism of injury to the tendon.<sup>38</sup> This suggestion has led to concerns in the clinical setting about whether it is safe to load the tendon in association with non-isometric contractions. Our findings suggest that both concentric training and eccentric training, when performed within the limits of a patient's pain tolerance, are safe methods for loading the tendon.

Pain during functional activities is one of the main concerns for people with PTTD. In the present study, we captured self-reported pain under 2 conditions: first, as a recall of pain recently experienced during various functional activities (FFI pain subcategory), and second, immediately after completion of the 5-Minute Walk Test. When averaged across groups, FFI pain subcategory scores showed a significant improvement after the intervention (Tab. 2). This change also exceeded the minimum clinically important difference of 12.3 mm established for the FFI pain subcategory by Landorf and Radford for small samples of patients with plantar fasciitis.<sup>39</sup> Although changes in the scores for all groups exceeded the 12.3-mm threshold, the OE group demonstrated the greatest improvement, with a change of 36.3 (16.8); the gains for the OC and O groups were more modest, at 21.7 (17.2) and 16.3 (20.6), respectively. Similarly, when averaged across groups, the VAS pain ratings after the 5-Minute Walk Test showed a significant improvement after the intervention that also exceeded the previously established minimum clinically important difference of 13 mm.<sup>40</sup> Although changes in the scores for all groups exceeded the 13-mm threshold, the VAS pain ratings among the groups were not significantly different.

A reduction in function is common in people with PTTD. To better understand the effects of the intervention on function, measures recorded for the FFI disability subcategory, distance traveled during the 5-Minute Walk Test, and FFI activity limitation subcategory were evaluated. The significant improvement in the disability subcategory scores after the intervention (Tab. 2) exceeded the minimum clinically important difference of 6.7 mm established by Landorf and Radford.<sup>39</sup> Although changes in the scores for all groups exceeded

the 6.7-mm threshold, the OE group showed changes that were more than 2-fold greater than the changes showed by the OC and O groups (Tab. 2). Distance traveled during the 5-Minute Walk Test did not increase significantly after the intervention for all participants (Tab. 3). This result may have reflected the absence of a walking impairment at entry into the study, because the distances walked were close to 1 standard deviation of the values achieved by 22- to 54-year-old subjects who were healthy in the study by Simmonds et al.<sup>31</sup> Similarly, the participants in the present study also were independent in all functional activities and reported that they continued to take part in social activities and work despite pain. These data were reflected in the relatively low scores documented for the FFI activity limitation subcategory both before and after the intervention for all groups (Tab. 2). No value for the minimum clinically important difference for this category of the FFI has been established.

With respect to total foot function, FFI total scores improved significantly after the intervention when averaged across treatment groups, and the changes exceeded the minimum clinically important difference of 6.5 mm for this scale.<sup>39</sup> Changes in the scores for all groups exceeded the minimum threshold, but the OE group demonstrated the greatest improvement, with a change of 28.3 (17.4) (Tab. 2); the gains for the OC and O groups were more modest, at 14.3 (13.5) and 12.8 (16.9), respectively.

The duration of the intervention (3 months) may have influenced the rate of adherence among the participants. Poor adherence may explain the inferior outcomes for 2 participants identified as statistical outliers. For example, the outlier for the FFI total score in the OE group had the

lowest score for adherence to exercise. The outlier for the FFI total score in the O group lost contact with the research team and, upon reassessment, admitted to not wearing the orthoses because she was more comfortable in open-toe sandals.

One limitation of the present study arose from the random assignment of participants to the 3 intervention groups. Specifically, at pre-intervention testing, baseline FFI scores varied significantly among the 3 intervention groups. To account for these differences, we performed an ANCOVA to enable a comparison of post-intervention means after adjusting for the differences in the baseline scores. Despite larger apparent changes in scores between pre-intervention and post-intervention measurements for the OE group than for the OC group (Tab. 2), the design did not allow determination of whether the eccentric training resulted in greater improvements. Ultimately, both exercise groups achieved the same relative functional levels on the FFI after the intervention. Future studies in which subjects begin with equal baseline scores on the measures of interest should be conducted to determine whether eccentric exercise is superior to concentric exercise.

The present work has additional implications for future studies. In particular, the finding of enhanced function in people who have PTTD and are undergoing strengthening exercises raises questions about the impact of this intervention on tendon remodeling. Additional work incorporating ultrasonography would be beneficial in exploring the impact of different modes of exercise training on tendon remodeling as well as measures of function and pain.

Previous work on the Achilles tendon demonstrated improvements in tendon structure and reductions in

pain in association with an eccentric training program, but that work did not explore the collective impact on function. Ohberg and colleagues<sup>26</sup> imaged the Achilles tendon using ultrasound before and after initiating an eccentric calf muscle training program in patients with Achilles tendinosis. Before treatment, the tendon showed localized widening, focal hypoechoic areas, and irregular structures in association with the painful area. After treatment, there was a significant decrease in tendon thickness ( $P < .005$ ), and the structures were normal in 19 of the 26 tendons examined. Patients exhibiting decreased tendon pathology also reported decreased pain with loading of the Achilles tendon, indicating that ultrasonographic findings of hypoechoic areas and irregular structures may correlate with tendon pain during tendon loading activity. However, that study did not correlate the decreased tendon pathology with improvements in function. Future studies should extend these findings to patients with PTTD by exploring whether improvements in function and disability correlate with tendon pathology and to what extent either an eccentric or a concentric exercise intervention contributes to a successful outcome.

## Conclusion

Adults with stage I and II tibialis posterior tendinopathy exhibited significant increases in function and reductions in pain after participation in a 3-month intervention program that emphasized education and the use of custom-made orthoses. Simultaneous involvement in exercise that specifically targeted the tibialis posterior tendon furthered the improvements. Additionally, the OE group tolerated greater loading after the intervention. Additional work is needed to determine the impact of a focused tibialis posterior tendon exercise program on tendon remodeling in people with PTTD. Moreover,

the extent to which greater loading contributes to changes in tendon tissue quality should be explored in future studies.

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The Institutional Review Board at the University of Southern California granted approval for this randomized controlled trial.

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**Appendix.**

Pictorial and Written Descriptions of Stretching Technique Provided to Each Participant

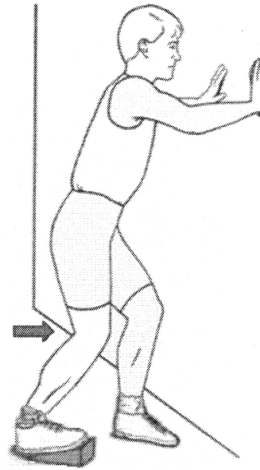
**Instructions for Stretching Exercises**

1. Perform a calf muscle stretch with a wedge and your knee *straight*



- Hold for 30 seconds
- Repeat 3 times

2. Perform a calf muscle stretch with a wedge and your knee *slightly bent*



- Hold for 30 seconds
- Repeat 3 times

Perform the above sequence twice daily

**Stretching Tips and Precautions:**

- Make sure that your foot on the side being stretched is pointing slightly inward.
- Take care that your feet have adequate arch support.
- You should only feel a mild stretch of your calf muscles or in the back of your knee.
- If you feel any foot pain, stop immediately, check your setup, and try again.
- If the pain persists, terminate the session and notify your therapist at your next visit.