

# Stage I and II Posterior Tibial Tendon Dysfunction Treated by a Structured Nonoperative Management Protocol: An Orthosis and Exercise Program

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## ABSTRACT

**Background:** Posterior tibial tendon dysfunction (PTTD) is a relatively common problem of middle-aged adults that usually is treated operatively. The purpose of this study was to identify strength deficits with early stage PTTD and to assess the efficacy of a focused nonoperative treatment protocol. **Methods:** Forty-seven consecutive patients with stage I or II posterior tibial tendon dysfunction were treated by a structured nonoperative protocol. Criteria for inclusion were the presence of a palpable and painful posterior tibial tendon, with or without swelling and 2) movement of the tendon with passive and active nonweightbearing clinical examination. The rehabilitation protocol included the use of a short, articulated ankle foot orthosis or foot orthosis, high-repetition exercises, aggressive plantarflexion activities, and an aggressive high-repetition home exercise program that included gastrocnemius tendon stretching. Isokinetic evaluations were done before and after therapy to compare inversion, eversion, plantarflexion, and dorsiflexion strength in the involved and uninvolved extremities. Criteria for successful rehabilitation were no more than 10% strength deficit, ability to perform 50 single-support heel rises with minimal or no pain, ability to ambulate 100 feet on the toes with minimal or no pain, and ability to tolerate 200 repetitions of the home exercises for each muscle group. **Results:** Before therapy weakness for concentric and eccentric contractures of all muscle groups of the involved ankle was significant ( $p < 0.001$ ). After a median of 10 physical therapy visits over a median period of 4 months, 39 (83%) of the 47 patients had successful subjective and functional outcomes, and 42 patients (89%) were satisfied.

Five patients (11%) required surgery after failure of nonoperative treatment. **Conclusion:** This study suggests that many patients with stage I and II posterior tibial tendon dysfunction can be effectively treated nonoperatively with an orthosis and structured exercises.

**Key Words:** Dysfunction; Nonoperative Management; Posterior Tibial Tendon

## INTRODUCTION

Posterior tibial tendon dysfunction (PTTD) can be painfully incapacitating without complete tendon rupture.<sup>25</sup> Benefits of operative treatment usually are not realized for 8 months or more after the surgery.<sup>35</sup> The methods of operative repair underscore the diversity of the presenting conditions and the uncertainty regarding optimal management.<sup>12,23,25,26,33</sup> The physical and financial burdens placed on patients by surgery stimulated our search for alternative measures to treat painful PTTD without tendon rupture.

We found only four reports<sup>2,4,16,51</sup> of nonoperative management of PTTD, all of which described the use of an ankle-foot orthosis (AFO) or foot orthosis (FO). None of the studies discuss muscle weakness and no formal, standardized neuromuscular rehabilitation was included. Our prospective study was designed to establish which muscles were weak in patients with PTTD without complete rupture and to treat these patients with a structured rehabilitation program. The goal of this study was to identify strength deficits and to determine if treatment of stage I or II PTTD with orthoses and a structured rehabilitation program can decrease pain and increase activity to levels satisfactory to the patient.

## MATERIALS AND METHODS

### Experimental Design

This was a prospective, observational study.<sup>44</sup> A frank discussion was held with each patient about the purpose

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of the treatment, alternatives to treatment, and the need for research followup, and each patient signed a consent to participate in the study. The study was exempt from institutional review board approval.

A consecutive series of patients seen in the principal investigator's (RGA) office with a presentation of PTTD were considered for inclusion in the study. The diagnosis of PTTD was based on the patients' history and clinical examination. The hallmarks of the clinical examination were tenderness and swelling along the posterior tibial tendon, clinical strength deficit, and difficulty performing or inability to perform a single-support heel rise (SSHR) test.<sup>25,26</sup> A careful attempt was made to exclude other possibilities that might cause similar pain, such as talonavicular, naviculocuneiform, or cuneiform-first metatarsal joint disease, deltoid ligament rupture, Charcot arthropathy, neuromuscular disease, and spring ligament injury.<sup>4,7,13,18</sup>

Criteria for study inclusion were the presence of a palpable and painful posterior tibial tendon, with or without swelling, and movement of the tendon with passive and active non-weightbearing clinical examination. Only patients with passively correctable deformities or no hindfoot deformity with standing were included. When there was bilateral involvement (two patients) the side deemed most severely involved by the senior investigator (RGA) was included in the study. Patients were excluded if they could not actively invert the foot with the ankle plantarflexed and the examiner (RGA) was unable to palpate the posterior tibial tendon moving with active or passive movement of the foot. These signs were thought to indicate complete tendon rupture. Patients with stage III (fixed deformity) or IV (fixed hindfoot deformity with ankle incongruity) PTTD also were excluded.<sup>38</sup>

### Subjects

Our study group consisted of 47 patients treated over a 3-year period, including 37 (79%) females and 10 (21%) males. The median age was 50 (range 15 to 81) years. Twenty-two patients (47%) had right-sided involvement, 23 (49%) had left-sided involvement, and two (4%) had involvement of both sides of which only one side was symptomatic. Only the symptomatic side was treated. The median patient height was 5 ft 6 in (range 5 ft to 6 ft 1 in), and the median weight was 163 (range 120 to 360) lbs.

### Orthotic Treatment

Two different foot orthoses were used, depending on the duration and severity of the symptoms. A short articulated ankle-foot orthosis (SAAFO) (Figure 1) was used if posterior tibial tendon pain had been present for more than 3 months or the patient was unable to perform a SSHR or ambulate more than one block (33 patients). An FO (Figure 2) was used if posterior tibial tendon pain had been present for less than 3 months, and the patient was able to perform at least



**Fig. 1:** Short articulated posterior opening ankle-foot-orthosis with instep wrap and full length toeplate.



**Fig. 2:** Three-quarter length TPE foot orthosis with a high medial and lateral trim lines.

one SSHR and could walk more than one block (14 patients). Patients were switched from a SAAFO to an FO when their strengths were within 10% to 15% of the contralateral side and pain had subsided.

## Rehabilitation

Strengthening was performed on a KinCom 57500 (Chatanooga Group, Hixson, Tennessee).<sup>14,36,39</sup> A strength deficit of more than 10% between the involved and uninvolved side was believed to be clinically relevant.

Rehabilitation involved specific strengthening exercises for the posterior tibial, peroneals, anterior tibial, and gastrocnemius and included isokinetic exercises, exercise band, heel rises (double and single support), and toe walking. Rehabilitation progress was monitored in several ways. For pain, patients reported their daily average pain on a standardized 10-cm visual analog scale (VAS). For function, the ability to ambulate a measured distance, the ability to perform a SSHR heel rise, and the ability to toe walk with the knees straight were evaluated. For strength, the isokinetic strength of all muscle groups around the ankle was measured.

Rehabilitation was divided into a pretreatment phase followed by three treatment phases (Table 1). At the first office visit, a home exercise program was initiated, consisting of sole-to-sole exercises of 25 repetitions per set starting at four sets per day and increasing to 12 sets by 10 days to 2 weeks. This exercise was performed with the patient seated, the heels together, and the ankles in slight equinus, and actively bringing the soles together. Once 12 sets per day were reached, the patient was encouraged to combine sets until he or she could easily do 300 at one setting (typically taking 3 to 5 minutes).

Phase I of the formal treatment protocol required one visit devoted to patient education, initial evaluation, and institution of a home exercise program. Isokinetic strength was recorded by a single rater for dorsiflexion, plantarflexion, eversion, and inversion for both lower extremities. Isokinetic set-up included positioning the patient sitting upright with a 30-degree incline of the back and a hip range of 95 to 100 degrees and knee flexion of 75 degrees. The foot was placed in the inversion and eversion attachment at 0 degrees of dorsiflexion. The foot also was placed at subtalar neutral and a range was selected of 6 degrees from neutral in both positions for a total of 12 degrees of movement. Three warm-up trials were allowed, and testing proceeded with three maximal excursions. The greatest of the three was used, averaging the two-dimensional force curves over 12 degrees. Use of ice (as often as every 2 hours) was encouraged, but no whirlpool, Epsom salt baths, or heat were used. Swimming or biking was permitted. A home exercise program with a red exercise band<sup>37,49</sup> (200 repetitions) was initiated for dorsiflexion, inversion, and eversion performed with a controlled eccentric return and without rotating the leg.<sup>49</sup>

Phase II involved an isokinetic workout at 30 degrees and 60 degrees per second. At both speeds, inversion and eversion were taken through an excursion of 12 degrees (6 degrees eversion and 6 degrees inversion). These settings were selected for highest amount of repetitions in a reasonable amount of time (20 to 25 minutes) without creating

excessive muscle fatigue.<sup>9,19,20,27,39</sup> Force limits were set low initially (~2 pounds) to obtain 200 repetitions per session and were increased as tolerated. Exercise-band resistance was increased in the home exercise program. Weight-bearing plantarflexion (SSHR) working towards 50 repetitions, toe ambulation working toward 100 yards, and Biomechanical Ankle Platform System (BAPS) (Jelaga, Inc., Jasper, MI)<sup>3,21,45</sup> to 200 repetitions (5 positions 20 reps each clockwise and counter clockwise) were initiated. Heel cord stretching into dorsiflexion was used as needed. Ice was used after workouts. Phase II was used for two to six visits.

Phase III started between the fifth and seventh visit. A second isokinetic strength evaluation, assessment of SSHR for 50 repetitions, and assessment of toe ambulation for distance were performed. With subjective and objective progress, phase II was continued at greater intensity. Phase III was repeated after four additional visits. Treatment was considered to have failed if a plateau had been reached, phase III could not be passed, or minimal improvement was noted; these patients were offered operative treatment.

Rehabilitation exercises began using a red exercise band for 200 consecutive repetitions with short periods of rest if needed. The patients began with double-support-heel-rise (DSHR) with the knees straight and toes slightly inward using the upper extremity for support and to control eccentric return to flatfoot. Progression to SSHR was encouraged with use of the upper extremities as needed. The goal was to achieve 50 SSHR consecutively at a pace tolerable to the patient with minimal or no ancillary help. After a short articulated AFO or FO was fitted, toe walking and heel walking were started. Starting at 25 to 30 feet, the goal was to progress as tolerated to 150 feet. Rest was permitted, but patients were encouraged to achieve their maximal tolerated distances. Knee extension was required to prevent patients from throwing their center of gravity forward to pull the heel off the ground, thus giving an appearance of toe ambulation. The frequency of the exercises was one or two times a day and at any opportune time.

## Statistical Analysis

The analysis was performed on an intent-to-treat basis. An interim analysis was not planned or performed. The level of statistical significance was set at  $p < 0.05$ . All tests were two-tailed.<sup>13,32</sup> Because exploratory analysis revealed that the distribution of our data was skewed, we report nonparametric statistics using Splus.<sup>32,44</sup> Medians and ranges are reported for continuous variables, while proportions are used for categorical data. We applied the Wilcoxon signed rank test<sup>32,44,46</sup> for comparison of paired samples (before and after treatment).

## RESULTS

For the 47 patients, the median duration of symptoms before inclusion in the study was 135 days. The onset of

**Table 1:** Summary of 3 Phase Protocol for Posterior Tibialis Rehabilitation

| Physical Therapy Day          | 1<br>Phase I | 2<br>Phase II | 3              | 4                  | 5                  | 6<br>Phase III | 7<br>Repeat<br>Phase II |
|-------------------------------|--------------|---------------|----------------|--------------------|--------------------|----------------|-------------------------|
| <b>PT evaluation</b>          | X            |               |                |                    |                    | X              |                         |
| <b>KIN/COM evaluation</b>     | X            |               |                |                    |                    | X              |                         |
| <b>Exercise band</b>          | red          | red           | green          | green              | blue               |                | blue                    |
| <b>KIN/COM rehabilitation</b> |              | X             | increase force | increase force     | increase force     |                | increase force          |
| <b>Heel rises</b>             | assess       | DSHR<br>5 lbs | DSHR<br>10 lbs | SSHR (A)<br>15 lbs | SSHR (I)<br>20 lbs | assess         | SSHR (I)                |
| <b>BAPS board</b>             |              |               |                |                    |                    |                |                         |
| <b>Dorsiflexion stretch</b>   | X            | X             | X              | X                  | X                  |                | X                       |
| <b>Ice</b>                    |              | X             | X              | X                  | X                  |                | X                       |
| <b>Toe ambulations</b>        | assess       | X             | X              | X                  | 100 yds            | assess         | 100 yds                 |

DSHR = double support heel rise, SSHR = single support heel rise, (A) = assisted, (I) = independent, BAPS = Biomechanical Ankle Platform System Board, Lbs = pounds, Yds = yards, (X) = procedure performed on this day. Note that Repeat Phase II under day 7 of the table is performed if criteria for discharge have not been achieved during Phase III.

**Table 2: Mean Baseline Strength Measures**

|     | Concentric (involved) | Concentric (uninvolved) | Eccentric (involved) | Eccentric (uninvolved) |
|-----|-----------------------|-------------------------|----------------------|------------------------|
| INV | 11.5                  | 28.1 ( $p < 0.001$ )    | 19.2                 | 34.8 ( $p < 0.001$ )   |
| EV  | 15.1                  | 26.3 ( $p < 0.001$ )    | 25.2                 | 33.9 ( $p < 0.001$ )   |
| PF  | 53.2                  | 79.3 ( $p < 0.001$ )    | 76.8                 | 115.8 ( $p < 0.001$ )  |
| DF  | 25.5                  | 29.4 ( $p < 0.001$ )    | 46.7                 | 49.6 ( $p < 0.001$ )   |

All values reported as median lbs. All involved muscle groups were compared to other uninvolved asymptomatic muscle groups for concentric ( $p < 0.001$ ) and eccentric strength with uninvolved side ( $p < 0.001$ ).

symptoms was insidious in 28 (60%), while injury accounted for symptoms in the remainder: three (6%) due to motor vehicle accidents, four (9%) due to falls, and 12 (25%) related to a twist, sprain, or overactivity.

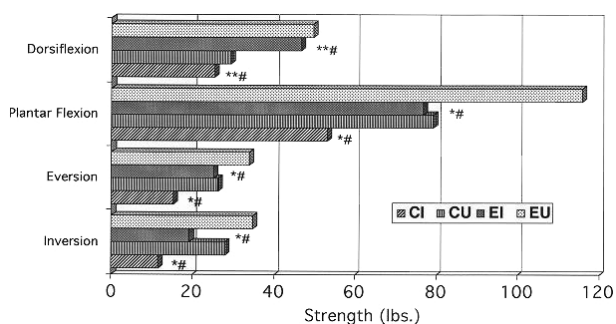
All patients were followed a minimum of 1 year. The median treatment period was 120 (range 28 to 392) days. The median number of visits to physical therapy was 10 (range 3 to 17). The mean number of days under direct physical therapy care was 33 (range 13 to 79). Forty-two (89%) of the 47 patients were satisfied with their treatment outcomes, while five (11%) were dissatisfied; all five had operative reconstruction. Three patients who described themselves as satisfied were classified as treatment failures because they had persistent tenderness, required bracing, or had pain during toe walking. Therefore, this nonoperative treatment strategy was successful in 39 (83%) of the 47 patients.

**Pain**

On the 0-cm to 10-cm VAS, foot and ankle pain improved from a pre-treatment median of 8 (range 6 to 10) to 1 (range 0 to 7) at followup ( $p < 0.001$ ). Before treatment five (11%) patients could perform a SSHR, but only with pain, and 42 (89%) could not perform a SSHR. At followup, painless SSHR could be performed by 39 (83%) patients ( $p < 0.001$ ); 7 others (15%) could perform a SSHR with pain, and one patient (2%) could not perform a SSHR. All five patients who were able to perform a SSHR with pain before treatment were able to do this without pain after treatment. Initially, patients could walk a median of 1 (range 0 to 5) block, while at followup patients reported being able to walk a median of 13 (range 1 to 30) blocks ( $p < 0.001$ ). Before treatment only three patients (6%) were able to toe walk and all three had pain with this activity. After treatment, 45 patients (96%) could toe walk 100 ft; seven had “minimal” pain during this activity. The three patients who could toe walk before treatment with pain had no pain with this activity after treatment.

**Orthotic Use**

Initially, 33 patients (70%) required an SAAFO, and 14 (30%) required an FO. Of the patients requiring an SAAFO,



**Fig. 3:** Baseline strength measures for involved and uninvolved sides. Values are reported and median strength (lbs). CI = concentric involved, CU = concentric uninvolved. EI = eccentric involved, EU = eccentric uninvolved; #  $p < 0.001$ , compared to other muscle groups, \* $p < 0.001$ , compared with uninvolved side, \*\* $p < 0.01$ , compared with uninvolved side.

24 (73%) were converted to the FO. Of the nine (27%) who did not convert, five required operative intervention. Two patients who had pain and decided to continue with use of their AFO, and two others who had minimal to no pain also wished to continue use of the AFO.

**Strength**

At baseline, the mean strength of the involved side was less than that the uninvolved side for all conditions tested. Concentric and eccentric strength was evaluated in each direction (inversion, eversion, plantarflexion, and dorsiflexion) ( $p < 0.05$ ) (Table 2). Eccentric weaknesses were relatively less than concentric weaknesses. The rank order of the relatively weakest muscle group to the least weak group was inversion < eversion < dorsiflexion < plantarflexion (Figure 3).

After the rehabilitation program, strength was improved from baseline for all comparisons (Table 3).

**DISCUSSION**

The main findings of this study of patients with stage I and stage II PTTD without complete tendon rupture were that most had global ipsilateral ankle weakness and most

**Table 3:** Mean Strength Measures Involved Side—Before and After Treatment

|                       | Concentric<br>(Before treatment) | Concentric<br>(After treatment) | Eccentric<br>(Before treatment) | Eccentric<br>(After treatment) |
|-----------------------|----------------------------------|---------------------------------|---------------------------------|--------------------------------|
| <b>Inversion</b>      | 11.5                             | 27.4 ( $p < 0.001$ )            | 19.2                            | 35.3 ( $p < 0.001$ )           |
| <b>Eversion</b>       | 15.1                             | 28.1 ( $p < 0.001$ )            | 25.2                            | 38.4 ( $p < 0.001$ )           |
| <b>plantarflexion</b> | 53.2                             | 73.9 ( $p < 0.001$ )            | 76.8                            | 113.6 ( $p < 0.001$ )          |
| <b>dorsiflexion</b>   | 25.5                             | 28.0 ( $p < 0.001$ )            | 46.7                            | 50.3 ( $p < 0.001$ )           |

All comparisons are made with baseline results of the involved side ( $p < 0.001$ ). Values are reported in median lbs.

responded favorably to a structured rehabilitation program, consisting of use of an orthotic device and a graduated strengthening and neuromuscular facilitation program. After a median of 10 physical therapy visits during an average of 4 months, most patients had minimal or no pain, could walk on tip toes, were not limited by walking distance, and could perform a painless SSHR.

These results are consistent with those reported for nonoperative treatment of musculotendinous injuries of the knee or shoulder.<sup>5,9,10,20</sup> In these 47 patients with PTTD, we observed ankle strength loss and a pattern of muscle imbalance. To our knowledge, previous reports on the treatment of PTTD have not considered the potential benefits of rehabilitation of the posterior tibial and other peri-ankle muscle groups.

The ankle muscles, whether static or dynamic during weightbearing, are in a constant state of synergistic contraction.<sup>8,28</sup> The posterior tibial works in unison with the peroneus brevis, anterior tibial, and gastrocnemus muscles during weightbearing. When the posterior tibial muscle fails, the others may fail as well. To determine the level of involvement of these muscles as they relate to PTTD, all four muscle groups were tested. The selection of a high-repetition exercise program was based on training the muscles in an aerobic manner for long-term endurance.<sup>5,9,50</sup> Low-repetition with strong resistance trains muscles anaerobically, which is not consistent with normal ankle function.<sup>1,6,11,15,22,31,45</sup> High-repetition isokinetic BAPS board, and exercise band exercises provide physiologic aerobic training.<sup>3,27,37,45,49</sup> In our patients, as symptoms of pain and impairment decreased, high compliance with a 30- to 40-minute daily home exercise program was observed.

We are aware of four published reports documenting the results obtained by nonoperative treatment of PTTD,<sup>2,4,16,51</sup> all of which described the use of a molded solid ankle AFO, a University of California Biomechanics Laboratory Shoe (UCBL) insert, and an Arizona AFO. Muscle strength deficits and physical therapy to rehabilitate the weakened muscles were not mentioned.

Because the diagnosis of PTTD can be made clinically,<sup>23,24,25,29,35,47</sup> MRI was not used.<sup>30</sup> The tendon is a subcutaneous structure, easily palpated along the medial border of

the ankle and foot. Active inversion with the ankle plantarflexed recruits the activity of the posterior tibial tendon, and this test done against resistance will bring the tendon into profile. An experienced examiner can determine that the tendon is not ruptured and is able to move the foot into inversion.

The principal limitation of this study relates to the observational design. We did not include a control (untreated) group for either orthotic use or the rehabilitation protocol. We cannot account for the effect of time alone on improved strength and function, or the independent effects of the two treatments (orthotics and rehabilitation). Given the presenting weakness and the pain and the longevity of these symptoms, we think it is unlikely that the results would have occurred without intervention.<sup>17,34,40,41,42,48</sup>

This study demonstrated that there was weakness of all long muscle groups of the foot and ankle in patients with stage I or II PTTD. Most patients (89%) responded to a regimen of orthotic use and supervised physical therapy. Support of the foot and ankle with an SAAFO or FO was important while function was regained through a four-muscle-group ankle-strengthening program. As symptoms and activity approached normal, the orthotic device generally became unnecessary. At an average of 4 months, most patients had improved to the extent that they could essentially function normally again. This treatment program may be of benefit to patients with PTTD without complete tendon rupture or fixed deformity as an alternative to operative treatment. The long-term results of the nonoperative treatment program remain unknown. Whether these patients will eventually develop premature hindfoot or ankle arthritis at rates different from those treated operatively deserves further study.

## REFERENCES

1. Aronen, JG; Garrick, JG: Sports-induced inflammation in the lower extremities. *Hosp. Pract.* (off ed). **34**(2):51–67, 1999.
2. Augustine, JF; Lin, SS; Berberian, WS; Johnson, JE: Nonoperative treatment of adult acquired flat foot with the Arizona brace. *Foot Ankle Clin.* **8**:491–502, 2003.
3. *Biomechanical Ankle Platform System: Protocol Manual.* Spectrum Therapy Products, Inc. Jasper, MI, 1997.

4. **Chao, W; Wapner, KL; Lee, TH; Adams, J; Hecht, PJ:** Non operative management of posterior tibial tendon dysfunction. *Foot Ankle* **17**:736–741, 1996.
5. **Chandler, TJ:** Physiology of aerobic fitness/endurance. *Instr. Course Lect.* **43**:11–15, 1994.
6. **Conley, KE; Kushmerick, MJ; Jubrias, SA:** Glycolysis is independent of oxygenation state in stimulated human skeletal muscle in vivo. *J. Physiol. (Lond)* **15**:935–945, 1998.
7. **Curtis, MJ; Myerson, M; Szura, B:** Tarsometatarsal joint injuries in the athlete. *Am. J. Sports Med.* **21**:497–502, 1993.
8. **Degens, H; Veerkamp, JH:** Changes in oxidative capacity and fatigue resistance in skeletal muscle. *Int. J. Biochem.* **26**:871–878, 1994.
9. **Dietz, V; Horstmann, GA; Berger, W:** Interlimb coordination of leg-muscle activation during perturbation of stance in humans. *J. Neurophysiol.* **62**:680–693, 1999.
10. **Desplantez, A; Cornu, C; Goubel, F:** Viscous properties of human muscles during contraction. *J. Biomech.* **32**:555–562, 1999.
11. **Dowson, MN; Nevill, ME; Lakomy, HK; Nevill, AM; Hazeldine, RJ:** Modeling the relationship between isokinetic muscle strength and sprint running performance. *J. Sports Sci.* **16**:257–265, 1998.
12. **Evans, D:** Calcaneovalgus deformity. *J. Bone Joint Surg.* **57-B**:270–278, 1975.
13. **Ferris, LR; Bargo, R; Alexander, IJ:** Late reconstruction of the midfoot and tarsometatarsal region after trauma. *Orthop. Clin. North.* **26-A**:393–406, 1995.
14. **Finucane, SD; Mayhew, TP; Rothstein, JM:** Evaluation of the gravity-correction feature of a Kin-Com isokinetic dynamometer. *Phys. Ther.* **74**:1125–1133, 1994.
15. **Fulco, CS; Lewis, SF; Frykman, PN; et al.:** Quantitation of progressive muscle fatigue during dynamic leg exercise in humans. *J. Appl. Physiol.* **79**:2154–2162, 1995.
16. **Frey, CC; Shereff, MJ:** Tendon injuries about the ankle in athletes. *Clin. Sports Med.* **7**:103–118, 1988.
17. **Fitts, RH; Widrick, JJ:** Muscle mechanics: adaptation with exercise-training. *Exerc. Sport Sci. Rev.* **24**:427–473, 1996.
18. **Hamilton, WG; Hamilton, LH:** Foot and ankle injuries in dancers in Mann RA and Coughlin MJ, editors: *Surgery of the Foot and Ankle 7<sup>th</sup> ed.* St Louis, Mosby. pp. 1225–1256, 1999.
19. **Hartsell, HD; Spaulding, SJ:** Eccentric/concentric ratios at selected velocities for the inverter and evertor muscles of the chronically unstable ankle. *Br. J. Sports Med.* **33**:255–258, 1999.
20. **Herzog, W; Leonard, TR:** Validation of optimization models that estimate the forces exerted by synergistic muscles. *J. Biomech.* **24**:31–39, 1991.
21. **Hoffman, M; Payne, VG:** The effects of proprioceptive ankle disk training on healthy subjects. *J. Orthop. Sports Phys. Ther.* **21**:90–93, 1995.
22. **Hortobagyi, T; Tracy, J; Hamilton, G; Lambert, J:** Fatigue effects on muscle excitability. *Int. J. Sports Med.* **17**:409–414, 1996.
23. **Jahss, MH:** Spontaneous rupture of the tibialis posterior tendon: clinical findings, tenographic studies and a new technique of repair. *Foot Ankle* **3**:158–166, 1982.
24. **Jahss, MH:** Tendon disorders of the foot and ankle. In Jahss, M (ed.) *Disorders of the foot and ankle: Medical and Surgical Management*, 2<sup>nd</sup> Ed., W.B. Saunders, Philadelphia, p. 1506, 1991.
25. **Johnson, KA:** Tibialis posterior tendon rupture. *Clin. Orthop.* **177**:140–147, 1983.
26. **Johnson, KA; Strom, DE:** Tibialis posterior tendon dysfunction. *Clin. Orthop.* **239**:196–206, 1989.
27. **Kanehisa, H; Ikegawa, S; Fukunaga, T:** Force-velocity relationships and fatiguability of strength and endurance-trained subjects. *Int. J. Sports Med.* **18**:106–112, 1997.
28. **Kellis, E; Baltzopoulos, V:** Muscle activation differences between eccentric and concentric isokinetic exercise. *Med. Sci. Sports Exerc.* **30**:1616–1623, 1998.
29. **Kettelkamp, DB; Alexander, HH:** Spontaneous rupture of the posterior tibial tendon. *J. Bone Joint Surg.* **51-A**:759–764, 1969.
30. **Khoury, NJ; el-Khoury, GY; Saltzman, CL; Brandser, EA:** MR imaging of posterior tibial tendon dysfunction. *Am. J. Roentgenol.* **167**:675–682, 1996.
31. **Kirkendall, DT; Garrett, WE:** Function and biomechanics of tendons. *Scand. J. Med. Sci. Sports* **7**:62–66, 1997.
32. **Kleinbaum, DG; Kupper, LL; Muller, KE:** *Applied Regression Analysis and Other Variables*, 2<sup>nd</sup> edition, PWS-Kent Publishing Company, Boston, 1988.
33. **Koutsogiannis, E:** Treatment of mobile flat foot by displacement osteotomy of the calcaneus. *J. Bone Joint Surg.* **53-B**:96–100, 1971.
34. **Maganaris, CN; Baltzopoulos, V; Sargeant, AJ:** Differences in human antagonistic ankle dorsiflexor co activation between legs; can they explain the moment deficit in the weaker plantarflexor leg? *Exp. Physiol.* **83**:843–855, 1998.
35. **Mann, RA:** Flatfoot in adult, In *Surgery of The Foot and Ankle 7<sup>th</sup> edition.* Coughlin MJ and Mann RA, editors. St. Louis, Mosby, 753–767, 1999.
36. **Mayhew TP, Rothstein JM, Finucane SD, Lamb RL:** Muscular adaptation to concentric and eccentric exercise at equal power levels. *Med. Sci. Sports Exercise* **27**:868–873, 1995.
37. **Mikesky AE, Topp R, Wigglesworth JK, Harsha DM, Edwards JE:** Efficacy of a home-based training program for older adults using elastic tubing. *Eur. J. Appl. Physiol. Occup. Physiol.* **69**:316–320, 1994.
38. **Myerson, MS:** Adult acquired flatfoot deformity. Treatment of dysfunction of the posterior tibial tendon. *J. Bone Joint Surg.* **78-A**:780–792, 1996.
39. **Muir IW, Chesworth BM, Vandervoort AA:** Effect of a static calf-stretching exercise on the resistive torque during passive ankle dorsiflexion in healthy subjects. *J. Orthop. Sports Phys. Ther.* **29**:106–113, 1999.
40. **Nielsen, J; Pierrot-Deseilligny, E:** Evidence of facilitation of soleus-coupled Renshaw cells during voluntary co-contraction of antagonistic ankle muscles in man. *J. Physiol.* **493(Pt 2)**:603–611, 1996.
41. **Nielsen, J; Sinkjaer, T; Toft, E; Kagamihara, Y:** Segmental reflexes and ankle joint stiffness during co-contraction of antagonistic ankle muscles in man. *Exp. Brain Res.* **102**:350–358, 1994.
42. **Petersen, N; Morita, H; Nielsen, J:** Evaluation of reciprocal inhibition of the soleus H-reflex during tonic plantar flexion in man. *J. Neurosci. Methods* **84**:1–8, 1998.
43. **Pomeroy, GC; Pike, RH; Beals, TC; Manoli II, A:** Current concepts review: acquired flatfoot in adults due to dysfunction of the posterior tibial tendon. *J. Bone Joint Surg.* **81-A**:8:1173–1182, 1999.
44. **Rosner, B:** *Fundamentals of Biostatistics* 3<sup>rd</sup> edition. PWS-Kent Publishing Company, Boston, 1990.
45. **Sheth, P; Yu, B; Laskowski, ER; An, KN:** Ankle disk training influences reaction times of selected muscles in a simulated ankle sprain. *Am. J. Sports Med.* **28**:538–543, 1997.
46. **Siegel, S; Castellan, NJ Jr:** *The case of k related samples in non parametric statistics for the behavioral sciences*, 2<sup>nd</sup> edition. McGraw-Hill Book Company, New York, pp. 168–188, 1988.
47. **Slovenkai, MP:** Adult flatfoot: posterior tibial tendon dysfunction, clinical and radiological evaluation. *Foot and Ankle Clin.* **2**:241–260, 1997.
48. **Suter, E; McMorland, G; Herzog, W; Bray, R:** Decrease in quadriceps inhibition after sacroiliac joint manipulation in patients with anterior knee pain. *J. Manipulative Physiol. Ther.* **22**:149–153, 1999.
49. “TheraBand: exercise bands, tubing and accessories.” The Hygienic Corporation. Akron. <http://www.thera-band.com> 1998.
50. **Viru M:** Differences in effects of various training regimens on metabolism of skeletal muscles. *J. Sports Med. Phys. Fitness* **34**:217–227, 1994.
51. **Williams R:** Chronic non specific tenovaginitis of the tibialis posterior. *J. Bone Joint Surg.* **45-B**:542–545, 1963.