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Exploring the clinical presentation of tibialis posterior tendinopathy

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Abstract

Foot pain is a common musculoskeletal complaint, that is associated with significant functional limitations and is often accompanied by systemic co-morbidities. Pain on the medial aspect of the foot and ankle between the medial malleolus and navicular is often diagnosed as dysfunction of the tibialis posterior tendon. Tibialis posterior tendinopathy (TPT) is considered to constitute the early stages of a condition that progresses to an acquired flatfoot deformity. Surgical intervention is recommended when conservative approaches are unsuccessful, with invasive and costly procedures recommended when significant deformity and dysfunction are present. Effective management in the early stages when tendon signs and symptoms predominate is desirable in order to prevent or delay progression of the condition.

The overarching objective of this thesis was to inform the future development of targeted interventions for TPT. Specific thesis aims were to systematically synthesise current evidence in relation to terminology, clinical presentation and management of TPT (Part A) and to address current gaps in the literature in relation to diagnosis, and to explore the presentation of TPT using the ICF framework (Part B).

The first study is a systematic review of randomised controlled trials investigating the efficacy of exercise management for TPT. Findings highlight the paucity of high-quality research for the conservative management of TPT, the lack of exercise prescription parameters reported in clinical trials and recommended that clinicians be guided by presenting impairments when prescribing exercise for TPT. Study 2 is a comprehensive review of selection criteria used in all primary research papers investigating the condition. The evidence led us to recommend that TPT is the preferred terminology when there are signs of local tendon dysfunction, with pain and/or swelling along the tendon and pain or difficulty with inversion or single leg heel raise the key clinical signs and symptoms.

Studies 3 and 4 were systematic reviews and meta-analyses of existing literature. Study 3 quantified differences in clinical impairments, pain and disability between individuals with TPT and controls and investigated the relative magnitude of deficits in muscle function, foot posture and motion, pain and disability. Evidence of impaired tibialis posterior capacity and lower arch height in individuals with TPT was accompanied by self-reported stiffness, difficulties caused by foot problems and social restrictions. While there was strong evidence for lower arch height in TPT, studies stipulated requirements for arch height in TPT and control groups for eligibility and as such further research was warranted. Study 4 investigated kinematic characteristics at the foot and ankle in TPT by comparison to controls and found that individuals with TPT had significantly greater forefoot

abduction, calcaneal eversion and lowering of the medial longitudinal arch during the stance phase of gait.

Three studies were designed to address the gaps identified in Part A and make a significant and substantial contribution to the current understanding of TPT. In Study 5, the diagnostic utility of the clinical signs identified in Study 1 was evaluated. Participants with medial foot/ankle pain underwent assessment of 4 clinical index tests and ultrasound assessment for the presence of grey scale changes in the tibialis posterior tendon. Overall, the ability of the evaluated clinical tests for TPT to predict grey scale changes in the tibialis posterior tendon on ultrasound was poor. Pain or inability to perform a single leg heel raise had the greatest diagnostic utility to detect grey scale changes.

In Study 6, foot posture, mobility and single leg heel raise capacity were investigated in individuals with TPT and compared to individuals with medial foot/ankle pain that was not attributable to TPT and controls. Consistent with the findings from Study 5, the selection criteria for TPT were the presence of medial foot/ankle pain and pain or inability to perform a single leg heel raise. In an attempt to ascertain whether arch height is a key feature of TPT, no selection criteria regarding foot posture were used. This study highlighted that more pronated foot posture, and not arch height, and bilaterally impaired single leg heel raise capacity may be useful in distinguishing TPT from medial foot/ankle pain that is not attributable to TPT. Foot-related function and quality of life were similar for all participants with medial foot/ankle pain and were significantly impaired compared to controls.

Study 7 was an investigation of the impact of TPT using the International Classification of Functioning framework in order to address and incorporate impairments, limitations, and restrictions of the condition in order to understand TPT from a biopsychosocial perspective. Impairments were not limited to the symptomatic foot and ankle; bilateral deficits in hip extensor torque and single leg heel raise endurance and limitations ascending and descending stairs were demonstrated in individuals with TPT compared to controls. Clinical impairments were accompanied by poorer self-reported function and quality of life, particularly relating to independent living, mental health and pain. These findings suggest a biopsychosocial approach should be considered for TPT.

Declaration by author

This thesis *is composed of my original work, and contains* no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, financial support and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my higher degree by research candidature and does not include a substantial part of work that has been submitted *to qualify for the award of any* other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

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Publications included in this thesis

Ross MH, Smith MD, Vicenzino B. Reported selection criteria for adult acquired flatfoot deformity and posterior tibial tendon dysfunction: Are they one and the same? A systematic review. *PLoS One*. 2017;12(12):e0187201. doi: 10.1371/journal.pone.0187201

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Statement of parts of the thesis submitted to qualify for the award of another degree

No works submitted towards another degree have been included in this thesis.

Research Involving Human or Animal Subjects

All research was approved by University of Queensland Human Research Ethics Committee A.

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"Success is the sum of small efforts, repeated day in and day out."- Robert Collier

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List of Abbreviations used in the thesis

5MWT	5 minute walk test
AAFD	Adult acquired flatfoot deformity
AHI	Arch height index
ANOVA	Analysis of variance
AOFAS	American Orthopaedic Foot and Ankle Score
AQoL6D	Assessment of Quality of Life 6 Dimensions
BW	Body weight
CI	Confidence interval
EMG	Electromyography
FFI	Foot function index
FFI-R	Foot function index – revised
ICF	International Classification of Functioning
MANCOVA	Multi-variate analysis of co-variance
MANOVA	Multi-variate analysis of variance
MD	Mean difference
MRI	Magnetic resonance imaging
Non-TPTMFP	Medial foot/ankle pain not attributed to tibialis posterior tendinopathy
NRS	Numerical rating scale
NWB	Non-weight bearing
PCS	Pain catastrophizing scale
PTTD	Posterior tibial tendon dysfunction
QoL	Quality of life
ROM	Range of motion
SD	Standard deviation
SLHR	Single leg heel raise

SMD	Standardised mean difference
SMFA	Short Musculoskeletal Function Assessment
TP	Tibialis posterior
TPT	Tibialis posterior tendinopathy
TPTplus	Tibialis posterior tendinopathy plus concomitant
TSK	Tampa scale of kinesiophobia
US	Ultrasound
VAS	Visual analogue scale
WBDF	Weight bearing dorsiflexion

CHAPTER 1 Introduction

The thesis begins with a brief introductory chapter, outlining the impact and significance of foot problems, and specifically tibialis posterior tendinopathy (TPT). How the condition is conceptualised, uncertainties surrounding terminology for the condition and the problems with research and clinical practice historically focussing on local impairments during assessment and management are highlighted. The introduction recognises the importance of considering TPT beyond a purely biomedical model and evaluating the impact of the condition from a psychosocial perspective. Finally, the introductory chapter outlines the thesis aims and objectives, and the research plan.

1.1 Introduction, thesis aims and objectives

1.1.1 Introduction

Musculoskeletal conditions are highly prevalent in the general population and can have a significant and profound impact on those affected. Studies estimate that up to two thirds of individuals over the age of 50 report recent musculoskeletal pain [1 2] and contribute a significant cost directly to the health care system. [3 4] Indirect costs to the economy, largely due to reduced workplace productivity, [5] far outweigh direct health care costs of reduced musculoskeletal health.

Persistent pain, activity limitations and functional restrictions are the most common sequelae of musculoskeletal disorders. [6] The International Classification of Functioning, Disability and Health (ICF) framework describes health and health related components of well-being pertaining to body structure, function, activity and participation. [7] The ICF serves to describe the overall *functioning* and *disability* of an individual by considering impairments in body structure and function, activity limitations and participation restrictions, relationships between the three domains, and personal and environmental factors that interact with these components (**Figure 1-1**). [7]

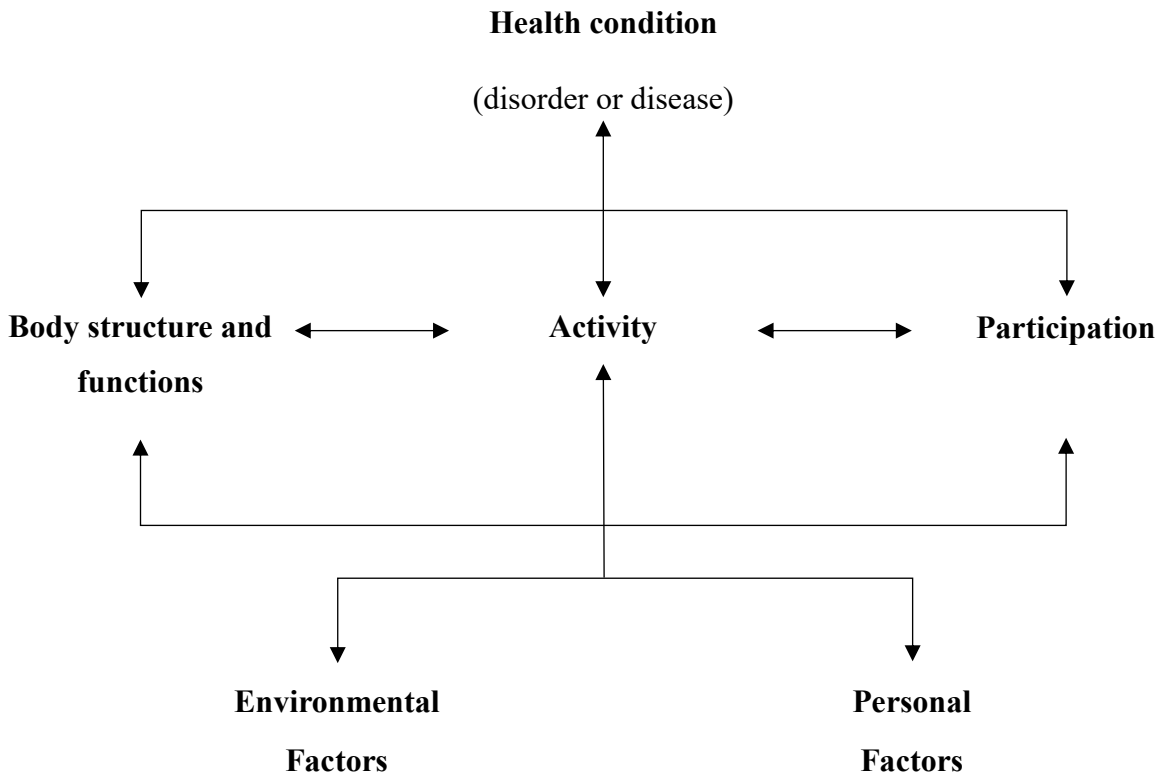


Figure 1-1 *ICF framework*

Research has investigated relationships between body structure and function in musculoskeletal disorders and participation. It has been shown that physical and functional impairments often affect self-perceived quality of life and mental well-being and as such, musculoskeletal disorders have a significant effect on the psychosocial status of those experiencing pain and dysfunction. [8 9] Musculoskeletal pain has been found to be associated with poorer general health and co-morbidities, [10-12] depression, [13 14] and anxiety. [15] Integration of psychological and social factors with physical factors of musculoskeletal pain conditions (i.e. the biopsychosocial approach) can help understand the overall functioning and disability of an individual. [16]

Foot and ankle problems form a significant proportion of all musculoskeletal complaints, [17] accounting for nearly 10% of all musculoskeletal consultations with general practitioners. [18] Foot pain has a significant impact on the lives of older adults in the community, and has been identified as a risk factor for decreased mobility, [19] balance deficits and increased falls risk [9 20-22] and difficulties with activities of daily living. [21 23] Considering the associated pain and functional limitations, foot problems impose a significant detriment on health-related quality of life.[8 24]

Small sample sizes, low response rates and lack of consistent definitions for frequency, duration and location of pain make interpreting foot pain data difficult, yet some key factors have been found to be associated with the development of generalised foot pain. [25] The prevalence of foot pain

increases with age, particularly in women, with a peak incidence around 50 – 65 years. [26-28] Female sex, [26 28-30] obesity [8 28 30 31] and chronic diseases [30 31] have repeatedly shown to be related to the development of foot pain.

Foot and ankle pain also constitutes a significant burden on the healthcare system; surgical intervention is frequently sought-after to correct foot deformity and relieve pain, particularly in individuals over 55 years of age. [32] An Australian audit (1997 – 2006) has shown the annual cost of foot and ankle surgery in 2006 exceeded $14 million in surgical fees. [32]

Foot and ankle problems are particularly prevalent in the general population with up to one in five people reporting foot problems. [25] Foot pain, aching and stiffness are the most common complaints. [26 28 33] A systematic review on the population prevalence of foot and ankle pain in middle and old age adults provided pooled prevalence estimates of 15% and 22% for frequent ankle and foot pain respectively. [25] In community-dwelling older people, 70% of respondents with disabling foot pain reported forefoot pain and 46% reported pain in the arch area. [24] Common foot and ankle conditions affecting older adults include symptomatic foot osteoarthritis (approximately 12% of the population over 50 years of age), [34] hallux valgus (37.5% of elderly people over 65 years), [35] plantar fasciitis (3.2% of older adults in the Framingham Foot Study cohort), [36] tendinopathies including Achilles tendinopathy (1.85 per 1000 persons presenting to general practice) [37] and symptomatic flatfoot.

The term “flatfoot” (or pes planus) is commonly used to describe feet with an absent or abnormally low arch, often in association with eversion of the rearfoot. [38] It is estimated that approximately 3-25% of the adult population have pes planus world-wide. [39] Pes planus in the adult population can present as either flexible or rigid and may be congenital or acquired. The condition in which flatfoot is acquired in adulthood is termed “adult acquired flatfoot deformity” (AAFD). A wide spectrum of aetiologies have been proposed for adult acquired flatfoot including neuropathic, arthritic and traumatic causes, [40 41] however dysfunction of the tibialis posterior (TP) tendon remains the most common. [42]

Posterior tibial tendon dysfunction (PTTD) or an adult acquired flatfoot are the likely diagnoses for medial ankle pain and difficulties with activities that load the TP tendon. [43 44] The condition is most frequently reported among overweight, middle aged women, affecting up to 10% of elderly females. [45-48] While the terms PTTD and AAFD may indicate pathology of vastly different structures, they are used interchangeably by clinicians and in the literature. [42 49 50] PTTD/AAFD is reported to occur along a spectrum and is theoretically divided into four progressive stages, with primarily tendon-related signs and symptoms in the early stages, progressing to a flatfoot deformity with associated failure of soft tissue structures. [42]

The first classification system was proposed by Johnson & Strom who described a three-stage classification system detailing the progression of tendon dysfunction and structural deformity, the key signs and symptoms and surgical treatment options for each stage (**Table 1-1**). [51]

Table 1-1 *Johnson & Strom classification* [51]

	Stage 1	*Stage 2*	*Stage 3*
Tendon condition	Peritendinitis and/or tendon degeneration	Elongation	Elongation
Hind foot	Mobile, normal alignment	Mobile, valgus position	Fixed, valgus position
Pain	Medial: focal, mild to moderate	Medial: along tendon, moderate	Medial: possibly lateral, moderate
Single-heel-rise test	Mild weakness	Marked weakness	Marked weakness
"Too-many-toes'' sign with forefoot abduction	Normal	Positive	Positive
Pathology	Synovial proliferation, degeneration	Marked degeneration	Marked degeneration
Treatment	Conservative, 3 months; surgical, 3 months with synovectomy, tendon debridement, rest	Transfer to flexor digitorum longus for posterior tibial tendon	Subtalar arthrodesis

Since Johnson & Strom's initial classification system, several authors have made amendments and sub-categories in each stage for more specific delineation of presenting signs and symptoms which are often used to guide management (**Table 1-1** and **Table 1-2**).

Table 1-2 *Myerson classification* [48]

Stage	*Characteristics*	*Non-operative management*	*Operative management*
Tenosynovitis	Acute medial pain and swelling, can perform heel-rise, seronegative inflammation, extensive tearing	Anti-inflammatory medication, immobilization for 6-8 wks; if symptoms improve, ankle stirrup-brace; if symptoms do not	Tenosynovectomy, tenosynovectomy + calcaneal osteotomy, or tenosynovectomy + tenodesis of flexor digitorum longus to posterior tibial tendon

		improve, operative treatment	
Stage I	Medial pain and swelling, hindfoot flexible, can perform heel-rise	Medial heel-and-sole shoe wedge, hinged ankle-foot orthosis, orthotic arch-supports	Debridement of posterior tibial tendon, flexor digitorum longus transfer, or flexor digitorum longus transfer + calcaneal osteotomy
Stage II	Valgus angulation of heel, lateral pain, hindfoot flexible, cannot perform heel-rise	Medial heel-and-sole shoe wedge, stiff orthotic support, hinged ankle-foot orthosis, injection of steroids into the sinus tarsi	Flexor digitorum longus transfer + calcaneal osteotomy or flexor digitorum longus transfer + bone-block arthrodesis at calcaneocuboid joint
Stage III	Valgus angulation of heel, lateral pain, hindfoot rigid, cannot perform heel-rise	Rigid ankle-foot orthosis	Triple arthrodesis
Stage IV	Hindfoot rigid, valgus angulation of talus	Rigid ankle-foot orthosis	Tibiotalocalcaneal arthrodesis

These classification systems recommend surgical intervention for PTTD/AAFD if non-operative management is unsuccessful, even in the early stages of the condition. Surgical management has historically been the mainstay of intervention, [52] with little evidence to support the efficacy of this approach. Surgical techniques range from synovectomy and tendon debridement in the early stages [53 54] to tendon transfer, osteotomy and arthrodesis in the later stages. [55 56] The majority of published literature investigating the efficacy of surgical intervention is level IV evidence, particularly retrospective case series, and no randomised control trials exist. Outcomes assessed following these invasive, costly procedures focus at the level of body structure (i.e. the correction of the structural deformity), [57] rather than activity or participation and therefore do not consider the overall functioning of the individual. Furthermore, complications following surgery for PTTD/AAFD have been found to be frequent and include infection, [58] non-union, [59 60] wound healing problems, deep vein thrombosis, [61] neurological trauma [62] and under or overcorrection. [42]

To facilitate best outcomes with non-operative approaches, it is vital that non-operative approaches are targeted and efficacious. This is of particular importance when surgical intervention is recommended after an *unsuccessful trial* of conservative management. [63] Early signs of PTTD/AAFD (i.e. medial pain and swelling, weakness with heel rise) [48 51] are consistent with

tendinopathy of the TP tendon. [64] This thesis pertains to the presentation of TP tendinopathy (TPT) and as such, TPT will be used, except where systematic reviews of the literature use PTTD/AAFD terminology. As the condition is progressive in nature, it is important that conservative management is trialled early in the continuum, when tendon signs and symptoms are the primary complaint (i.e. when there is TPT) [48 51] and before osseoligamentous involvement relegates surgical management the preferable option (i.e. degeneration of mid- and rear-foot joints and a rigid AAFD).

With the aim of preventing progression of symptoms and delaying, or negating, the need for costly and invasive surgical intervention, early, effective management of TPT requires a thorough understanding of the presenting condition. A number of steps are required to inform development of effective management approaches for TPT. Evaluation of the diagnostic utility of the clinical signs used to identify TPT [48 51] may assist with early, accurate identification of the condition. There is also a need for a clear understanding of the overall presentation of TPT, including the key signs and symptoms, physical impairments (both local and widespread) and the impact of the condition on function and quality of life, so that appropriate outcomes can be used to evaluate management.

1.1.2 Thesis aims and objectives

The overall aim of this thesis is to characterize TPT with regard to terminology, diagnosis, physical impairments, pain and disability which could inform effective management programs. This aim will be completed by fulfilling the following objectives:

1. Systematically evaluating the literature to determine the efficacy of current conservative management approaches for the condition
2. Systematically reviewing the PTTD and AAFD literature with regard to selection criteria used for inclusion in research studies in order to synthesize and provide recommendations for future research, particularly the early stages
3. Systematically reviewing the literature with regard to clinical impairments, kinematics, pain and disability, using meta-analysis where possible, to establish how individuals with TPT differ from controls
4. Determining the diagnostic utility of clinical tests in diagnosing TPT identified on ultrasound scan
5. Identifying clinical and psychosocial features that may characterise TPT and assist differential diagnosis amongst other causes of medial foot and ankle pain
6. Characterizing physical impairments, quality of life, physical activity levels, pain and functional limitations associated with TPT by comparison to age and sex matched controls using the ICF framework

PART A:

Understanding TPT from the literature

This section is comprised of four systematic reviews, critically appraising and evaluating the current literature for TPT.

CHAPTER 2 Management of tibialis posterior tendinopathy

2.1 Exercise for posterior tibial tendon dysfunction: a systematic review of randomized clinical trials and clinical guidelines [65]

*Classification systems for PTTD/AAFD recommend surgical intervention when conservative approaches are unsuccessful. Effective management in the early stages of the condition, when there is TPT, may prevent or delay progression and help to avoid costly and invasive surgical procedures. The aim of this chapter (Study 1) was to critically appraise and evaluate the efficacy of exercise management for TPT by systematically reviewing randomized controlled trials and is an adaptation of the published paper below (**Appendix 2**). While local strengthening exercises may provide some benefit for those with TPT, optimal prescription parameters are unknown. As such, when managing individuals presenting with TPT, clinicians should be guided by presenting impairments.*

Ross MH, Smith MD, Mellor R, Vicenzino B. Exercise for posterior tibial tendon dysfunction: a systematic review of randomised clinical trials and clinical guidelines. *BMJ open sport & exercise medicine*. 2018;4(1):e000430.

Contributor	Statement of contribution
Megan H Ross (Candidate)	Conception and design (50%) Analysis and interpretation (55%) Drafting and production (55%)
Dr Michelle D Smith	Conception and design (20%) Analysis and interpretation (15%) Drafting and production (15%)
Dr Rebecca Mellor	Conception and design (10%) Analysis and interpretation (15%) Drafting and production (15%)
Professor Bill Vicenzino	Conception and design (20%) Analysis and interpretation (15%) Drafting and production (15%)

2.1.1 Introduction

TPT is prevalent, with estimates of prevalence ranging between 3.3 and 10%, [47] but suspected to be much higher, as the condition is often not formally diagnosed until the later stages. [47] TPT is disabling and characterised by impaired mobility, [66] poor function [67 68] and often a range of comorbidities including hypertension and diabetes and higher body mass index (BMI).[43 67 69]

Decisions regarding management vary according to the stage of the pathology, [51] with reports of surgery predominating, probably due to the condition more commonly presenting in later and more severe stages. [70] Surgery aims to correct deformity in the later stages of the condition (i.e. stages III and IV) [55 71 72] and, relatively recently, to prevent soft tissue and joint destruction in earlier stages (I-II) that do not respond to conservative management. [53 54 73-77]

Conservative management is utilized in earlier stages (I-II) with a focus on local strengthening exercises for the tibialis posterior musculotendinous unit and use of an orthosis to brace the foot. [78-80] The level of evidence in support of this approach is currently unevaluated and is the basis of this systematic review. In evaluating the level of evidence it is important to also evaluate the quality of reporting of the exercise prescription parameters due to the potential influence variations in these parameters may have on the effectiveness of the treatment, [81] and clinical practice.

The aim of this systematic review of randomised clinical trials (RCTs) was to provide estimates of treatment effects of local strengthening exercises compared to other forms of conservative management for adults with TPT on outcomes relating to the ICF framework (impairments, activity limitations and participation restrictions) and to evaluate the completeness of exercise prescription descriptors.

2.1.2 Methods

This systematic review was performed using a pre-determined protocol in accordance with the preferred reporting items for systematic review and meta-analysis (PRISMA) statement. [82] It was registered with PROSPERO (CRD42017076156) and is available from: http://www.crd.york.ac.uk/PROSPERO/display_record.php?ID=CRD42017076156.

Search strategy and data sources

To answer the research question about the treatment effects of local strengthening exercises for TPT, four electronic databases (CINAHL, Cochrane, Embase and PubMed) were searched from inception to June 2018 for full-text papers published in peer-reviewed journals. A comprehensive search strategy was developed to capture variations in terminology used in the literature for TPT and key conservative interventions (**Table 2-1**). No further limits were applied to the initial search

strategy. Reference list checks and author searches were also performed to ensure all relevant literature was identified.

Table 2-1 *Search strategy showing terms and how terms were combined*

Search Number	Keyword/s
1	'posterior tibial tendon dysfunction'
2	'adult acquired flatfoot'
3	'adult-acquired flatfoot'
4	orthotics
5	orthoses
6	orthosis
7	nonoperative
8	non-operative
9	nonsurgical
10	non-surgical
11	exercise
12	stretching
13	conservative
14	#1 OR #2 OR #3
15	#4 OR #5 or #6 OR #7 OR #8 OR #9 OR #10 OR #11 OR #12 OR #13
16	#14 AND #15

Eligibility criteria

Eligibility criteria were determined prospectively using the PICO framework. [83] Trials were eligible for inclusion if they investigated individuals with TPT or adult acquired flatfoot deformity due to TPT, if they were randomised, and if local strengthening was compared to other forms of conservative management with respect to pain, function and/or physical impairment outcome measures. Diagnosis of TPT was required to be made based on a minimal list of diagnostic criteria, [84] with two or more of: tenderness on palpation of the posterior tibial tendon, pain and/or swelling along the posterior tibial tendon, medial foot pain, difficulty and/or pain with single leg heel raise, and inability to invert the calcaneus on double leg heel raise. Flatfoot deformity was not considered as a selection criterion and as such, all stages of TPT were included.

Trials were excluded if they compared surgical interventions for TPT, did not include a comparator group, and combined data for individuals diagnosed with conditions other than TPT. Reviews, case studies and trials for paediatric flatfoot, asymptomatic flatfoot, neurological conditions and rheumatoid arthritis were also excluded.

Study selection

The lead reviewer (MHR) performed the search and exported all retrieved records into Endnote X7 (Thompson Reuters, Carlsbad, California, USA). Duplicates were removed and titles and abstracts were screened independently by two reviewers (MHR and RM), based on established eligibility criteria. Full texts were retrieved for all potentially eligible papers and reviewed for inclusion and exclusion criteria. Where there were uncertainties, at least one additional author (MDS or BV) was consulted to determine final eligibility.

Data extraction

Data extraction for each included trial was completed by two investigators (MHR, RM) using a predetermined spreadsheet. Where reference was made to protocol papers or supplementary materials, these sources were obtained and used for data extraction. For each trial, study design, sample size, participant characteristics/demographics, diagnostic criteria, methods, intervention details (type, frequency, duration), outcomes, follow-up and results (means and standard deviations (SDs)) for each time point were extracted.

As reporting of parameters of exercise prescription are essential for the implementation of research findings in exercise therapy, this data was also extracted. The 'Template for Intervention Description and Replication' (TIDieR) checklist [85] (developed to facilitate reporting and replication of intervention studies) and guidelines developed by Toigo and Boutellier [86] specifically for resistance exercise prescription provide a framework appropriate for the appraisal of exercise prescription in intervention studies for musculoskeletal conditions. [87] As such, specific parameters (% repetition maximum, repetitions, time under tension, etc) were extracted to allow for analysis of mechanobiological descriptors of exercise prescription. [86] Data for the 12-item TIDieR checklist [85] were also independently extracted by two reviewers and the completeness of reporting was evaluated by allocating 1 point for complete items (clear, unambiguous descriptions allowing replication), and 0 for incomplete items (partial or no description) as per Holden (2017). [87] Total scores were calculated for each checklist and two authors (MDS and BV) verified all extracted data for accuracy.

Risk of bias

Risk of bias was assessed as recommended by The Cochrane Collaboration's tool for assessing risk of bias in randomised trials.[83] The tool assesses six potential sources of bias under five domains (selection bias, performance bias, detection bias, attrition bias and reporting bias) and considers each as being either 'low risk', 'high risk' or 'unclear risk' of bias. Two independent reviewers (MHR and RM) rated included trials and results were collated and examined for discrepancies. Inter-rater disagreements were discussed and where a consensus could not be met were taken to a third party (BV or MDS).

Statistical analyses / Data synthesis

Analyses were performed in Review Manager (RevMan) V5.3 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration). For continuous measures of pain, function and/or physical impairment, individual study effect sizes were expressed as standardised mean differences (SMDs) using means and SDs. The mean change scores from pre-intervention to post-intervention were compared between two independent participant groups (i.e. strengthening vs no strengthening; type of strengthening comparison). Change scores (mean and SD) for each group were calculated as post-score minus pre-score with within group correlation assumed to be 0.5 [83] and were used to estimate the SD of the mean change using t-distributions.

The difference between each group was considered significant where 95% confidence intervals (CIs) did not contain zero. For pain and self-reported outcome measures, higher scores indicated worse outcomes, and as such, the inverse of effect size was reported so that positive effect sizes indicated a beneficial effect for the intervention group. Improvements in strength and function measures were indicated by higher scores and positive effect sizes. The strength of the effect size was interpreted based on Hopkins, as follows; < 0.2 trivial effect, 0.2 - 0.6 small effect, 0.61 – 1.2 medium effect, > 1.2-2.0 large effect and 2.0 – 4.0 extremely large effect. [88]

Inter-rater reliability of methodological quality was calculated in Stata v13 (College Station, TX: StataCorp LP) using the κ-statistic (95% CI). The reliability of the quality ratings between the two assessors was interpreted as κ <0.00 poor agreement; 0.00 – 0.20 slight agreement, 0.21 – 0.40 fair agreement, 0.41 – 0.60 moderate agreement, 0.61 – 0.80 substantial agreement and 0.81 to 1.00 almost perfect agreement. [89]

2.1.3 Results

Study selection and design

The electronic database search retrieved 347 studies. After removing duplicates, 242 titles and abstracts were screened and 16 potentially eligible full text trials were assessed for eligibility

(**Figure 2-1**). Three randomized controlled trials were included in qualitative and quantitative synthesis.

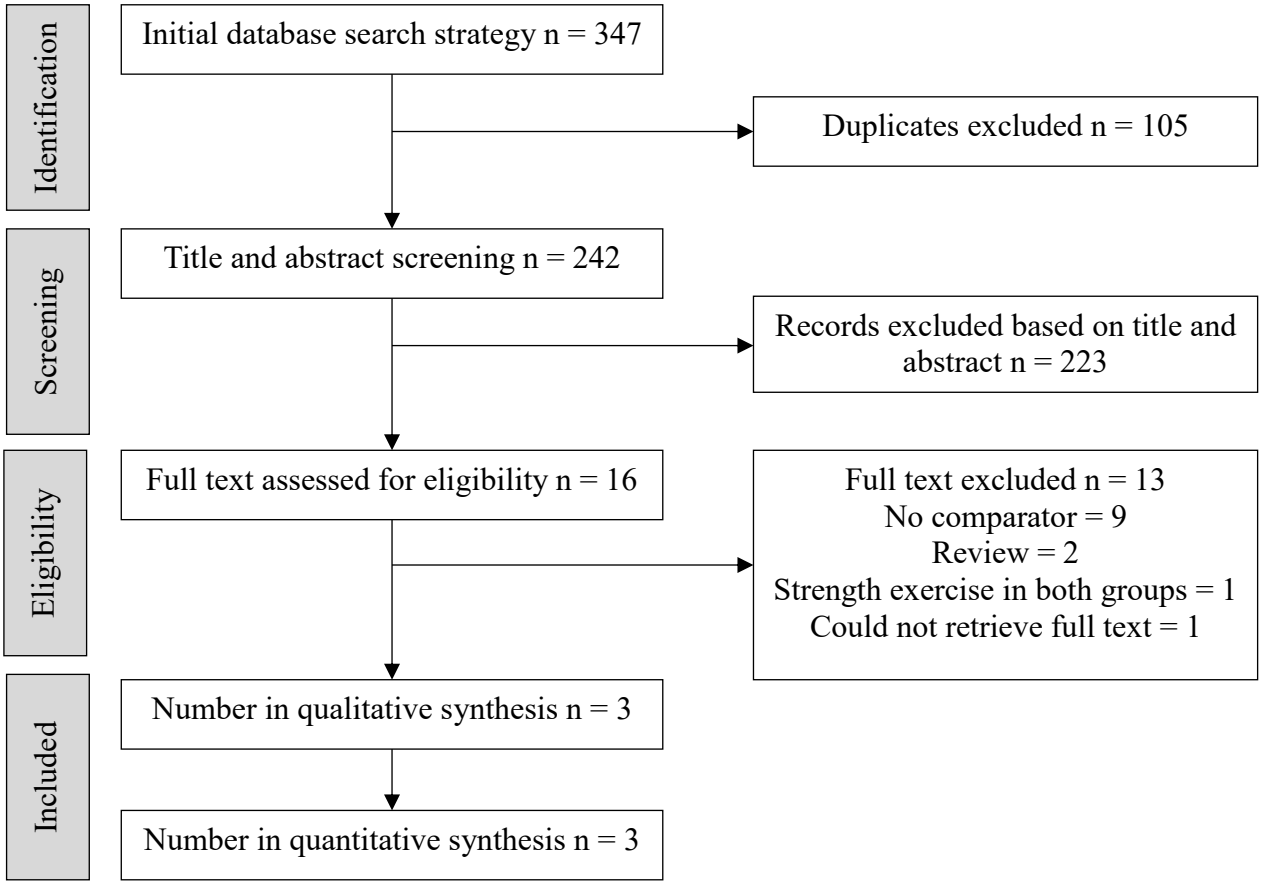


Figure 2-1 *PRISMA flow chart for selected trials included for the systematic review*

Risk of bias

The inter-rater reliability for the risk of bias assessment was almost perfect (agreement on 16/18 ratings, κ = 0.857 (0.47 to 1)). Risk of bias was variable across the six items, with insufficient information available to permit a judgement for two of three trials on four items (random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment; **Table 2-2**). Considering attrition, two trials were deemed to have low risk of bias as reasons were provided for missing data (drop-outs) which were unrelated to outcomes of the intervention, and drop-outs were balanced across groups. The third trial had an imbalance of missing data across groups (2 (29%) vs 0 (0%)) for all outcomes and due to the already small sample size (n = 14), it is plausible this was large enough to induce clinically relevant bias. Selective reporting overall had a high risk of bias. Of the two trials in which a judgement could be

made, there were outcomes specified in the trial protocol that were omitted from the final analyses and manuscript.

Table 2-2 *Risk of bias table: review authors' judgements about each risk of bias item presented for each included study*

Bias	Houck[90]	Jeong[91]	Kulig[92]
Random sequence generation (selection bias)	Low	Unclear	Unclear
Allocation concealment (selection bias)	High	Unclear	Unclear
Blinding of participants and personnel (performance bias)	High	Unclear	Unclear
Blinding of outcome assessment (detection bias)	Unclear	Unclear	Low
Incomplete outcome data (attrition bias)	Low	High	Low
Selective reporting (reporting bias)	High	Unclear	High

Participant characteristics

A total of 93 individuals with TPT were enrolled across all trials, with individual sample sizes ranging from 14 to 40 participants (5 to 19 per group) (**Table 2-3**). Studies enrolled participants with a mean age from 52.9 [91] to 57.5 [90] years and body mass index (BMI) between 23.3 [91] and 30.5 [90] kg/m^2. All studies had a predominance of women, with percentage of females ranging from 77.7 [90 92] to 100%. [91] Two trials [91 92] included individuals with stage I or II TPT and one trial [90] included those with only stage II TPT.

Table 2-3 *Included studies*

						Intervention Group				Comparator Group			
Study	Number screened	Number enrolled^	Intervention	Comparator	Stage	n	Age* years	BMI* kg/m	Female (%)	n	Age* years	BMI* kg/m	Female (%)
Houck [90]	88	39	Orthoses + stretching + isotonic strengthening	Orthoses + stretching	II	19	57 (2)	30 (6)	15 (78.9)	17	58 (9)	31 (5)	13 (76.5)
Jeong [91]	NR	14	Stretching + isotonic ankle strengthening + balance training	No intervention	I or II	7	52.57 (16.13)	22.6 (2.37)	7 (100)	5	53.2 (12.61)	24.02 (3.63)	5 (100)
Kulig [92]	126	40	Orthoses + stretching + concentric strengthening	Orthoses + stretching	I or II	12	55.3 (16.4)	32 (9.24)	10 (83.3)	*12*	*51.3 (17.2)*	*28.7 (6.26)*	*8 (66.7)*
Kulig [92]	126	40	Orthoses + stretching + eccentric strengthening	Orthoses + stretching	I or II	12	49.4 (12.6)	28.5 (7.09)	10 (83.3)	*12*	*51.3 (17.2)*	*28.7 (6.26)*	*8 (66.7)*

Key: * = mean (SD), NR = not reported, *italics* = same comparator group, ^ = pre-randomisation (includes drop-outs)

Selection criteria

In all trials, diagnosis of TPT was established based on physical examination findings performed by either physical therapists or foot and ankle physicians. The number of essential/compulsory diagnostic criteria ranged between two and six with pain along the posterior tibial tendon, tenderness on palpation of the posterior tibial tendon, medial foot pain and a correctable flatfoot deformity most frequently utilised (**Table 2-4**). Imaging was not utilised in any trial to confirm diagnosis or exclude other potential sources of pain. Only one trial [92] reported a minimum duration of symptoms and one reported restrictions in function (able to walk >15m) and age (>40 years) [90] as study selection criteria.

Table 2-4 *Selection criteria as stated in each study*

Trial	Medial foot/ankle pain	Pain PTT	Swelling of PTT	TOP PTT	Correctable flatfoot deformity	Foot flattening	Abducted midfoot	Duration of symptoms	Imaging	Other inclusion criteria
Houck [90]	NR	Either		NR	√	NR	NR	NR	NR	Able to walk >15m >40 years of age
Jeong [91]	√	√	NR	√	NR	NR	NR	NR	NR	NR
Kulig [92]	√	NR	NR	√	√	√	√	>3 months	NR	NR

Key: √ = essential eligibility criteria for the study, Either = one finding from this group of tests/clinical findings was required, NR = not reported

Outcome measures

The trials included in this review reported a range of outcome measures relating to physical impairment, pain and function. Two studies [91 92] used a Visual Analogue Scale (VAS) to measure pain immediately post 5 minute walk test (5MWT). The same two studies [91 92] also reported distance ambulated (m) during the 5MWT. Houck [90] reported tibialis posterior muscle torque with combined plantar flexion and inversion, whereas Jeong [91] reported ankle strength and range of motion in dorsiflexion, plantar flexion, inversion and eversion. A total of three patient-reported outcome measures were utilised, with two trials [90 92] reporting the Foot Function Index (FFI). The FFI consists of three domains (pain, disability and activity limitations) which are summed to provide an overall total score. Houck [90] also utilised the Short Musculoskeletal Function Assessment (SMFA) which consists of mobility, dysfunction and bother indexes. Jeong [91] reported the American Orthopaedic Foot and Ankle Society (AOFAS) score which combines both patient self-report and clinician physical examination findings into one aggregate score. [93] Reassessment of outcomes varied from 6 weeks [90 91] to 12 weeks. [90 92]

Interventions

The exercise intervention protocol varied in each of the included trials. Local tibialis posterior exercises were compared with foot orthoses and stretching in two trials,[90 92] however the type of exercise (concentric, eccentric or isotonic) varied. Participants in the Kulig [92] trial were randomly assigned to either an eccentric or concentric exercise group (combined with stretching and orthoses) or a stretching and orthoses only group (3 groups in total). Houck [90] used an isotonic strengthening regime combined with stretching and orthoses compared to stretching and orthoses only. Participants in the Jeong [91] trial were randomised to receive either a isotonic ankle strengthening, stretching and balance program or no intervention.

Completeness of reporting

Completeness of intervention reporting based on the TIDieR checklist is provided in **Table 2-5**. Of the 12 items, Jeong [91] provided adequate information for 4 items, Houck [90] for 11 items and Kulig [92] for all 12 items. Houck [90] and Kulig [92] both included sufficient information in regards to adherence (both the plan for assessment of adherence and reports of actual adherence).

Table 2-5 *TIDieR Checklist for included trials*

	Houck [90]	Jeong [91]	Kulig [92]
1 Intervention name	Yes	Yes	Yes

2 Why (rationale)	Yes	No	Yes
3 What (materials)	Yes	Yes	Yes
4 What (procedures)	Yes	Yes	Yes
5 Who provided	Yes	No	Yes
6 How	Yes	No	Yes
7 Where	No	No	Yes
8 When and how much	Yes	Yes	Yes
9 Tailoring	Yes	No	Yes
10 Modifications	Yes	No	Yes
11 How well (planned)	Yes	No	Yes
12 How well (actual)	Yes	No	Yes
TOTAL	**11**	**4**	**12**

No trial provided complete reporting of interventions based on the Toigio and Boutellier (2006) [86] exercise prescription descriptors (**Table 2-6**). Of the 13 items, Jeong [91] provided adequate information for 5 items, Houck [90] for 7 items and Kulig [92] for 11 items. Of the six classical descriptors, only number of sets and repetitions of the exercises and duration of the experimental period over which exercises were performed were consistently described for all exercises in all trials (**Table 2-6**). Load magnitude (% repetition maximum) was only described in one trial. [92] Of the seven remaining mechanobiological descriptors, range of motion and an anatomical definition of the exercise was described in the methodology of two trials, [90 92] and time under tension was described in one trial. [92]

Table 2-6 *Exercise descriptors (from Toigio and Boutellier[86]) for included trials*

Exercise descriptors	**Houck [90]**			**Jeong [91]**				**Kulig [92]**	
	BLHR	*Theraband ADD/INV in PF*	*SLHR*	*Theraband PF, DF, INV, EV (wk 1-6)*	*Seated HR (wk 1-2)*	*BLHR (wk 3-4, 5-6)*	*SLHR (wk 5-6)*	*ADD in PF (concentric)*	*ADD in PF (eccentric)*
1 Load magnitude	BW	Increasing resistance	BW	Red → Blue → Black	Partial BW	BW → loaded	BW	15RM	15RM
2 Number of repetitions	10 → 30	10 → 30	10 → 30	20	20	15	15	15	15
3 Number of sets	2 → 3	2 → 3	2 → 3	4	4	3	3	3	3
4 Rest in-between sets (s or min)	NR	NR	NR	30s	30s	30s	30s	1-2 min	1-2 min
5 Number of exercise interventions (per day or wk)	2x/day	2x/day	2x/day	NR	NR	NR	NR	2x/day	2x/day
6 Duration of experimental period (days or wks)	12 wks	12 wks	12 wks	6 wks	6 wks	6 wks	6 wks	12 wks	12 wks
7 Fractional/temporal distribution of the contraction per repetition and duration (s) of one repetition	Isotonic	Isotonic	Isotonic	Isotonic	Isotonic	Isotonic	Isotonic	Concentric	Eccentric
8 Rest in-between repetitions (s or min)	NR	NR	NR	NR	NR	NR	NR	NR	NR
9 Time under tension (s)	NR	NR	NR	NR	NR	NR	NR	5s	5s
10 Volitional muscular failure	No	Yes	No	NR	NR	NR	NR	No	No
11 Range of motion	Full	Full	Full	NR	NR	NR	NR	Neutral → EOR	EOR → Neutral

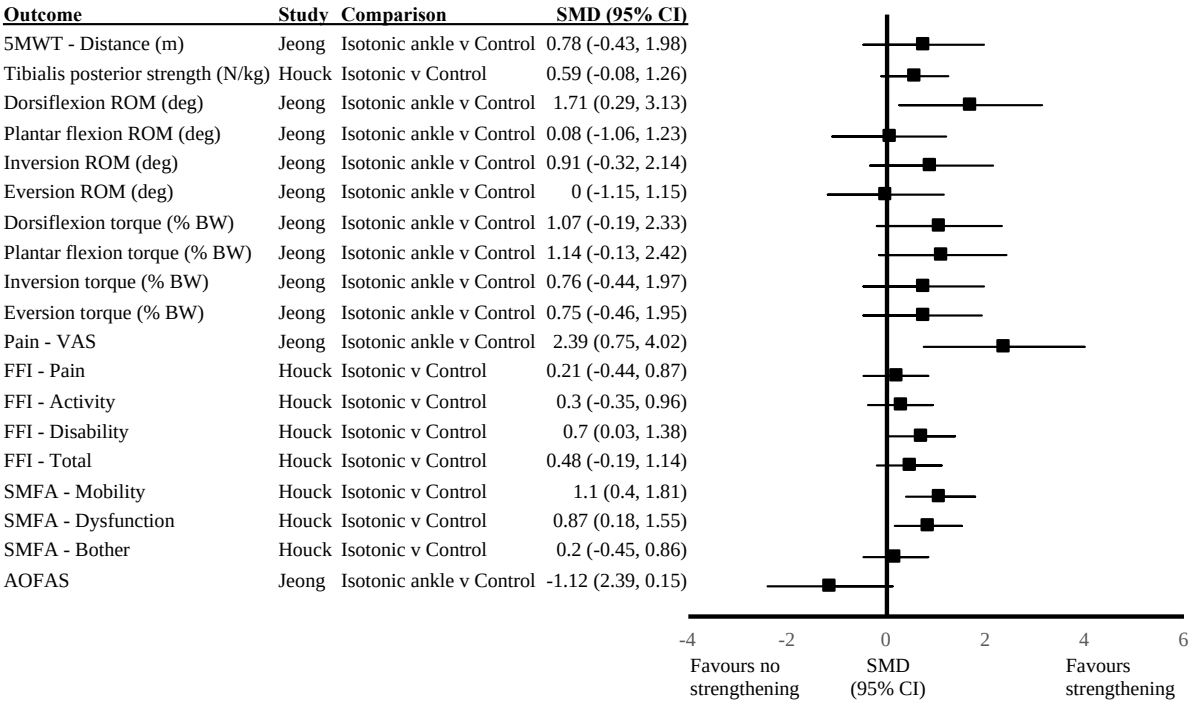
12 Recovery time in-between exercise sessions (hrs or days)	NR	NR	NR	NR	NR	NR	NR	NR	NR
13 Anatomical definition of the exercise (exercise form) described	Yes	Yes	Yes	No	No	No	No	Yes	Yes
TOTAL	7			4				11	

Abbreviations: BLHR; bilateral heel raise, ADD; adduction, INV; inversion, PF; plantar flexion, SLHR; single leg heel raise, DF; dorsiflexion, INV; inversion, EV; eversion, HR; heel raise, wk; week, BW; body weight, RM; repetition maximum, s; seconds, min; minutes, NR; not reported, EOR; end of range , hrs; hours
Key: Items 1 – 6 = classical set of descriptors, Items 7 – 13 (shaded) = new set of descriptors

Main findings

Physical impairments

Isotonic ankle strengthening, balance and stretching improved ankle dorsiflexion range at six weeks beyond that of no intervention (SMD (95% CI) 1.71 (0.29 to 3.12)) (**Figure 2-2**). Plantar flexion inversion torque was not different at six weeks following isotonic tibialis posterior strengthening exercise combined with stretching and orthoses compared to stretching and orthoses alone (SMD (95% CI) 0.59(-0.08 to 1.26)) (**Figure 2-2**). Isotonic ankle strengthening, balance and stretching did not improve ankle torque in any direction at six weeks beyond that of no intervention (**Figure 2-2**). Local strengthening was not superior to control comparator for any other physical impairment outcomes at six weeks (**Figure 2-2**).

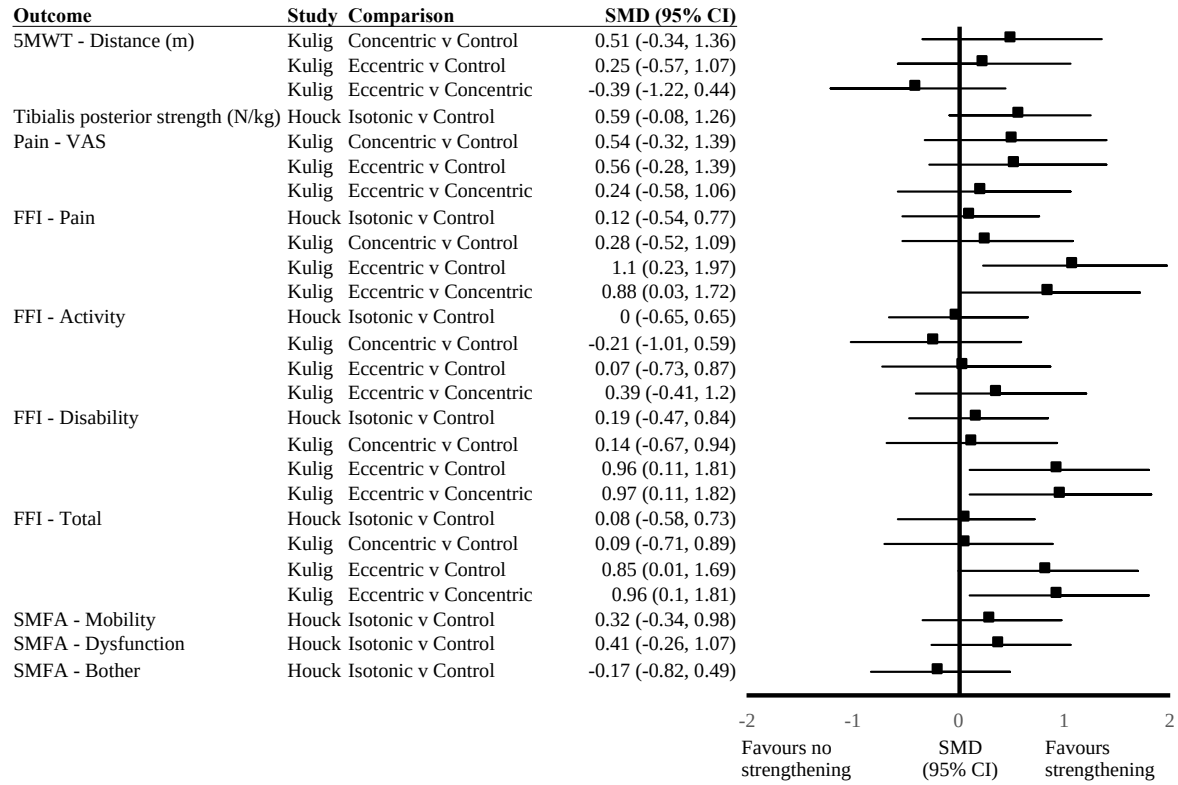


Abbreviations: 5MWT; 5-minute walk test, m; metres, N/kg; Newtons per kilogram, ROM; range of motion, deg; degrees, BW; body weight, VAS; visual analogue scale, FFI; foot function index, SMFA; short musculoskeletal functional assessment

Figure 2-2 Standardised mean differences (95% CI) for outcomes at 6 weeks

Neither concentric nor eccentric tibialis posterior strengthening exercises combined with stretching and orthoses were significantly different to control for the distance covered during the 5MWT at 12 weeks (SMD (95% CI) 0.51 (-0.34 to 1.36) and 0.25 (-0.57 to 1.07) respectively), [92] nor were there differences between eccentric and concentric strengthening groups (SMD (95% CI) -0.39 (-1.22 to 0.44))(**Figure 2-3**). There was no difference between isotonic tibialis posterior strengthening and

the control group for tibialis posterior strength (isometric combined plantar flexion and inversion) at 12 weeks (SMD (95% CI) 0.59 (-0.08 to 1.26)) (**Figure 2-3**). [90]



Abbreviations: 5MWT; 5-minute walk test, m; metres, N/kg; Newtons per kilogram, ROM; range of motion, deg; degrees, BW; body weight, VAS; visual analogue scale, FFI; foot function index, SMFA; short musculoskeletal functional assessment

***Figure 2-3** Standardised mean differences (95% CI) for outcomes at 12 weeks*

Patient reported outcomes

Isotonic ankle strengthening, balance and stretching reduced pain on a VAS scale beyond that of no intervention with a large, significant effect size at six weeks (SMD (95% CI) -2.39 (-4.02, -0.75)) (**Figure 2-2**). [91] Isotonic strengthening moderately reduced scores for the mobility and dysfunction subscales of the SMFA at six weeks (SMD (95% CI) -1.10 (-1.81 to -0.4) and -0.87 (-1.55 to -0.18) respectively)(**Figure 2-2**), but not 12 weeks (SMD (95% CI) 0.32 (-0.98 to 0.34) and -0.41 (-1.07 to 0.26) respectively) (**Figure 2-3**). [90] There were no differences between local strengthening and control groups for mean change on the FFI subscales or total score at six weeks (**Figure 2-2**) or the SMFA bother subscale at six or 12 weeks (**Figure 2-3**). [90]

Eccentric strengthening combined with stretching and orthoses reduced mean scores for FFI-pain, FFI-disability and FFI-total beyond that of concentric strengthening, stretching and orthoses combined, and stretching and orthoses alone at 12 weeks with moderate effect sizes (SMD (95% CI) -1.1 (-1.97 to -0.23), -0.97 (-1.82 to -0.11) and -0.96 (1.81 to -0.1) respectively) and (SMD

(95% CI) -1.1 (-1.97 to -0.23), -0.96 (-1.81 to -0.11) and -0.85 (-1.69 to -0.01) respectively) (**Figure 2-3**). [92] Neither concentric nor isotonic tibialis posterior strengthening combined with stretching and orthoses were significantly different to stretching and orthoses alone for the 3 subscales of the FFI and FFI-total at 12 weeks (**Figure 2-3**). [90 92]

2.1.4 Discussion

This systematic review evaluated pain and functional outcomes following local strengthening exercise in individuals with TPT. Two main findings emanate from this systematic review: the first is the lack of rigorous RCTs investigating the effects of non-surgical management on impairments, activity limitations and participation in adults with TPT and the second is that exercise parameters are poorly reported.

Detailed reporting of exercise parameters for musculoskeletal interventions trialled in RCTs is essential for clinical replication and translation of research into practice. The implications of omitting important exercise parameters in reporting, however, extends beyond just clinical replication of exercise prescription. Exercise parameters such as time under tension, range of motion and rest or recovery time can be manipulated and are expected to influence both physiological response to and efficacy of the exercise prescription, [81 86] meaning that slight variations in prescription parameters may have vastly different physiological effects. Factors related to biophysical response to exercise were not sufficiently described in the included studies and strengthening interventions failed to improve strength related outcome measures at both 6 and 12 weeks. Lack of detailed reporting becomes an important matter when a primary goal in rehabilitation of tendinopathies is to improve the load management capacity of the musculotendinous unit. [94]

Current literature implicates appropriate load management as the most important component of rehabilitation for tendinopathies. [94-96] The benefit of therapeutic exercise in the management of lateral epicondylalgia and Achilles, patellar and rotator cuff tendinopathies has been established in previous systematic reviews. [97-100] While early literature has focussed on eccentric exercise for tendinopathies, [101-103] more recent approaches with good efficacy include patient education on load management strategies and individualised, progressive loading exercises. [104] Overall, effect sizes from this systematic review provide limited evidence to suggest that isotonic tibialis posterior strengthening, stretching and orthoses and general isotonic ankle strengthening, balance and stretching exercises similarly improve pain, mobility and dysfunction in TPT in the short term compared to no strengthening. Considering the specific type of strengthening protocol, data from this review suggests that eccentric strengthening may be marginally more effective than other types

of strengthening; with eccentric but not concentric exercise resulting in significant reductions in self-reported pain, disability and overall foot function compared to controls at 12 weeks.

The mechanism of effect for improved outcomes in tendinopathy following strengthening exercise is understood to be related to load. It has been suggested that the load through the tendon during therapeutic exercises needs to be sufficiently high enough to elicit physiological changes within the tendon. While relationships between internal tendon structure and pain and function are currently unclear,[96] heavy-slow resistance appears to be beneficial in managing Achilles and patellar tendinopathies.[105] It has been suggested that the physiological response to therapeutic exercise may be greater with heavy-slow resistance and eccentric strengthening due to higher loads applied through the tendon during these exercises. The device used for strengthening exercise in the study by Kulig allowed for quantification of load and constant resistance throughout the exercise. [92] Participants in the eccentric exercise group in their clinical trial achieved loads 3.3 times higher than those in the concentric group by the end of the 12 week intervention. [92] This raised the possibility that differences in outcomes were dependent on load rather than specific contraction type. Tolerance and ability to perform the exercise with good form were criteria for progressing load, which suggests that participants in the eccentric group were better able to tolerate higher loads during the exercise program, optimising tendon response, and leading to the reporting of greater improvements in pain, disability and overall foot function. Physical tests of function (distance covered during 5MWT) however, were not different between groups. This suggests that while participants felt more confident loading their tendon, physical capacity of the tendon might not have improved.

Exercise prescription parameters can be manipulated depending on the desired physiological response to exercise stimulus for example, to improve skeletal muscle strength, endurance or power. Each of the three trials indicated that the intention of the prescribed exercises was to improve strength. On further examination of the exercise prescription parameters (**Table 2-6**) in reference to the current American College of Sports Medicine (ACSM) guidelines for muscular strength, [106] some discrepancies were apparent. Considering load magnitude, the ACSM guidelines for strength recommend up to 12 repetition maximum, where Kulig [92] prescribed 15, fitting the ACSM guidelines for muscular endurance. [106] Similarly, papers prescribed between 15 and 30 repetitions which is above the recommendations for inducing strength adaptations (8-12) and falls into the recommended repetitions for improving muscular endurance. [106]

Adherence should be considered in calculating the exercise stimulus (load) actually delivered to the musculotendinous unit and any strength gains accrued. Adherence was not reported in Jeong, [91] but ranged between 29% to 126% (average 79%) in Houck [90] and 39% to 98% (average = 68%) in

Kulig. [92] Considering this, it is possible the actual load participants performed was not high enough to elicit adaptations in skeletal muscle that would subsequently result in clinical improvements in strength (Houck) or physical tests of function (Kulig). Houck (2015) examined tibialis posterior force production in plantar flexion and forefoot adduction at baseline and 6 and 12 weeks following isotonic tibialis posterior exercises against the heaviest Theraband® resistance that could be tolerated, in addition to bilateral and unilateral heel raises. [90] The strengthening group did not exhibit increases in tibialis posterior strength at 6 or 12 weeks which suggests that while the intention of the prescribed exercise program was to increase strength, with poor adherence taken into consideration, actual load may not have been appropriate to elicit changes in musculotendinous strength.

It was common among included trials for the intervention protocol to include co-interventions such as stretching and orthoses in addition to specific local strengthening exercises. It is possible that the effect of the local strengthening intervention was affected by these co-interventions. As no randomised trial has looked at local strengthening in isolation (i.e. not combined with stretching/orthoses or balance and stretching exercises), it is difficult to ascertain to what degree improvements can be attributed to targeted exercises only. Two trials that investigated stretching, orthoses and local strengthening compared to stretching and orthoses alone showed similar improvement in pain and function in all groups. It is possible that orthoses and/or stretching play a role in reduction of pain. Future research is required to investigate strength interventions in isolation of other treatments to establish its efficacy in the management of TPT.

Interestingly, stretching exercises were included in all intervention groups across the three included trials. Both gastrocnemius and soleus stretches were prescribed for 3-10 repetitions of 30 second duration, 2-4 times per day. This stretch is performed in maximal dorsiflexion, which increases the compressive as well as the tensile load on the posterior tibial tendon posterior to the medial malleolus, [107] the combination of which has been found to be most damaging to the tendon. [108] Load management for pain relief in tendinopathy rehabilitation is two-fold, incorporating the reduction of both compressive and tensile loads. [109] So while foot orthoses and activity modification may aid in altering tensile loads (supporting the medial longitudinal arch and reducing the torque required from the tibialis posterior during activities), accompanying these interventions with static stretches in full dorsiflexion may be counterproductive to pain management and rehabilitation.

Pain with palpation, pain on tendon loading and impaired function are key features in the clinical presentation of tendinopathies. [110-113] Pain and difficulty during activities that load the medial aspect of the foot and the posterior tibial tendon, such as the single leg heel raise, are key clinical features of TPT. Results from this systematic review have highlighted that interventions that aim to modify

the load through the tendon and foot locally (i.e. via tibialis posterior strengthening and/or arch supporting devices such as foot orthoses) have limited ability to improve pain and functional outcomes in TPT. As such, alternative means of modifying load to improve clinical outcomes warrant further investigation. Hip function can affect motion at the foot during gait [114-116] and weak hip external rotators and abductors have been associated with increased femoral internal rotation [117] [118] and adduction, [119] increased knee valgus, [118] [120] tibial internal rotation [120-122] and subtalar joint pronation, [121] [123] which may impact on tibialis posterior. Increased rearfoot eversion [124-128] and hip abduction strength [66] deficits have been demonstrated in TPT, which suggests that some proximal changes may be evident in the condition. Further research investigating proximal muscle function and kinematics in TPT would provide further support for interventions targeting proximal hip motor control and strength.

Limitations

While this is the first systematic review to investigate the efficacy of exercise as a treatment for TPT, there are several limitations that must be acknowledged. The small number and variability of interventions and outcomes of included studies did not allow meta-analysis or pooling of results. Meta-analysis was prevented due to variability in selection criteria, methodological quality, interventions and outcome measures assessed among the three included studies. Small sample sizes of individual studies can influence the ability to detect true effects. With very few outcomes replicated between studies, meta-analysis was prohibited and effect sizes presented in this review should be interpreted with this in mind. These aspects of the literature limits the inferences that might be drawn from the findings. Notwithstanding, this review is a synthesis of all available evidence from randomised controlled trials relating to exercise management for TPT and highlighted the dearth of evidence on which to guide management. It must be acknowledged that studies included in this review related to stage I and/or II TPT only. This is an important consideration in terms of the clinical application of findings and the generalizability of results, given that patient presentation may vary as the condition progresses.

2.1.5 Conclusion

This is the first systematic review on exercise therapy for TPT. Based on the limited available literature, it appears that local strengthening exercises provide some benefit in TPT, and eccentric exercises may be superior for improving pain, disability and self-reported overall foot function than concentric exercises and foot orthoses and stretching alone. No recommendations can currently be made regarding optimal exercise prescription based on published clinical trials. Clinicians should be

guided by presenting impairments to prescribe exercise, which holds some promise in managing TPT.

CHAPTER 3 Clinical features of tibialis posterior tendinopathy

3.1 Reported selection criteria for adult acquired flatfoot deformity and posterior tibial tendon dysfunction: are they one and the same? A systematic review [84]

*Findings from Chapter two suggest that clinicians should be guided by presenting impairments when prescribing exercise for TPT. In order to investigate the presentation of TPT, it is important to understand the selection criteria for TPT. This chapter is adapted from systematic synthesis of the selection criteria used in the literature for TPT and AAFD (**Appendix 3**). The term posterior tibial tendon dysfunction (PTTD) is used instead of TPT throughout this chapter to be consistent with terminology used in each original research article. Only 35% of papers investigating either PTTD or AAFD stated condition-specific inclusion or selection criteria. Of those that stated selection criteria, the majority required signs of both tendon dysfunction and structural deformity (84% for AAFD and 81% for PTTD). This systematic review also provided recommendations for the future use of terminology for the two conditions, and more specifically, recommended selection criteria for TPT (stage one and two PTTD) and AAFD.*

Ross MH, Smith MD, Vicenzino B. Reported selection criteria for adult acquired flatfoot deformity and posterior tibial tendon dysfunction: Are they one and the same? A systematic review. PLoS One 2017;12(12):e0187201. doi: 10.1371/journal.pone.0187201

Contributor	Statement of contribution
Megan H Ross (Candidate)	Conception and design (60%) Analysis and interpretation (70%) Drafting and production (50%)
Dr Michelle D Smith	Conception and design (20%) Analysis and interpretation (15 %) Drafting and production (25%)
Professor Bill Vicenzino	Conception and design (20%) Analysis and interpretation (15%) Drafting and production (25%)

3.1.1 Introduction

Presentation of a progressively flat foot with medial ankle pain is likely to be diagnosed as a PTTD or AAFD. [43 44] These terms seem to be used interchangeably in the literature, [42 49 50] even though they suggest possible dysfunction of different structures. The evolution of the terminology used for this condition began with emphasizing the tendon pathology; PTTD [46 51 129] and increasingly over recent times the focus has shifted to the foot deformity; AAFD. The characteristic flat foot deformity, and the notion that PTTD does not adequately describe the ligamentous failure and resultant joint destruction that ultimately occurs, [49 130] are possible reasons for the adoption of AAFD terminology. The problem with using the term AAFD is that in addition to being a result of PTTD, [46 131] it also results from other aetiologies, such as traumatic (injury to ligament or tendon), degenerative, arthritic and neuromuscular conditions. [40 41 45 132] This situation is potentially problematic in both clinical practice and research, because AAFD may not adequately represent the underlying pathology and consequently the diagnosis. One of the problems with this is that management decisions are likely to differ according to the diagnosis. This review will systematically synthesise the key signs and symptoms of PTTD and AAFD from the literature to ascertain if there is a difference in diagnostic criteria related to nomenclature and provide recommendations for selection criteria to be used in future research.

3.1.2 Methods

A systematic review of the literature reporting work on PTTD and AAFD was undertaken to test the hypothesis that there would be overlapping terminology for selection criteria used by investigators in PTTD and AAFD literature.

Search strategy

Electronic databases (CINAHL, Cochrane, Embase, PubMed and Web of Science) were comprehensively searched by one reviewer (MR) for all years available up to and including June 13 2016. The search strategy was developed in consultation with an experienced academic librarian and was undertaken using a combination of keywords and MeSH terms. Keywords used in the search strategy aimed to capture all past and present variations in terminology for the condition: Flatfoot OR (posterior AND tibia* AND (tendon* OR tendin*)) OR “pes planus” OR “pes planovalgus”. No restrictions or second string limitations were used to further narrow the search. All search results were imported in Endnote X7 (Thompson Reuters, Philadelphia, PA, USA) and duplicates were removed. This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and it was registered at http://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42016046943.

Selection criteria

Articles were included if they investigated PTTD or AAFD and clearly defined diagnostic or inclusion criteria. Articles were excluded if they did not investigate PTTD or AAFD, and did not detail specific inclusion or diagnostic criteria (i.e. reported that diagnosis was only made by a specified health professional or was only based on a PTTD or AAFD classification system without detailing specific clinical signs or symptoms). Asymptomatic flatfoot conditions were not considered for this review. Non-English publications, clinical reviews/narratives or single case reports, as well as paediatric, animal and cadaveric studies were also excluded. Assessment of study eligibility was performed by one investigator (MR) and uncertainties were resolved by two other reviewers (BV and MS).

Data extraction and synthesis

A custom data extraction table was developed. One reviewer (MR) extracted data from all included studies including condition (PTTD or AAFD), stage of condition (I – IV; based on classification systems) and individual inclusion or diagnostic criteria specified in the article. Studies included in this review staged the condition using the Johnson & Strom, [51] Myerson [48] and Bluman [133] classification systems. The Johnson & Strom and Myerson classification systems are the same and hence forth referred to as the former. It consists of 4 progressive stages [48 51] defined as follows: I) tenosynovitis and mild to moderate pain and tenderness of the tibialis posterior tendon, with no signs of foot deformity; II) degeneration and elongation of the tendon and flexible hindfoot eversion with forefoot abduction; III) rigid hindfoot eversion with forefoot abduction; IV) the same as III) with valgus angulation of the talus and degeneration of the tibiotalar joint. [48] The classification system defined by Bluman maintains the existing outline of Johnson & Strom, except each stage is divided into sub-categories, which include reference to radiographic findings and more refined delineation of presenting signs and symptoms. [133] For example, Bluman's Stage IIB refers to talonavicular uncovering on radiographs, as well as flexible hindfoot eversion with forefoot abduction. [133] In this review the specific classification system used in each paper is indicated by the format used (i.e IIB indicates Bluman classification system was used, whereas II indicates Johnson & Strom was used).

All criteria presented in individual papers were initially recorded using the exact terminology from the study (**Table 3-1**) and then reduced to key terms for reporting (e.g., hindfoot valgus was used as a key term to represent heel valgus, calcaneal valgus, hindfoot eversion). These key terms formed the aggregate list of diagnostic/inclusion criteria against which all included studies were scored.

We sought to represent criteria used in each paper by categorising them as either being compulsory (mandatory signs or symptoms required for diagnosis or inclusion) or optional (one of a number of possible signs or symptoms required for diagnosis or inclusion). When signs and symptoms were listed with the conjunction "and", all criteria were considered to be compulsory. Where criteria were listed with "or" as the conjunction, or "at least one of" preceding the criteria, each criteria was considered to be optional, but the group of optional criteria (with 'or' 'at least one of' operand) was considered as one compulsory criterion. The total number of criteria for each description of diagnostic/inclusion criteria was the total number of compulsory (single or grouped optional) criteria.

Table 3-1 *Classification table collapsed terms*

Headings	Terms used in study inclusion and diagnostic criteria
Pain along PTT	Pain over the tendon
Pain medial ankle/foot	Posteromedial ankle pain, medial hindfoot pain, pain on medial aspect of arch of the foot, medial ankle pain
Tender on palpation PTT	Palpable tenderness, tenderness over the tendon, pain on palpation of the TP tendon, tenderness along TP tendon, tenderness to palpation, pain reproduced on palpation of the TP tendon
Pain with resisted inversion	-
Pain with SLHR	Pain with unilateral heel rise, pain when rising onto toes while weightbearing
Swelling along PTT	Localized oedema, swelling over the tendon, local swelling, swelling along the course of TP tendon, swelling over tendon sheath, enlargement over the TP tendon
Swelling medial ankle/foot	Medial hindfoot swelling, swelling posteromedial aspect of ankle, swelling on medial aspect of arch of the foot, enlargement of the medial retromalleolar region
Inversion strength deficit	Weakened inversion force, weakness of TP, positive resistance test results, reduced or absent power of inversion, clinical strength deficit when tested with the foot in inversion and plantar flexion, weak strength upon supination on manual testing, inability to bring the foot across the midline from an abducted position, diminished TP power
Difficulty with SLHR	Inability to perform SLHR, lack of active hindfoot inversion during SLHR, inability to do single-limb toe raises, difficulty lifting one foot

Decreased walking ability	Difficulty ambulating, decreased ability to walk any distance, reduced walking distance
Flatfoot deformity	Acquired flatfoot deformity, planovalgus deformity, pes planovalgus
Hindfoot valgus	Heel valgus, rearfoot abduction, calcaneal valgus, hindfoot eversion, valgus angulation of the heel
Medial arch collapse	Flattening of medial longitudinal arch, midfoot collapse, loss of height in the arch, loss of longitudinal arch, loss in medial arch contour, arch collapse, flattened midfoot posture, fallen medial longitudinal arch
Forefoot abduction	Too many toes sign, varus forefoot, first metatarsal abduction, lateral deviation of the forefoot
Midfoot abduction	Abduction at the transverse tarsal joint, abducted midfoot posture
Forefoot supination	-
Flexible deformity	Passively correctable deformity, flatfoot deformity with a mobile hindfoot, hindfoot valgus passively correctable, flexible pes planovalgus, manually correctable valgus deformity, non-fixed hindfoot valgus deformity, supple deformity, absence of rigid foot deformity, mobile mid- and hind-foot
Talar head prominence	-

3.1.3 Results

The electronic database search yielded a total of 13 526 records. **Figure 3-1** outlines studies excluded at each stage of the selection process. After screening of title and abstract of all retrieved articles, 354 full text articles investigating either PTTD or AAFD were examined for final inclusion. Following this final full text screening, 80 articles met all inclusion criteria and were included in the review. Diagnostic or inclusion criteria for PTTD or AAFD were specified 82 times in 80 papers (**Table 3-2**). One article (Kohls-Gatzoulis, 2009) detailed diagnostic criteria for stage I PTTD, stage II PTTD and AAFD. Sixty-nine of the 82 definitions in the articles were for PTTD and the remaining 13 defined AAFD.

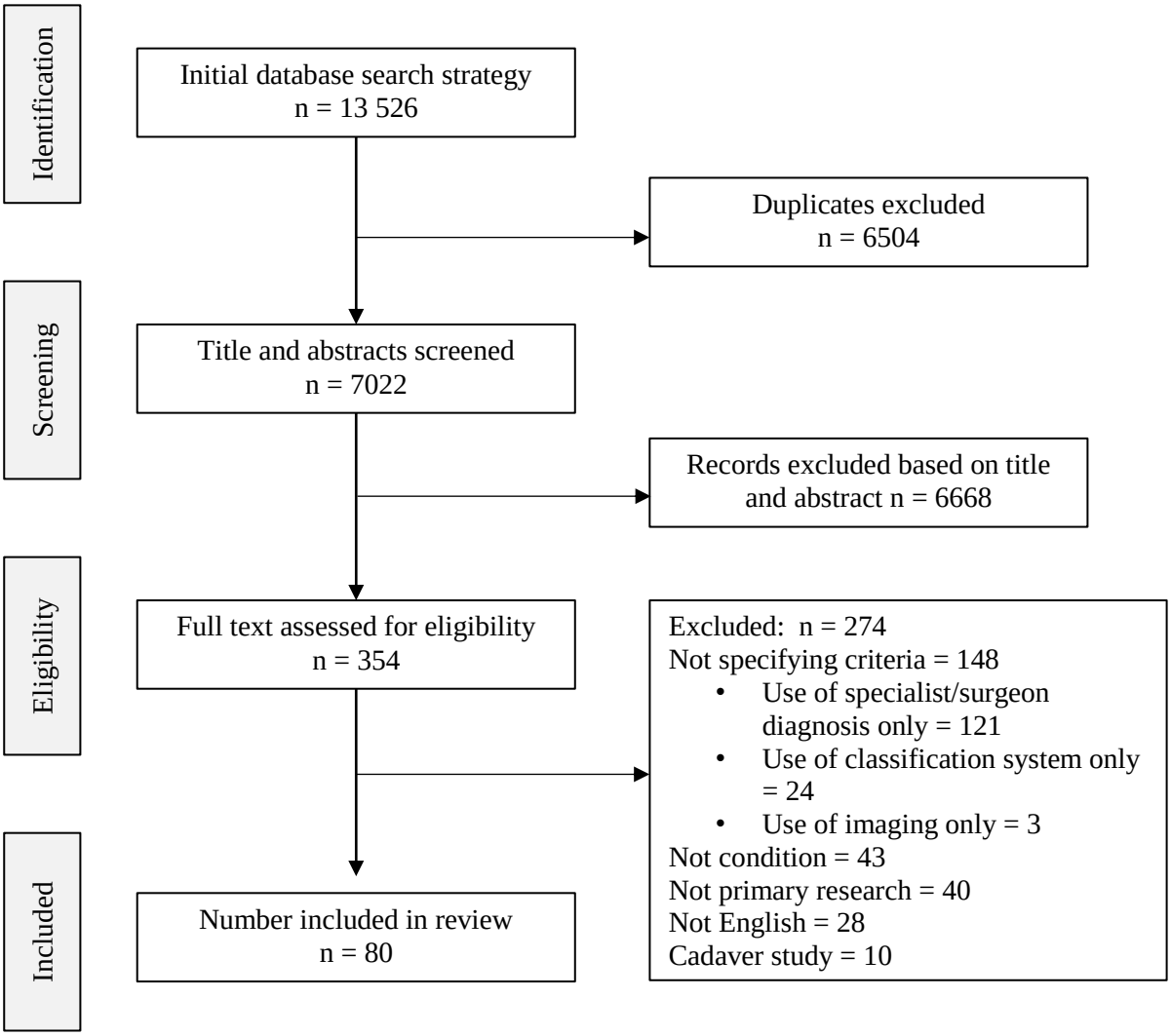
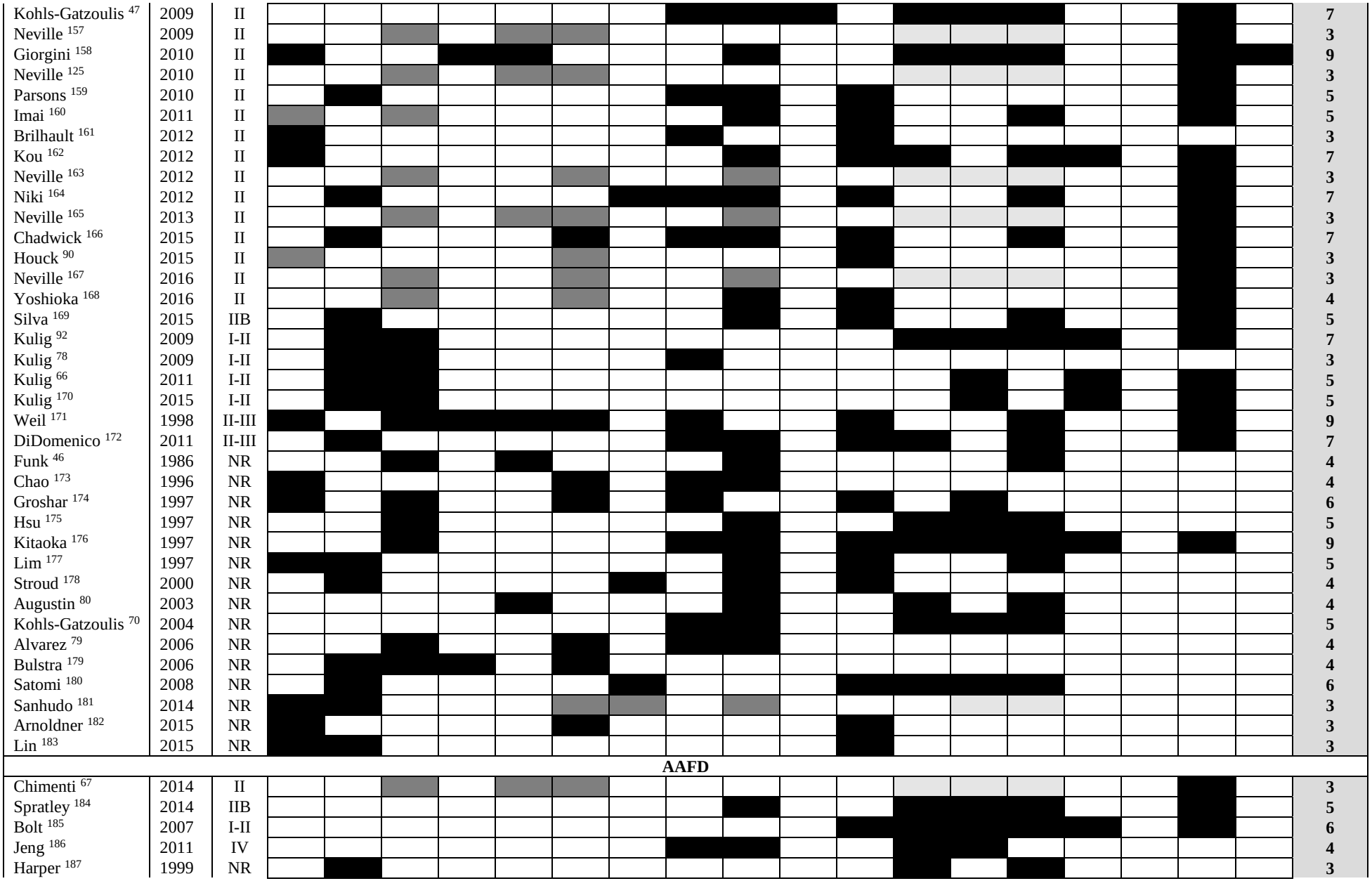


Figure 3-1 *Flow chart of study selection process*

Table 3-2 *Selection criteria for posterior tibial tendon dysfunction (PTTD) and adult acquired flatfoot deformity (AAFD) for included studies.*

Author	Year	Stage	Related to tendon dysfunction										Related to structural deformity								No. of criteria
			Pain PTT	Pain medial ankle/ foot	TOP PTT	Pain res. INV	Pain with SLHR	Swelling PTT	Swelling medial ankle/ foot	INV strength deficit	Difficulty with SLHR	Dec. walking ability	FF def.	HF valgus	Medial arch collapse	FF ABD	MF ABD	FF SUP	Flex. def.	Talar head prominence	
PTTD																					
Teasdall [77]	1994	I		■	■						■										**3**
Crates [53]	1999	I			■			■								■					**3**
Perry [134]	2003	I			■	■	■												■		**4**
Sharma [54]	2003	I		■					■		■										**3**
Rosenfeld [135]	2005	I			■					■			■			■			■		**5**
Cooper [136]	2007	I	■					■													**2**
Kohls-Gatzoulis [47]	2009	I	▒			■		▒		■	■										**4**
Rabbito [126]	2011	I		■	■				■												**3**
Chow [137]	2015	I	■					■		■	■										**4**
Hua [138]	2015	I		■	■	■				■											**4**
Chen [139]	1997	II		■		■			■												**4**
Hintermann [140]	1999	II		■						■	■		■	■	■	■	■		■		**9**
Toolan [141]	1999	II		■						■				■		■			■		**5**
Conti [60]	2002	II		■						■	■	■	■	■	■	■			■		**9**
Fayazi [142]	2002	II		■						■		■	■	■	■	■			■		**8**
Wacker [143]	2002	II		■					■	■	■		■			■			■		**7**
Viladot [144]	2003	II		■							■		■			■			■		**5**
Wacker [145]	2003	II		■					■	■	■		■			■			■		**7**
Brodsky [146]	2004	II	■		■			■		■	■										**5**
Myerson [147]	2004	II	■		■					■	■			■		■	■		■		**8**
Valderrabano [148]	2004	II		■						■	■	■	■	■	■	■			■		**9**
Needleman [149]	2006	II								■			■						■		**3**
Tome [127]	2006	II			▒		▒	▒						▒		▒			■		**3**
Knupp [150]	2007	II		■						■	■	■		■				■	■		**7**
Migues [151]	2007	II	■		■						■			■		■	■	■	■		**8**
Neville [68]	2007	II			▒			▒			▒			▒	▒	▒			■		**3**
Houck [152]	2008	II		▒					▒					▒	▒	▒			■		**3**
Krause [153]	2008	II	■			■					■		■			■			■		**6**
Wukich [154]	2008	II									■		■								**2**
Brodsky [155]	2009	II								■				■					■		**3**
Houck [124]	2009a	II			▒		▒	▒						▒	▒	▒			■		**3**
Houck [156]	2009b	II			▒		▒	▒						▒		▒			■		**3**


Kohls-Gatzoulis [47] 2009 II 7
Neville [157] 2009 II 3
Giorgini [158] 2010 II 9
Neville [125] 2010 II 3
Parsons [159] 2010 II 5
Imai [160] 2011 II 5
Brilhault [161] 2012 II 3
Kou [162] 2012 II 7
Neville [163] 2012 II 3
Niki [164] 2012 II 7
Neville [165] 2013 II 3
Chadwick [166] 2015 II 7
Houck [90] 2015 II 3
Neville [167] 2016 II 3
Yoshioka [168] 2016 II 4
Silva [169] 2015 IIB 5
Kulig [92] 2009 I-II 7
Kulig [78] 2009 I-II 3
Kulig [66] 2011 I-II 5
Kulig [170] 2015 I-II 5
Weil [171] 1998 II-III 9
DiDomenico [172] 2011 II-III 7
Funk [46] 1986 NR 4
Chao [173] 1996 NR 4
Groshar [174] 1997 NR 6
Hsu [175] 1997 NR 5
Kitaoka [176] 1997 NR 9
Lim [177] 1997 NR 5
Stroud [178] 2000 NR 4
Augustin [80] 2003 NR 4
Kohls-Gatzoulis [70] 2004 NR 5
Alvarez [79] 2006 NR 4
Bulstra [179] 2006 NR 4
Satomi [180] 2008 NR 6
Sanhudo [181] 2014 NR 3
Arnoldner [182] 2015 NR 3
Lin [183] 2015 NR 3
AAFD
Chimenti [67] 2014 II 3
Spratley [184] 2014 IIB 5
Bolt [185] 2007 I-II 6
Jeng [186] 2011 IV 4
Harper [187] 1999 NR 3

Thomas [59]	2001	NR		■			■			■			■	■	■	■	■			■		**8**
Greisberg [188]	2003	NR		■									■									**2**
Kang [189]	2003	NR	■		■		■				■			■	■	■	■					**7**
Greisberg [190]	2005	NR		■									■									**2**
Arangio [191]	2006	NR									■			■	■	■	■		■			**5**
Arangio [192]	2006	NR													■	■	■					**2**
Arangio [193]	2009	NR		■							■			■	■	■	■		■			**6**
Kohls-Gatzoulis [47]	2009	NR												■	■	■	■					**3**

Legend: Black cells represent compulsory criteria and white cells represent not applicable to the individual article. Dark grey is a group of criteria relating to tendon dysfunction and light grey is a group of criteria relating to structural deformity where individual criteria in shaded boxes are optional and at least one from the group is compulsory.

Abbreviations: *PTT: posterior tibial tendon; TOP: tender on palpation; res.: resisted; INV: inversion; SLHR: single leg heel raise; dec.: decreased; FF: forefoot; def.: deformity; HF: hindfoot; ABD: abduction; MF: midfoot; SUP: supination; Flex: flexible; NR: not reported.*

Twenty-four articles (24/82; 29.3%) did not report which stage of the condition the paper investigated (9 AAFD, 13 PTTD). Two articles (2/58; 3.4%) used Bluman's classification system (1 AAFD, 1 PTTD) and the remaining 56 (56/58; 96.6%) used the Johnson and Strom classification. Of the 58 that did report stage of condition, 65.5% (38/58 articles) investigated stage II (1 AAFD, 37 PTTD). All articles investigating stage I dysfunction looked at PTTD (10/58; 17.2%). The remaining articles investigated stage I-II (5/58; 8.6%; 1 AAFD, 4 PTTD), IIB (2/58; 3.4%; 1 AAFD, 1 PTTD), II-III (2/58; 3.4%; 2 PTTD) and stage IV (1/58; 1.7%; 1 AAFD).

After collapsing variations in terminology (**Table 3-1**), a total of 18 criteria were extracted from the 80 individual papers. The criteria were separated into two main groups; those pertaining to tendon dysfunction (10 criteria) and those relating to structural deformity (8 criteria). Those relating to dysfunction of the tibialis posterior tendon were further categorised into symptoms of pain and swelling (7 criteria), and signs of deficits in strength or function (3 criteria). Pain was delineated based on location (i.e. along the posterior tibial tendon and/or medial ankle/foot) and provocating activity (i.e. tenderness on palpation, with resisted inversion and/or with single leg heel raise). Swelling was also separated into two categories based on location (i.e. along the posterior tibial tendon or the medial ankle/foot). The three criteria relating to strength or functional deficit were resisted inversion strength deficit, difficulty with single leg heel raise, and compromised walking ability. The eight criteria for foot posture and structural deformity were: flatfoot deformity, hindfoot valgus, medial arch collapse, forefoot abduction, midfoot abduction, forefoot supination, a flexible deformity, and talar head prominence.

Individual studies reported between 2 (5/82; 6.1%) and 9 (6/82; 7.32%) compulsory criteria for the diagnosis of PTTD or AAFD. The most frequently occurring number of compulsory criteria in any paper was 3 (25 articles; 30.49%), but specific criteria differed between articles.

The papers that referred to PTTD contained 69 diagnostic/inclusion criteria in 68 articles, with one paper (Kohls-Gatzoulis, 2009) describing criteria for both stage I and II PTTD separately (**Table 3-3**). Thirteen PTTD articles (18.8%) required symptoms of tendon dysfunction but not structural deformity; whereas, 56 articles (81.2%) required signs of both tendon dysfunction and structural deformity. Considering all listed signs and symptoms (n = 382), a flexible deformity (41; 10.7%), forefoot abduction (41; 10.7%) and difficulty with single leg heel raise (39; 10.2%) were the most frequently reported criteria (optional and compulsory) required for the diagnosis of PTTD.

Table 3-3 *Frequency of criteria for diagnosis of PTTD and AAFD based on tendon symptoms, structural deformity and a combination of both.*

	Tendon	Structure	Both	Total
AAFD	0	2	11	13
PTTD	13	0	56	69
Total	13	2	67	82

Thirteen papers describe diagnostic criteria for AAFD (**Table 3-3**). Eleven articles (84.6%) required both signs of tendon dysfunction and structural deformity. Two (15.4%) papers required only signs of structural deformity, with no mention of tendon dysfunction. Considering all signs and symptoms (n = 60), forefoot abduction (10; 16.7%), medial arch collapse (10; 16.7%) and hindfoot valgus (10; 16.7%) were most frequently reported criteria for the diagnosis of AAFD.

Considering all criteria for both PTTD and AAFD combined (n = 442), the most commonly reported (optional and compulsory) were forefoot abduction (51; 11.5%), a flexible deformity (45; 10.2%) and difficulty performing a single leg heel raise (44; 10.0%).

Considering signs and symptoms listed in articles investigating stage I PTTD (n = 36), the most frequently reported (optional and compulsory) criteria were tenderness on palpation of the posterior tibial tendon (6; 16.7%) followed equally by pain in the medial foot/ankle, swelling along the posterior tibial tendon, inversion strength deficit, and difficulty performing a single leg heel raise (4; 11.1%). There were no articles reporting grade 1 AAFD.

The most commonly reported criteria (n = 237) for stage II (including IIB) PTTD were the presence of a flexible deformity (33; 13.9%), forefoot abduction (28; 11.8%) and difficulty with single leg heel raise (43; 10.1%). There were 2 papers investigating stage II AAFD (including 2B) and the most frequently reported criteria were the presence of a flexible deformity, forefoot abduction, medial arch collapse and hindfoot valgus.

Consistent with data from when all PTTD studies were combined, when criteria (n = 293) for the early stages of PTTD were combined (stage I, II, I-II and IIB) the most frequently reported criteria were the presence of a flexible deformity (38; 13.0%), forefoot abduction (31; 10.6%) and difficulty with a single leg heel raise (28; 9.6%). When articles investigating the early stages of AAFD were combined, the most frequently reported criteria (n = 18) were the presence of a flexible deformity (3; 16.7%), forefoot abduction (3; 16.7%), medial arch collapse (3; 16.7%) and hindfoot valgus (3; 16.7%).

There were 2 articles describing stage II-III PTTD. Pain (either along the tendon, medial foot or with inversion or single leg heel raise), difficulty with resisted inversion, forefoot abduction and a flexible flatfoot deformity were reported in both studies. One article described diagnostic criteria for stage IV AAFD, which included difficulty with resisted inversion and single leg heel raise, hindfoot valgus and decreased medial longitudinal arch.

3.1.4 Discussion

It is apparent from this systematic synthesis of available literature that there is significant overlap in the key signs and symptoms used to include PTTD and AAFD in research studies. While the hypothesis was to identify selection criteria, a major finding was that within the body of PTTD and AAFD literature, over half did not report how the condition was diagnosed. Of 228 primary research articles, 148 (65%) did not specify the specific criteria used to diagnose the condition or determine inclusion into the study (**Figure 3-1**). These studies frequently reported that the condition was diagnosed by the clinician or based on a classification system, without stating the impairments (signs and symptoms) that led to the diagnosis. Specifying impairments that confirmed diagnosis and led to inclusion in the study would improve consistency between studies and better enable comparisons. In order to appropriately apply evidence based practice in the clinic it is important to closely align or match patients with those reported in the literature. To accomplish this, it is essential that inclusion/diagnostic criteria are firstly reported in all studies and secondly consistent between studies. Of the articles investigating PTTD and AAFD that did report eligibility criteria, 67 (81%) included signs and symptoms relating to both tendon dysfunction and structural deformity. The exception to this was articles investigating early stage I PTTD where tendon signs (pain, swelling, weakness) were most prevalent (indicative of TPT). Although terminology for a tendon related condition was used (PTTD); the presence of signs and symptoms indicating an acquired flatfoot deformity were still required for a positive diagnosis and study inclusion for stage II and above PTTD. Similarly, articles using the terminology AAFD for the condition included signs and symptoms relating to dysfunction of the posterior tibial tendon (i.e., TPT), not just the acquired flatfoot deformity. This suggests, despite differing nomenclature, these articles are investigating the same condition, which is characterised by dysfunction of the tibialis posterior tendon and an acquired flatfoot deformity.

When data for PTTD and AAFD were combined, the overarching diagnostic criteria were difficulty performing a single leg heel raise, the presence of a flexible deformity and forefoot abduction. This is consistent with early descriptions of PTTD and classification systems; in which the ‘too many toes’ sign (forefoot abduction), a flexible flatfoot deformity and difficulty inverting the calcaneus

while rising onto the toes were reported as indicative of dysfunction of the tibialis posterior tendon. [46 51]

Presenting signs and symptoms understandably vary with the stage of the condition. The majority of articles reported in this review pertain to stage I and or II PTTD (i.e., TPT) and, consistent with the progressive nature of tendon dysfunction, there were clear differences between these stages. In stage I PTTD tenderness on palpation, pain and swelling around the tendon played a key role in diagnosis. These were not the most common diagnostic criteria for stage II PTTD. Tendon involvement was evidenced by impaired function (i.e. difficulty with single leg heel raise) rather than pain or inflammation, and diagnosis of this stage included signs of deformity (**Figure 3-2**). This suggests that in stage I the tendon is reactive, [107] whereas in stage II it has progressed to a dysfunctional state where it is no longer able to invert the calcaneus and support the medial longitudinal arch.

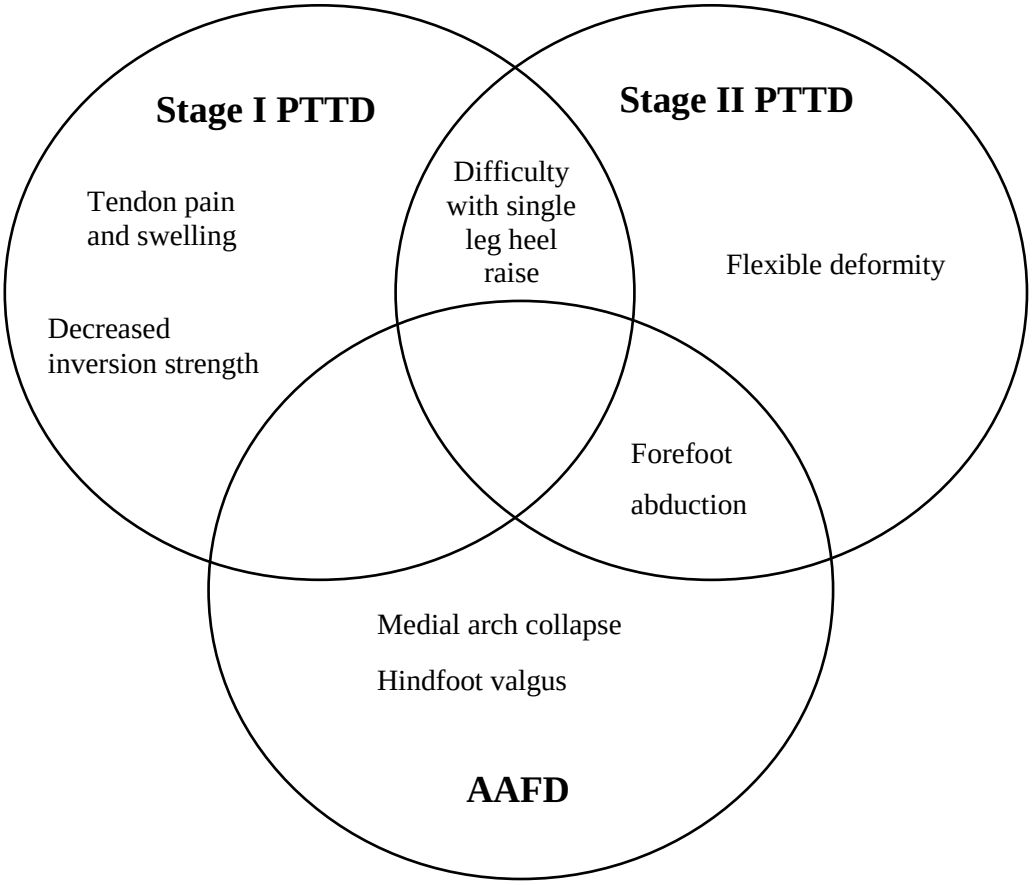


Figure 3-2 *Diagrammatic summary. Similarities and differences in selection criteria for Stage I and II PTTD and AAFD.*

There were commonalities in the criteria used to diagnose stage II PTTD and stage II AAFD. A flexible deformity and forefoot abduction were required for both diagnoses. Consistent with the

nomenclature, tendon related symptoms (e.g. difficulty with single leg heel raise) were also required for the diagnosis of PTTD, whereas additional symptoms of structural deformity (e.g. hindfoot valgus and medial arch collapse) were required for the diagnosis of AAFD. An important consideration is that in the early stages (I-II) of both PTTD and AAFD, flexibility of the deformity is a key sign.

There were substantially less articles detailing diagnostic criteria for the later stages of PTTD and AAFD. Two articles described criteria for stage II-III PTTD. It is interesting that stage II and III were combined in these papers, as original classification systems have a clear delineation between stage II and III; being that the flatfoot deformity is flexible in stage II and rigid in stage III. [51] Both papers listed the presence of a flexible deformity as a key criteria, which suggests stage II was the condition being studied. [171 172] The remaining criteria for these papers were also consistent with the most commonly reported signs for stage II PTTD. The criteria in the one paper investigating stage IV AAFD suggest that pain and inflammation are no longer key (or present) and the structural deformity and lasting functional deficits (e.g. difficulty with inversion and single leg heel raise) is emphasised. Two key issues have become apparent on review of the literature that did identify selection/inclusion criteria for PTTD and/or AAFD. First, PTTD and AAFD are being used interchangeably to describe the same condition. Where there are clear signs of a dysfunctional tendon (pain, swelling, weakness), we suggest the condition be referred to as PTTD. To negate the confusion surrounding early stages of the condition in which a flatfoot deformity is not present, we suggest that PTTD is the preferred terminology for the condition. The acquired flatfoot deformity may be a sign that develops in the later stages of the condition. This aligns with the literature that considers PTTD to be only one of several potential causes of AAFD. [40 132 194]

Second, research studies use inconsistent inclusion criteria for participants with PTTD and AAFD. Based on data from studies included in this review, we recommended the following signs pertaining to tendon dysfunction form the inclusion criteria for studies investigating stage I PTTD (i.e., TPT): pain along the tendon, swelling and weakness with inversion and/or single leg heel raise. Suggested inclusion criteria for stage II include difficulty with single leg heel raise and a flexible flatfoot deformity; characterised by forefoot abduction, a lowered medial longitudinal arch and/or hindfoot eversion. Recommendations for stage III and IV are unable to be made as few studies investigated the later stages of the condition.

As PTTD is only one potential cause of AAFD, it is important to differentiate AAFD that is predominantly related to PTTD from other causes. An adult acquired flatfoot due to rheumatoid arthritis may not present with the same impairments (pain, function and/or disability) as those with an adult acquired flatfoot due to PTTD, nor will they likely respond in the same manner to

conservation or surgical intervention. It is important to clearly characterise the key signs and symptoms of PTTD in isolation from other causes of AAFD in order to best guide effective treatment protocols. To avoid potential misunderstanding, it stands to reason that when AAFD is used in the literature as an umbrella term for acquired flatfoot deformities, the underlying aetiology of the AAFD should be reported. As there are considerable differences in the diagnostic criteria used in each stage of PTTD and AAFD, it is also important that the stage of the condition be indicated.

There are some limitations that need to be considered for this review. First, due to resource implications, after the search strategy was developed, a single reviewer independently searched the literature and assessed eligibility. Secondly, a hand search was not employed due to the broad search terms used and the large number of references retrieved. Thirdly, we might have excluded some studies that only stated they used a classification system and did not list the specific selection criteria. We felt justified in doing this to avoiding ambiguity in matching our extracted data and that which was specifically reported in those papers.

3.1.5 Conclusion

In conclusion, it is recommended that TPT is the preferred terminology for the condition of a painful, dysfunctional tibialis posterior tendon, even in the later stages where an acquired flatfoot deformity has developed. This will remove ambiguity regarding other potential causes for AAFD. There is a need for more consistent and uniform reporting of inclusion/selection criteria for studies investigating TPT. This chapter has outlined suggested eligibility criteria for TPT (i.e. stages I and II PTTD that can be used in future research and will enhance the applicability of evidence based practice in the clinic.

CHAPTER 4 Review of clinical impairments

4.1 Self-reported social and activity restrictions accompany local postural and strength impairments in tibialis posterior tendinopathy: a systematic review [195]

*Chapter two recommended that clinicians are guided by presenting impairments to manage TPT conservatively. In order to inform these approaches and develop targeted intervention strategies, it is important to identify clinical features which are characteristic of TPT. This chapter is adapted from a systematic review of the literature to identify clinical impairments, pain and disability in TPT compared to controls (**Appendix 4**). Where possible, meta-analyses were used to calculate pooled standardised differences between those with TPT and those without. Primary findings include significant effects for altered foot posture and reductions in local strength. Data also revealed that individuals with TPT demonstrate reduced global functioning and more pain, functional difficulties and activity limitations compared to controls.*

Ross MH, Smith M, Plinsinga ML, Vicenzino B. Self-reported social and activity restrictions accompany local impairments in posterior tibial tendon dysfunction: a systematic review. *Journal of Foot and Ankle Research*. 2018;11(1):49.

Contributor	Statement of contribution
Megan H Ross (Candidate)	Conception and design (60%) Analysis and interpretation (55%) Drafting and production (50%)
Dr Michelle D Smith	Conception and design (20%) Analysis and interpretation (15%) Drafting and production (25%)
Melanie L Plinsinga	Analysis and interpretation (15%)
Professor Bill Vicenzino	Conception and design (20%) Analysis and interpretation (15%) Drafting and production (25%)

4.1.1 Introduction

Diagnosis of TPT is most commonly made clinically, based on patient history (e.g., area of pain) and physical examination. [44] Chapter two highlights key features of the physical examination for TPT; swelling, pain on palpation, and/or pain with loading of the TP tendon (e.g., resisted plantar flexion inversion and heel raises) that may be accompanied by a flatfoot deformity. [48 51 133] Historically, and as mentioned in chapter two, TPT has been considered as the 'early stage' of PTTD/AAFD (i.e. stage I and II), when tendon signs and symptoms are the predominant features.

Non-operative management is usually advocated for TPT, and typically focuses on musculotendinous conditioning exercises and arch supporting devices (e.g., in-shoe foot orthoses, braces). [79 80 90] There is a lack of high quality evidence for these treatments, which relegates physical therapy treatment decisions to one that targets presenting impairments and are based largely on the clinical reasoning skills of the clinician.

The objective of this study was to systematically review the literature on clinical impairments of TPT. The main research question for this systematic review was: Do individuals with TPT have quantifiable differences in clinical impairments, pain and disability compared to controls? The second research question was: What is the relative magnitude of deficits in muscle function, foot posture and motion, pain and disability?

4.1.2 Methods

The systematic review protocol was developed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement[82] and registered online at http://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42016046951. Literature search criteria and methods were specified and agreed on in advance to minimise selection bias.

Identification and selection of studies

An electronic database search was conducted across CINAHL, Cochrane, Embase, PubMed and Web of Science from database inception up to and including 13 June 2016, limited to the English language. The search strategy was broad to capture all relevant papers pertaining to past and present variations in terminology for the condition: Flatfoot OR (posterior AND tibia* AND (tendon* OR tendin*)) OR "pes planus" OR "pes planovalgus". The terms flatfoot, pes planus and pes planovalgus were included only to capture articles using varying terminology to describe TPT; other causes of AAFD and asymptomatic flatfoot were not included in this review. Due to limited literature available on the condition, a 'participant' (condition) only search was performed where articles were manually excluded based on intervention, comparator and outcome specifications.

Two independent reviewers (MR and MP) performed the search separately and results were imported into Endnote X7 (Thompson Reuters, Carlsbad, California, USA) where duplicates were removed. Titles and abstracts were screened for relevance by two reviewers (MR and MP), with disagreements resolved by consensus with reference to a third reviewer (BV). Full text versions of remaining articles were obtained and screened against final eligibility criteria by two reviewers (MR and MP).

Studies were eligible for inclusion if they were published in the English language and contained data on clinical impairments, pain or disability compared between participants diagnosed with TPT (or AAFD related to tendon dysfunction) and pain-free individuals (**Table 4-1**). Studies including participants who had undergone a specific intervention were included only if baseline or pre-intervention data was reported and compared to control participants without the condition. Any post-intervention data was not included.

Table 4-1 *Inclusion criteria*

- Peer reviewed papers in the English language
- Adult participants with TPT or AAFD related to PTTD
- Baseline measures of clinical impairments, pain and/or disability
- Data compared to healthy control participants

Studies were excluded if there was no comparison group or clinical measures of pain, function or disability; the study was published in a language other than English or the full text was not available. Review articles, single case reports, paediatric, cadaver and animal studies were excluded. Studies including participants with other conditions such as osteoarthritis or rheumatoid arthritis that did not include separate data for individuals with TPT or AAFD were also excluded.

Assessment of characteristics of studies

Quality: Methodological quality of included articles was evaluated using the Epidemiological Appraisal Instrument (EAI), which has been shown to be a valid and reliable tool for the assessment of observational studies. [196] Twenty-one items from the original EAI were used following removal of items that were not applicable to cross sectional and case control study designs. Removed items specifically related to interventions, randomization, follow-up period and environmental factors. Detailed criteria for each response were clarified a-priori to match the purpose of this review.

Two independent assessors (MR and MP) rated all included articles. Where a consensus was not able to be reached, disagreements were resolved by a third investigator (BV). Each item was scored as either “Yes” (score = 1), “Partial” (score = 0.5), “No” (score = 0), “Unable to determine” (score

= 0) or "Not Applicable" (item removed from scoring) and an overall score was derived as an average score across all applicable items (range = 0 to 1).

Outcome measures: Where available, the following information was extracted from all eligible studies: study design, recruitment source, inclusion/exclusion criteria, sample size, stage of TPT, [48] population characteristics and comparison group characteristics. Quantitative data relating to outcome measures for physical impairment, pain and disability, specifically mean SD for continuous outcomes, were extracted to enable calculation of effect size. Data extraction was performed by two independent reviewers (MR and MP) and recorded in a pre-determined spreadsheet. Corresponding authors were contacted for additional information when reported data was insufficient for analyses. A third reviewer (MS) verified data extraction prior to analysis.

Data analysis

Reliability of the methodological quality assessment was calculated in Stata v13 (College Station, TX: StataCorp LP). The κ statistic (95% CI) was used to report the inter-rater reliability of the quality ratings between the two assessors. The κ statistic was interpreted as <0.00 poor agreement; 0.00 – 0.20 slight agreement, 0.21 – 0.40 fair agreement, 0.41 – 0.60 moderate agreement, 0.61 – 0.80 substantial agreement and 0.81 to 1.00 almost perfect agreement. [89]

Standardized mean differences and 95% CIs were calculated for continuous variables in Review Manager (RevMan) V5.3 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration) using random effects models. SMDs were calculated as the difference between TPT and control group means, divided by the pooled SD. [197] Where 95% CIs did not contain zero, the difference between groups was considered statistically significant. For each outcome measure, a positive SMD reflected greater values in the TPT population and a negative SMD reflected greater values in the control population. Effect sizes were interpreted based on Hopkins, as follows; < 0.2 trivial effect, 0.2 - 0.6 small effect, 0.61 – 1.2 medium effect > 1.2 large effect. [88]

Meta-analysis was performed where similar methodology and outcome measures (study homogeneity) allowed pooling of data. Chi-squared tests ($P<0.1$) and the I^2 statistic were used to quantify study heterogeneity for pooled SMDs with ≥0.75 considered substantial heterogeneity. [198] A summary of main findings and study conclusions were presented where data was not available to calculate SMD.

4.1.3 Results

Flow of studies through the review

The search strategy identified a total of 13 526 articles of which 6504 were removed as duplicates (**Figure 4-1**). The remaining 7022 articles were screened by title and abstract and 67 potentially eligible articles were identified. Full text screening of the 67 articles excluded 57 articles which did not meet the inclusion criteria (**Figure 4-1**). The 10 remaining articles underwent methodological quality assessment and data extraction. Four authors were contacted for additional data for five papers. Data from two studies was made available [68 125] but not from others [66 67 152] with reasons being that the data was not collected or not available. Papers that reported on the same population sample were only included once in the analysis. One author was contacted to clarify that two papers [125 165] reported data from the same sample, and as no additional (unique) data was provided, the second paper was excluded. [165]

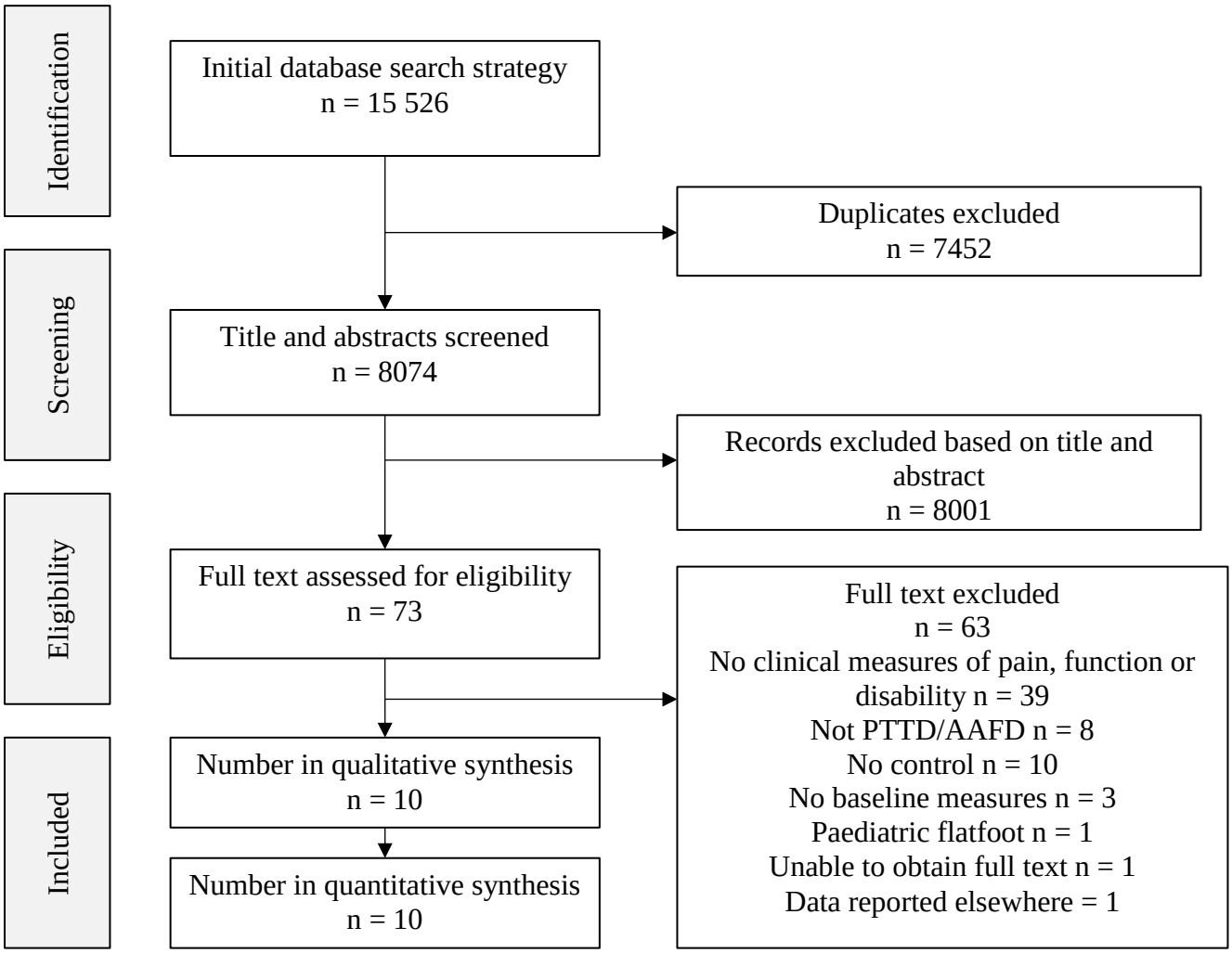


Figure 4-1 *Flow of studies through the review*

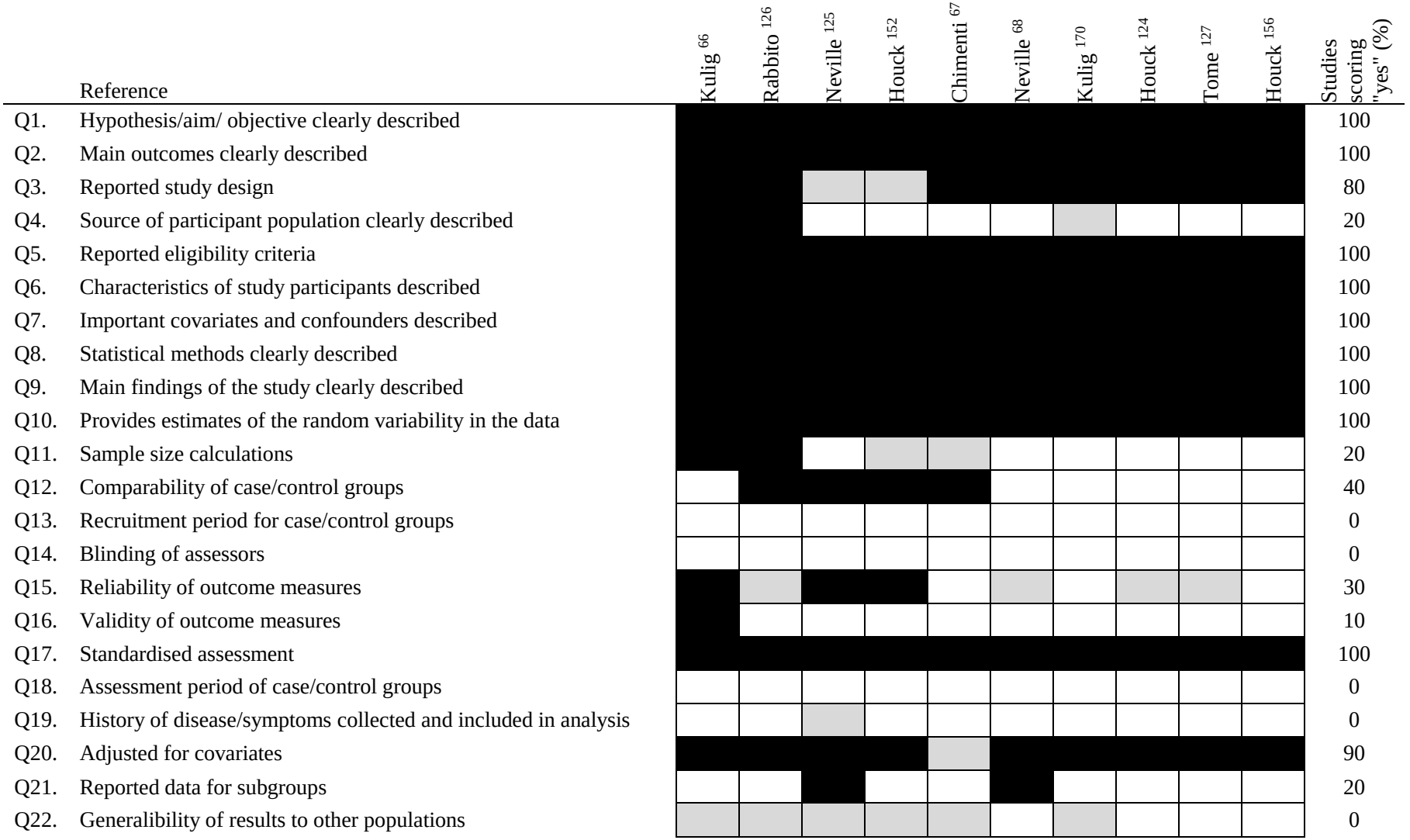
Characteristics of studies

Quality: Overall agreement on methodological quality of included studies was almost perfect (absolute agreement = 98.64%, κ = 0.97, 95% CI 0.85 to 1). Agreement was reached on 215 out of 220 EAI items in total. Consensus was obtained on the quality rating of the 5 remaining items. Overall EAI scores ranged from 0.5 to 0.682 out of a possible score of 1 (Table 1). The methodological quality assessment revealed that only 2 studies (20%) adequately reported the source of the participant population, 20% performed sample size calculations and 40% had a control group adequately comparable to the case group. The reliability and validity of outcome measures were reported by 30% and 10% of studies respectively. One study collected data on duration of symptoms yet no studies (0%) accounted for history of symptoms in analyses. Generalizability of results to other populations was low (0%); 6 studies reported samples of convenience and the remaining 4 studies reported data for participants seeking treatment for their condition (referral from clinics).

Participants: The 10 included studies contained a total of 213 participants with TPT compared to 144 healthy controls. Sample sizes ranged from 12 [126] to 30 [124 125 156] TPT participants (**Table 4-2**) and 10 [68 127] to 20 [170] controls. Mean (SD) age of TPT patients ranged from 30.3 (7.9) [126] to 61 (10) [152] years and the proportion of females ranged from 63.3% [125] to 100%. [66 170]

Table 4-3 has details of the 'stage' (as reported in studies) and criteria by which participants with TPT were selected. In brief, one study investigated stage I TPT, [126] 2 studies investigated stage I-II TPT [66 170] and the remaining 7 studies investigated stage II TPT only. [67 68 124 125 127 152 156] The method of diagnosis was by clinical assessment in all studies with 9 out of 10 studies requiring both signs of tendon pathology and flexible flatfoot deformity for a positive diagnosis. The one study investigating stage I TPT [126] required only signs of tendon pathology including mild swelling and/or tenderness posterior to the medial malleolus that had been present for at least 3 weeks and aggravated by recreational activity.

Table 4-2 *Results from quality assessment of all included papers (n = 10) on the EAI*



	Reference	Kulig [66]	Rabbito [126]	Neville [125]	Houck [152]	Chimenti [67]	Neville [68]	Kulig [170]	Houck [124]	Tome [127]	Houck [156]	Studies scoring "yes" (%)
Q1.	Hypothesis/aim/ objective clearly described											100
Q2.	Main outcomes clearly described											100
Q3.	Reported study design											80
Q4.	Source of participant population clearly described											20
Q5.	Reported eligibility criteria											100
Q6.	Characteristics of study participants described											100
Q7.	Important covariates and confounders described											100
Q8.	Statistical methods clearly described											100
Q9.	Main findings of the study clearly described											100
Q10.	Provides estimates of the random variability in the data											100
Q11.	Sample size calculations											20
Q12.	Comparability of case/control groups											40
Q13.	Recruitment period for case/control groups											0
Q14.	Blinding of assessors											0
Q15.	Reliability of outcome measures											30
Q16.	Validity of outcome measures											10
Q17.	Standardised assessment											100
Q18.	Assessment period of case/control groups											0
Q19.	History of disease/symptoms collected and included in analysis											0
Q20.	Adjusted for covariates											90
Q21.	Reported data for subgroups											20
Q22.	Generalibility of results to other populations											0
	Overall quality score (range 0 to 1)	0.70	0.68	0.66	0.61	0.57	0.57	0.55	0.52	0.52	0.50	0.59

Black shading = "yes" (1), Grey shading = "Partial" (0.5), White (no shading) = "No" or "Unable to determine", NA = "not applicable"

Table 4-3 *Study design, TPT diagnosis, clinical impairments and participant characteristics (mean (SD) or count (percentage))*

Study ID	Study design	Diagnosis	Selection criteria for TPT	Clinical Impairments	TPT				Control			
					n	Female (%)	Age years	BMI kg/m	n	Female (%)	Age years	BMI kg/m
Chimenti[67]	Cross-sectional laboratory	Stage II AAFD	1 or more signs of tendinopathy (tenderness, swelling or pain with unilateral heel raise) and 1 or more signs of flexible flatfoot deformity (excessive non-fixed hindfoot eversion, excessive first metatarsal abduction or loss of medial longitudinal arch height)	Function & strength, Foot posture, PROM	20	14 (70)	57 (11.3)	30 (5.2)	15	11 (73)	56 (5.3)	26 (4.4)
Houck[124]	Cross-sectional laboratory	Unilateral stage II TPT	1 or more signs of tendinopathy (tenderness, swelling or pain with unilateral heel raise) and 1 or more signs of flexible flatfoot deformity (excessive non-fixed hindfoot eversion, excessive first metatarsal abduction or loss of medial longitudinal arch height)	Foot posture	30	22 (73)	59.3 (10.8)	29.6 (4.8)	15	14 (93)	56.5 (7.7)	30.5 (3.6)
Houck[156]	Cross-sectional laboratory	Unilateral stage II TPT	1 or more signs of tendinopathy (tenderness, swelling or pain with unilateral heel raise) and 1 or more signs of flexible flatfoot deformity (excessive non-fixed hindfoot eversion, excessive first metatarsal abduction or loss of medial longitudinal arch height)	Function & strength, Foot posture	30	21 (70)	59.8 (11.1)	29.9 (4.8)	15	14 (93)	56.5 (7.7)	30.6 (3.6)
Houck[152]	Case-control	Unilateral stage II TPT	Signs of tendon pathology (pain and/or swelling along medial ankle) and flexible flatfoot deformity (hindfoot eversion, forefoot abduction or loss of medial longitudinal arch height)	Function & strength, Foot posture	24	18 (75)	61 (10)	30 (5)	15	13 (87)	55 (8)	28 (5)
Kulig[66]	Cross-sectional laboratory	Unilateral early stage	Pain along medial ankle, tender on palpation posterior tibial tendon, lowered medial longitudinal arch,	Function & Strength,	17	17 (100)	52.1 (7.5)	29.5 (6.3)	17	17 (100)	50.7 (5.5)	26.9 (5.9)

		TPT (I or II)	abducted midfoot, absence of rigid foot deformity	Foot posture, PROM								
Kulig[170]	Case-control	Unilateral early stage TPT (I or II)	Pain along medial ankle, tender on palpation posterior tibial tendon, lowered medial longitudinal arch, abducted midfoot, absence of rigid foot deformity	Function & strength, Foot posture, Balance	19	19 (100)	54.6 (6.3)	28.9 (4.5)	20	20 (100)	50.8 (5.5)	26.9 (5.9)
Neville[125]	Cross-sectional	Unilateral stage II TPT	1 or more signs of tendinopathy (tenderness, swelling or pain with unilateral heel raise) and 1 or more signs of flexible flatfoot deformity (excessive non-fixed hindfoot eversion, excessive first metatarsal abduction or loss of medial longitudinal arch height)	Function & strength, ROM, Foot posture	30	19 (63)	58.1 (10.5)	30.6 (5.4)	15	14 (93)	56.5 (7.7)	30.6 (3.6)
Neville[68]	Case-control	Unilateral stage II TPT	1 or more signs of tendinopathy (tenderness, swelling or pain with unilateral heel raise) and 1 or more signs of flexible flatfoot deformity (excessive non-fixed hindfoot eversion, excessive first metatarsal abduction or loss of medial longitudinal arch height)	Foot posture, PROM	17	14 (82)	56.1 (11.6)	33.2 (7.4)	10	7 (70)	50.2 (6.8)	31.8 (3.8)
Rabbito[126]	Case-control	Stage I TPT	Mild swelling, tenderness, pain posterior to the medial malleolus, aggravated by recreational activity	ROM, Foot posture	12	9 (75)	30.3 (7.9)	23.2 (3.4)	12	9 (75)	28.5 (8.6)	23.7 (2.8)
Tome[127]	Case-control	Unilateral stage II TPT	1 or more signs of tendinopathy (tenderness, swelling or pain with unilateral heel raise) and 1 or more signs of flexible flatfoot deformity (excessive non-fixed hindfoot eversion, excessive first metatarsal abduction or loss of medial longitudinal arch height)	Foot posture	14	12 (85)	56.8 (11.7)	33.7 (7.4)	10	7 (70)	51.2 (7.3)	31.8 (3.6)

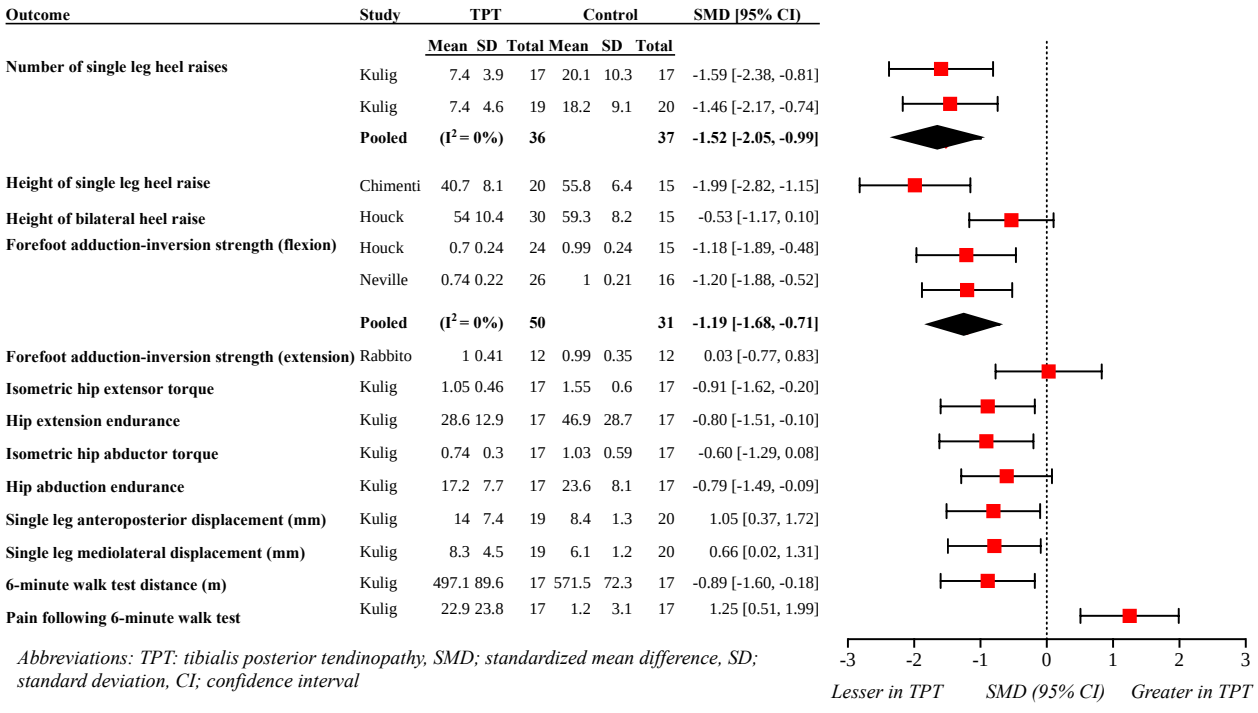
Abbreviations: AAFD; adult acquired flatfoot deformity, TPT; tibialis posterior tendinopathy, ROM; range of motion, PROM; patient reported outcome measure

Outcome measures: Outcome measures reported for clinical impairments included heel raise performance, [66 67 156 170] leg muscle strength, [125 152] ankle ROM, [125 126] hip muscle function, [66] foot posture, [66-68 124-127 152 156 170] single leg balance [170] and distance walked and pain experienced during the 6-minute walk test (6MWT). [66] Pain was reported as an outcome measure following the 6MWT. [66] Patient reported outcome measures included the Foot Function Index-Revised (FFI-R) [66 67] and the Short Musculoskeletal Functional Assessment (SMFA). [68] Meta-analysis was able to be conducted for a total of 8 outcome measures.

Main findings:

Heel raise performance

Two clinical measures of heel raise performance (maximum number completed and height) were reported across 4 studies. Two studies were pooled and found a large effect size for the number of single leg heel raises performed by individuals with TPT compared to controls (i.e. approximately 7 v 20 respectively; **Figure 4-2**). [66 170] One study reported significantly lower height on single leg heel raise, [67] whereas another reported no differences for bilateral heel raise height between TPT and control groups (**Figure 4-2**). [156]



Abbreviations: TPT: tibialis posterior tendinopathy, SMD; standardized mean difference, SD; standard deviation, CI; confidence interval

Figure 4-2 *Standardised mean difference (95% CI) for function and strength outcomes in TPT vs controls.*

Leg muscle strength

Combined isometric forefoot adduction and subtalar inversion strength in plantar flexion was reported in three studies. [125 126 152] Pooled data from two studies that measured strength in 90 degrees of knee flexion [125 152] revealed a moderate deficit (SMD) in TPT compared to controls (MD -0.27 N/kg) (**Figure 4-2**). The other study measured forefoot abduction and subtalar inversion strength in full knee extension [126] and showed no difference (MD 0.01 N/kg). It was excluded from the pooled analysis due to heterogeneity of testing position.

Hip muscle function

Hip extensor and abductor muscle strength and endurance in individuals with TPT were compared to controls in one study. [66] Large SMDs indicate that participants with TPT had significantly reduced hip extensor strength and endurance compared to controls (**Figure 4-2**). There was a small-moderate effect for hip abductor muscle strength differences between TPT and control groups, which did not reach statistical significance. SMDs for hip abductor muscle endurance revealed a significant medium effect with control participants demonstrating greater hip abductor muscle endurance than TPT participants.

Single leg balance

Anteroposterior and mediolateral centre of pressure displacement during single leg stance was moderately greater in participants with TPT compared to control (**Figure 4-2**). [170] The same study reported that 47% (9/19) of participants with TPT were unable to maintain single leg balance for 10 seconds compared with 15% of controls (3/20).[170]

6-minute walk test

One study measured distance walked in 6 minutes (6MWT) and pain experienced on a 100 mm visual analogue scale.[66] Participants with TPT covered a significantly shorter distance (approximately 74 metres) and reported a significantly higher pain level (22mm on visual analogue scale) when compared to individuals without TPT (**Figure 4-2**).

Foot posture

Foot posture was examined in two studies by using the Arch Index (AI) [66 170] and in eight studies using the Arch Height Index (AHI). [67 68 124-127 152 156] Pooled SMDs for the two studies investigating AI, [66 170] revealed a significant large effect indicating that TPT participants demonstrated a flatter foot posture compared to controls. AHI in bilateral stance was substantially (large SMD) lower in individuals with TPT compared to controls (**Figure 4-3**). [67 68 124-127 152 156] There was a large SMD for AHI taken in a seated position, yet the Arch Rigidity Index (ratio of standing AHI to seated AHI) was not different between TPT and control groups (**Figure 4-3**). [126]

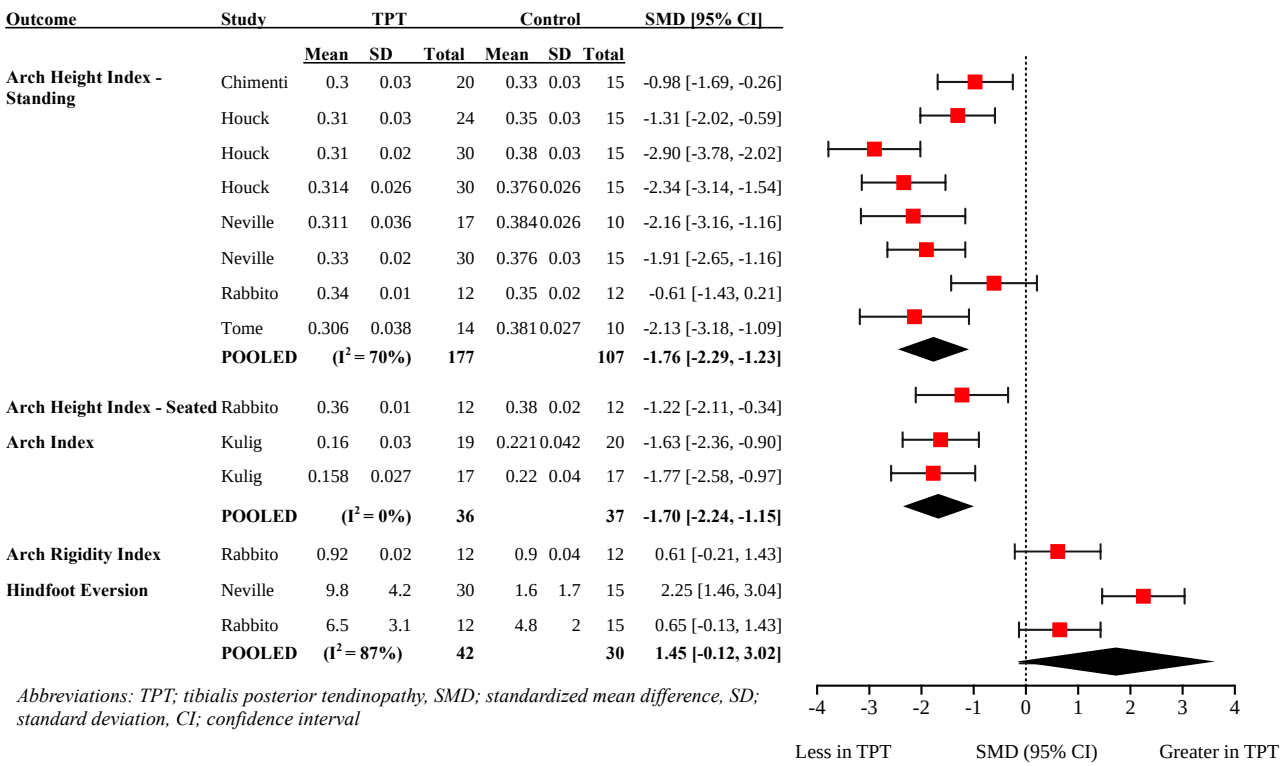


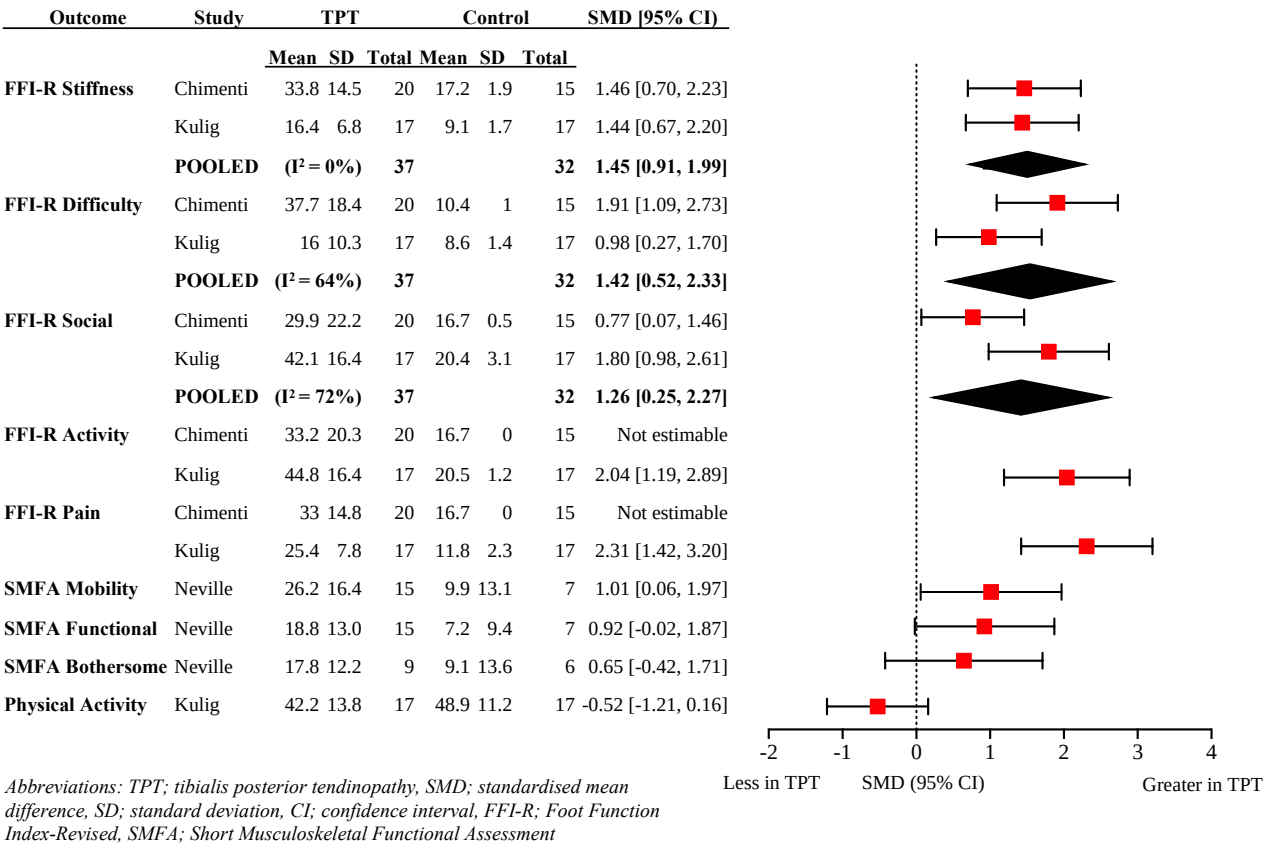
Figure 4-3 *Standardised mean difference (95% CI) for foot posture and range of motion outcomes in TPT vs controls.*

Hindfoot Range of Motion

Two studies measured hindfoot eversion range of motion [125] [126] and reported a large pooled point estimate of effect for more eversion in TPT compared to controls (mean difference (95% CI) 4.97 (-1.4 to 11.34) degrees), but this was not statistically significant (confidence intervals contained 0) (**Figure 4-3**).

Self-reported function

Five studies investigated self-reported function compared to controls using the Foot Function Index-Revised (FFI-R) [66] [67] and the Short Musculoskeletal Functional Assessment. [68] Pooled SMDs were calculated for the stiffness, difficulty and social subscales of the FFI-R with large effect sizes demonstrating significantly more self-reported stiffness, difficulty and social restrictions in individuals with TPT (**Figure 4-4**). As one study reported SD of 0 for the pain and function subscales, pooled SMDs were not able to be calculated. [67] Another paper [66] revealed that compared to controls, participants with TPT had significantly higher self-reported pain and activity limitations (**Figure 4-4**).



Abbreviations: TPT; tibialis posterior tendinopathy, SMD; standardised mean difference, SD; standard deviation, CI; confidence interval, FFI-R; Foot Function Index-Revised, SMFA; Short Musculoskeletal Functional Assessment

Figure 4-4 *Standardised mean difference (95% CI) for patient reported outcome measures.*

Participants with TPT demonstrated significantly more self-reported mobility difficulties (**Figure 4-4**) than controls on the Short Musculoskeletal Functional Assessment. [125] No significant differences between groups were found for functional limitations or the bothersome index (**Figure 4-4**). Levels of self-reported physical activity were not significantly different between individuals with TPT and controls (**Figure 4-4**). [66]

4.1.4 Discussion

This is the first review to systematically evaluate and synthesise results of research investigating clinical impairments and self-reported pain and disability associated with TPT. Data from the meta-analysis indicate strong evidence for lower arch height and a lesser capacity to perform repeated unilateral heel rise in individuals with TPT. These deficits align with the function of tibialis posterior muscle, which is governed by its orientation and attachments. A large effect size for a deficit in single leg heel rise height and a medium effect for combined isometric forefoot adductor and subtalar invertor muscle strength in plantar flexion from individual studies further supports impaired musculotendinous function in TPT.

While meta-analysis revealed strong evidence for lower arch height in individuals with TPT compared to controls. The magnitude of this effect must be interpreted with caution because control participants in five studies were only included if they had normal AHI and visually assessed normal foot posture. [68 124 125 127 156] A requirement for pain-free individuals to demonstrate normal AHI and foot posture may have potentially magnified the effect seen between TPT and controls. A finding that mitigates against this over-estimate of effect is that there was a large effect size of lower foot arch height in two studies that did not require controls to demonstrate normal foot posture. This suggests that key features of TPT are likely a combination of both tendon pathology (as discussed above) and postural deformity.

Impairments demonstrated in TPT compared to controls were not limited to the level of body structure and function; lower self-reported function and greater pain also appear to be characteristic of TPT. Meta-analyses of FFI-R data suggest that stiffness, functional difficulties and social limitations are key features of TPT, with individual study SMDs also showing large effects for pain and activity limitations. Activity limitations were also not limited to self-report measures; poorer balance and mobility were demonstrated in TPT compared to controls with a moderate effect. The deficit in physical capacity (heel raise number and height and plantar flexion inversion weakness) and concomitant self-report concerns in functional, social and activity limitations as well as pain ought to be considered in the management of the condition.

Clinical impairments in TPT are not limited locally to the foot and ankle. Medium effects were found for deficits in hip extension strength and endurance and hip abduction endurance in individuals with TPT. [66] Hip abduction strength deficits did not reach statistical significance (SMD (95% CI) -0.6 (-1.29, 0.08)) yet sample size was small and this may reflect a type II error. While further research is needed to determine true effects, these results are consistent with findings of impaired hip muscle function in other distal joint pathologies of the lower limb including knee osteoarthritis, [199] patellofemoral pain [200-202] and midportion achilles tendinopathy.[203] These data suggest the need to assess and consider addressing any potential deficits in hip muscle capacity in the management of patients with TPT.

All papers included within this review pertained to either stage I (n of papers =1), II (n=6) or I-II (n=2) TPT with data combined for analysis. Data for stage I and II TPT were pooled for two meta-analyses; hindfoot eversion and AHI. Considering hindfoot eversion, one paper investigating stage II TPT found strong evidence for increased hindfoot eversion ROM, [125] whereas differences between individuals with stage I TPT and controls were less prominent (**Figure 4-3**). [126] Similarly, 7 of the 8 papers investigating AHI found significant medium to large effects for lower AHI in stage II TPT compared to controls, whereas AHI in stage I TPT [126] did not appear to be different

when compared to controls. When data for these outcomes were pooled, there was substantial heterogeneity (I^2 = 87% and 70% respectively) and wide 95% confidence intervals which makes it difficult to draw conclusions about the true effects. The variability observed may be a result of underlying differences between stage I and II TPT and as such, the results must be interpreted with caution.

Variations in participant characteristics, including age, BMI and physical activity participation, between studies investigating stage I and II TPT need to be considered in terms of contribution to some of the differences observed in the outcomes reported in this systematic review. Participants in the study that investigated stage I TPT were younger [126] and had a markedly lower BMI [126] than those in the studies that investigated stage II TPT (**Table 4-3**). Age and BMI for participants in two studies investigating stage I-II TPT [66 170] sat between those reported for stage I and stage II separately. All participants in the study investigating stage I TPT were undertaking running and running-related activities for at least 30 minutes three times per week. [126] While physical activity participation was not reported in most stage II studies, individuals with stage II TPT were found to have significant activity limitations compared to controls based on the FFI-R activity subscale.

As TPT is considered a progressive condition,[48] younger, active individuals with stage I TPT may not yet have progressed to a point where they present with certain signs of the condition, such as flatfoot deformity or an everted hindfoot, that may be more apparent in stage II TPT. In line with classification systems [48 51 133] and consistent with other studies, [204] this suggests that changes in foot posture may not be a key feature of stage I TPT. Differences between stage I and II TPT also appear to relate to tendon function. In stage I TPT, no difference was found for ankle inverter strength compared to controls. [126] This is in direct contrast to results from stage II studies which found strong evidence for decreased isometric forefoot adduction and subtalar inversion strength in individuals with stage II TPT compared to controls. This suggests that despite early signs of tendon reactivity, [107] the TP tendon may still be functionally competent in stage I of the condition.

There are a number of factors to consider when interpreting results of this systematic review. While no restrictions were made regarding the stage of condition, these results apply to only stage I and II TPT as no data was available for stage III or IV (when foot deformity. Without quantifiable methods for staging the condition, [205] delineation between stages must be interpreted with caution. While all papers reported eligibility criteria relating to stage I or II TPT (100% on the quality appraisal), assessment of stage was based on classification systems that have not been validated. [205] Clinical differentiation between stage II and III TPT has been based on the widely accepted notion that stage II is a flexible deformity, whereas in stage III the deformity is fixed. [48] The problem with this is that the method used to determine flexibility of the deformity is not reported. Perhaps this is

an omission in reporting, but it is more likely due to the lack of a valid clinical method of quantifying flexibility. Future research investigating clinical tools that may be able to provide a valid and reliable method of determining the stage of the condition would be beneficial for clinicians and academics.

Another consideration is that this review was limited to 10 papers with relatively small sample sizes. The outcome with the strongest effect was based on a sample of 177 individuals with TPT and 107 controls. The majority of outcomes had a sample size much smaller than this and were calculated from individual papers. Small sample sizes and heterogeneity among included studies suggests effect estimates should be interpreted with caution. While SMDs were calculated in this review where possible to overcome small sample sizes, the current small body of TPT literature would benefit from larger, well-designed studies.

4.1.5 Conclusion

This review has appraised the existing literature and shows that TPT is characterised by impairments related to both local tendon dysfunction and foot posture as expected. However, the condition is also associated with changes in hip strength, walking, balance and global measures of self-reported function. These results highlight the need to consider both local impairments and measures of overall function when assessing the presentation and impact of the condition clinically, the effectiveness of TPT management, and when designing future studies

CHAPTER 5 Gait characteristics in tibialis posterior tendinopathy

5.1 Foot and ankle kinematics during gait in tibialis posterior tendinopathy: a systematic review

Chapter four identified clinical features of TPT that appear to be characteristic of the condition including impairments in foot posture, walking and self-reported function. To further investigate the presentation of TPT, this chapter systematically synthesises the literature exploring the kinematic gait characteristics in TPT compared to controls. In order to increase the confidence in findings, meta-analytic methods were used to pool data where homogeneity of methods and outcomes allowed.

Ross MH, Smith MD, van den Hoorne W, Plinsinga, ML, Vicenzino B. Kinematic gait characteristics in tibialis posterior tendinopathy: a systematic review

Contributor	Statement of contribution
Megan H Ross (Candidate)	Conception and design (60%) Analysis and interpretation (40%) Drafting and production (50%)
Dr Michelle D Smith	Conception and design (20%) Analysis and interpretation (15%) Drafting and production (15%)
Wolbert van den Hoorne	Analysis and interpretation (20%) Drafting and production (20%)
Melanie L Plinsinga	Analysis and interpretation (10%)
Professor Bill Vicenzino	Conception and design (20%) Analysis and interpretation (15%) Drafting and production (15%)

5.1.1 Introduction

Tibialis posterior tendinopathy (TPT) is characterised by pain on the medial aspect of the foot and ankle and difficulties with activities that load the tibialis posterior (TP). [195] Dysfunction is considered to occur along a spectrum where clinical signs of tendinopathy are predominant in the early stages, with pain and difficulty during activities that load the tendon primary complaints, [64 84 195] which may be accompanied by an acquired flatfoot deformity. [42 130]

The TP tendon is a key dynamic support for the medial longitudinal arch and contributes to ankle plantar flexion, forefoot adduction and hindfoot inversion during stance. [206 207] The important role the TP tendon plays in stabilisation of the arch is evident when there is dysfunction of the tendon. Individuals with TPT have significant difficulty with activities that involve plantar flexion at the ankle and inversion at the subtalar joint. Large deficits have been demonstrated in single leg heel raise height and repetitions, in addition to forefoot adduction/inversion strength. [195] Furthermore, there is evidence for alterations in static foot posture, with large effects for lower arch height in TPT compared to health controls. [195] Asymptomatic flatfoot has been associated with altered lower limb kinematics during gait when compared to individuals with normal foot posture, [208] yet there has been no synthesis of available literature for lower limb kinematics in individuals with TPT compared to controls.

Any pain related issues of the TP and accompanying clinical features are likely to affect lower limb kinematics during locomotion. It is therefore important to explore existing literature that has investigated foot kinematics during gait when there is pain and dysfunction of the TP. The aim of this systematic review was to synthesise the literature investigating kinematics of the foot and ankle in individuals with TPT compared to controls.

5.1.2 Methods

The protocol for the systematic review was developed in accordance with guidelines contained in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement and registered online at: http://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42016051527.

Search Strategy

A comprehensive literature search across electronic databases (CINAHL, Cochrane, Web of Science, Embase and PubMed) was performed up to and including 17 October 2018. The search strategy was broad to account for variations in terminology and ensure all relevant literature was captured (Flatfoot OR (posterior AND tibia* AND (tendon* OR tendin*)) OR “pes planus” OR

"pes planovalgus"). Reference lists of included papers were hand searched for potentially eligible articles.

Two independent reviewers (MR and MP) performed the search and results were imported into Endnote X7 (Thompson Reuters, Carlsbad, California, USA). Duplicates were removed prior to screening titles and abstracts. Full text screening of potentially relevant articles against final eligibility criteria was performed by two reviewers (MR and MP). Where disagreements could not be resolved, a third reviewer (BV or MS) was consulted.

Eligibility criteria

Studies were included if: i) participants in each study were described as having clinical signs of TPT (and detailed eligibility criteria consistent with tendinopathy of tibialis posterior); ii) kinematic variables of the foot and ankle were evaluated in individuals with TPT and compared to healthy controls during gait (treadmill or over ground); iii) kinematic data were recorded from the foot and ankle, collected using three-dimensional (3D) multi-segment foot models; and iv) written in English.

Reviews, single case reports, paediatric studies, studies investigating participants with rheumatoid arthritis or other conditions in addition to TPT and cadaver or animal studies were excluded. Where TPT data could not be separated from participants with other foot/ankle conditions or when there were no clinical signs of tendinopathy (i.e., other reasons for AAFD), studies were also excluded.

Quality evaluation

Methodological quality evaluation of included studies was performed via two methods. First, a modified version of the Epidemiological Appraisal Instrument (EAI)[196] was used to evaluate methodological quality. As intervention/exposure outcomes were not the aim for this systematic review, some items were removed leaving only those relevant to cross-sectional studies. Each item was recorded as "Yes" (score = 1), "Partial" (score = 0.5), "No" (score = 0), "Unable to determine" (score = 0) or "Not Applicable" (item removed from scoring). The mean score across all applicable items was calculated to give the final overall score (range = 0 to 1).

In addition to the EAI, an appraisal tool was used to assess the methodological quality specific to 3D kinematic gait analysis. This 7-item tool was developed by Buldt, [208] based on a series of reviews addressing the issues associated with motion capture. [209-212] Each item was recorded as "Yes" (score = 1) or "No" (score = 0) for each article with a maximum score of 7 (i.e., highest methodological quality).

Two reviewers (MR and MP) rated the methodological quality of each included study against both appraisal tools. Inter-rater agreement was calculated for each scale prior to disagreements being discussed, and where a consensus could not be reached, a third reviewer (MS) was approached.

Data extraction

One reviewer extracted the following data in a predetermined spreadsheet: (i) participant characteristics – population source, sample size, sex, age, body mass index (BMI) and selection criteria (including for the diagnosis of TPT), (ii) details about 3D motion capture methods – including segments, planes, and (iii) main outcomes reported for each study. Means and standard deviations (SD) were extracted for all continuous kinematic and spatiotemporal data to allow standardised mean differences (SMDs) to be calculated for each included study. Where there was not sufficient information provided in the article to calculate ES (i.e. no mean or SD) for kinematic variables, the original authors were contacted for additional information. Kinematic data were extracted for the stance phase of gait only. When terminology/timing of each sub-phase (i.e. initial contact, loading response, mid-stance, terminal stance, pre-swing) varied between studies, data were categorised according to the following: initial contact; 0-10%, loading response; 0-20%, mid-stance; 30-50%, terminal stance; 50-80%; pre-swing 90-100%. Prior to analysis, data extraction was verified by two additional reviewers (MS and BV).

Statistical analyses

Inter-rater agreement for reliability of the methodological quality assessment was calculated in Stata v14. The Cohen's Kappa (κ) statistic (95% confidence interval (CI)) was interpreted as poor agreement (<0.00), slight agreement (0.00 – 0.20), fair agreement (0.21 – 0.40), moderate agreement (0.41 – 0.60), substantial agreement (0.61 – 0.80) or almost perfect agreement (0.81 to 1.00). [89]

SMDs were calculated in Review Manager (RevMan) v5.3 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration) using random effects models for Hedge's g and calculated as the difference between TPT and control group means, divided by the pooled SD. [197] SMDs and 95% CIs were calculated and interpreted as small (≤0.59), medium (0.6-1.19) or large (≥1.2) [213] effect size.

Meta-analysis was performed where methodology and reporting of outcome measures allowed pooling of data. Chi-squared tests ($P<0.1$) and the I^2 statistic were used to quantify between study heterogeneity for pooled SMDs with ≥0.75 considered substantial heterogeneity. [198] A descriptive summary of main findings and study conclusions were presented where data was not available to calculate SMD.

5.1.3 Results

Search strategy

The initial database search identified 16 538 potentially eligible articles (**Figure 5-1**). After removal of duplicates, 8718 articles were screened by title and abstract of which 8644 did not meet the eligibility criteria. A total of 74 full text articles were screened against the eligibility criteria with 7 articles included in the qualitative synthesis. Additional data for effect size calculations were provided by authors for Rabbito et al [126] and Ness et al. [128]

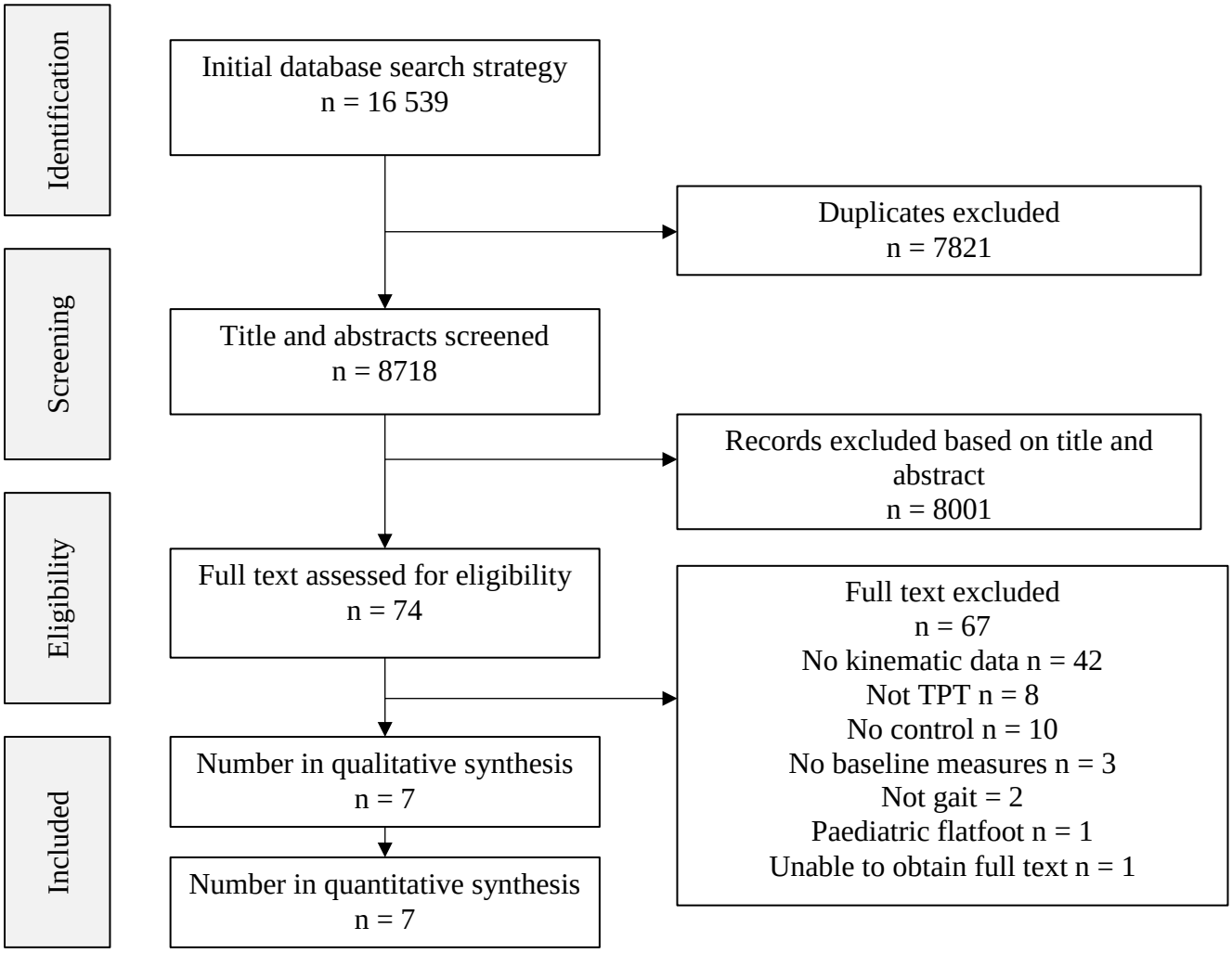


Figure 5-1 *PRISMA flowchart*

Methodological quality

The methodological quality of included articles, scored on the EAI, is represented in **Table 5-1**. Agreement between quality assessors, calculated as weighted κ, was almost perfect (κ statistic (95% CI) 0.94 (0.88, 1.00)) for the EAI. Two raters agreed on a total of 170 out of a possible 176 EAI items. All studies (100%) clearly described the objectives, main outcomes and characteristics of the participants included in the study. All studies (100%) also performed a standardised assessment on

all participants. Eligibility criteria, important covariates, statistical methods, main findings and estimates of random variability were clearly described in 8 out of 9 studies (88.9%). One study (11.1%) reported the reliability of outcome measures and no studies reported the validity. One study collected disease history but no studies accounted for duration of symptoms in analyses. Two studies (22.2%) reported results for subgroups of PTTD participants and 6 (66.7%) studies adjusted for covariates in analyses.

Table 5-1 *Epidemiological appraisal instrument for included studies (n = 7)*

	Reference	Houck et al [124]	Ness et al [128]	Neville et al [125]	Rabbito et al [126]	Ringleb et al [214]	Tome et al [127]	Van de Velde [215]	Studies scoring "yes" (%)
Q1.	Hypothesis/aim/ objective clearly described	■	■	■	■	■	■	■	100
Q2.	Main outcomes clearly described	■	■	■	■	■	■	■	100
Q3.	Reported study design	■	▒	▒		▒	■	▒	42.9
Q4.	Source of subject population clearly described		▒					▒	14.3
Q5.	Reported eligibility criteria	■		■	■	■	■	■	85.7
Q6.	Characteristics of study participants described	■	■	■	■	■	■	■	100
Q7.	Important covariates and confounders described	■	■	■	■		■	■	85.7
Q8.	Statistical methods clearly described	■	▒	■	■	■	■	■	85.7
Q9.	Main findings of the study clearly described	■	▒	■	■	■	■	■	85.7
Q10.	Provides estimates of the random variability in the data	■	▒	■	■	■	■	■	85.7
Q11.	Sample size calculations								14.3
Q12.	Comparability of case/control groups			■	■			■	42.9
Q13.	Recruitment period for case/control groups								0.0
Q14.	Reliability of outcome measures	▒		■	▒		▒		14.3
Q15.	Validity of outcome measures		▒						0.0
Q16.	Standardised assessment	■	■	■	■	■	■	■	100
Q17.	History of disease/symptoms collected and included in analysis			▒					0.0
Q18.	Adjusted for covariates	■		■	■		■	■	71.4
Q19.	Reported data for subgroups			■				■	28.6
Q20.	Generalibility of results to other populations			▒	▒			▒	0.0
Overall quality score (range 0 to 1)		0.58	0.40	0.73	0.75	0.43	0.58	0.68	0.59

Black shading = "yes" (1), Grey shading = "Partial" (0.5), White (no shading) = "No" or "Unable to determine", NA = "not applicable" (0)

The assessment of 3D kinematic specific methodological quality for gait studies is presented in **Table 5-2**. Agreement between two independent raters, calculated as κ, was almost perfect (κ statistic (95% CI) 0.86 (0.72, 1.01)). The median score was 5 (range 2 to 6). Details of the assessors carrying out the 3D kinematic analysis were not given in any paper, and only 2 papers (28.6%) provided adequate information about the reliability, precision and accuracy of data capture equipment. All papers (100%) clearly and accurately described marker placement, modelling technique, segments, anatomical reference planes and motion between segments.

Participants

Population source, sample sizes and participant characteristics (sex, age, BMI) are included in **Table 5-3**. Included TPT were predominantly females (% female ranging from 63.3% [125] to 100% [214]), mean age (SD) ranging from 30.3 (7.9) [126] to 69 (7.0) [214] and BMI between 23.4 (3.4) [126] and 33.7 (7.4). [127]

Details regarding methods specific to 3D motion capture are provided in **Table 5-4**. Kinematic characteristics during gait were captured during treadmill walking in one study, and overground walking in remaining studies. Data for the medial longitudinal arch were captured in four of seven studies, with most studies reporting data for ankle, hindfoot and forefoot segments (**Table 5-4**).

Table 5-2 *Methodological assessment scores for items relating to 3D kinematic gait analysis (n = 8)*

Item	Houck et al [124]	Ness et al [128]	Neville et al [125]	Rabbito et al [126]	Ringleb et al [214]	Tome et al [127]	Van de Velde [215]	Studies scoring 'Yes' (%)
1. Were details of the assessors carrying out the 3D kinematic gait analysis provided?	0	0	0	0	0	0	0	0
2. Were spatiotemporal data and gait analysis procedure methodology described?	1	0	1	1	0	1	1	71.4
3. Were movement tasks clearly defined?	1	0	1	1	0	1	1	71.4
4. Was marker placement clearly and accurately described and was the modelling technique described?	1	1	1	1	1	1	1	100
5. Was data capture equipment reported including the reporting of reliability, precision and accuracy of equipment?	0	1	1	0	0	0	0	28.6
6. Was a reference position reported?	1	1	1	1	0	1	0	71.4
7. Were the segments, anatomical reference planes and motion between segments reported?	1	1	1	1	1	1	0	85.7
Total (/7)	**5**	**4**	**6**	**5**	**2**	**5**	**3**	**5***

*Key: 1; yes, 0; no, *; median score across all studies*

Table 5-3 *Sample sizes and population characteristics for included studies (n = 7)*

Paper	Source of participants	Sample size		Sex (TPT group)	Age (mean (SD))		BMI (mean (SD))		Diagnostic criteria	
		TPT	Control	Female (%)	TPT	Control	TPT	Control	Tendinopathy signs	Flatfoot requirement
Houck et al [124]	Orthopaedic clinic	30	15	22 (73.3)	59.3 (10.8)	56.5 (7.7)	29.6 (4.8)	30.5 (3.6)	TOP, swelling, pain with SLHR	Yes
Ness et al [128]	Orthopaedic clinic	34	25	30 (88.2)	52.8 (9.5)*	41.3 (12.5)	32 (7.5)*	26.3 (3.8)	Not reported	NR
Neville et al [125]	General community	30	15	19 (63.3)	58.1 (10.5)	56.5 (7.7)	30.6 (5.4)	30.6 (3.6)	At least 1 of: TOP, swelling, pain with SLHR	Yes
Rabbito et al [126]	Recreational running community	12	12	9 (100)	30.3 (7.9)	28.5 (8.6)	23.2 (3.4)	23.7 (2.8)	Swelling, pain or TOP	No
Ringleb et al [214]	Podiatric clinic	5	20	5 (85.7)	69.0 (7.0)*	46.0 (14.0)	29.0 (1.0)	25.0 (4.0)	TOP, swelling, pain with SLHR	NR
Tome et al [127]	Orthopaedic clinic	14	10	12 (70.0)	56.8 (11.7)	51.2 (7.3)	33.7 (7.4)*	31.8 (3.6)	TOP, swelling, pain with SLHR	Yes
Van de Velde [215]	Orthopaedic clinic	15	15	10 (66.7)	51 (12.2)	52 (10.1)	29 (3.9)	24 (3.7)	TOP, difficulty performing SLHR	Yes

** indicates significant difference (p < 0.05) between groups, TPT; tibialis posterior tendinopathy, SD; standard deviation, TOP; tenderness on palpation, SLHR; single leg heel raise*

Table 5-4 *Population types, activities, variables and spatiotemporal characteristics*

Paper	Activity	Equipment	Sampling rate	Reference position	Model	Segments	Planes	Number of trials	Spatiotemporal characteristics
Houck et al [124]	Walking	IRED, 6-camera Optitrack Motion Analysis System	60 Hz	Subtalar neutral	NR	4: Tibia, hindfoot (calcaneus), first metatarsal,	Sagittal, coronal	5	Controlled (1 m/s)
Ness et al [128]	Walking	15-camera Vicon Motion Analysis System	120 Hz	Relaxed standing	Milwaukee Foot Model	4: Tibia, hindfoot (calcaneus), forefoot (1st - 5th metatarsals), hallux	Sagittal, coronal, transverse	3	Uncontrolled (avg 0.79 m/s)
Neville et al [125]	Walking	IRED, 6-camera Optitrack Motion Analysis System	60 Hz	Subtalar neutral	NR	5: Tibia, hindfoot (calcaneus), medial forefoot (1st metatarsal), lateral forefoot (2nd - 4th metatarsals) (navicular tuberosity)	Coronal, transverse, MLA	5	Controlled (1 m/s)
Rabbito et al [126]	Treadmill walking	8-camera Vicon Motion Analysis System	120 Hz	Subtalar neutral	NR	3: Tibia, hindfoot (calcaneus), 1st metatarsal, hallux, (navicular tuberosity)	Coronal, MLA	10	Controlled (1.2 m/s)
Ringleb et al [214]	Walking	10-camera, Real-Time ExpertVision System	120 Hz	Relaxed standing	Custom	3: Tibia, hindfoot (calcaneus), midfoot (1st & 5th metatarsals)	Sagittal, coronal, transverse	NR	Uncontrolled (avg 1.1 m/s)
Tome et al [127]	Walking	IRED, 6-camera Optitrack Motion Analysis System	60 Hz	Relaxed standing	NR	5: Tibia, hindfoot, medial forefoot (1st metatarsal), lateral forefoot (2nd - 4th metatarsals), hallux (navicular tuberosity)	Coronal, transverse, MLA	5	Uncontrolled (avg 1.2 m/s)

Van de Velde [215]	Walking	10-camera Vicon Motion Analysis System	100 Hz	Subtalar neutral	Rizzoli	5: Tibia, calcaneus, midfoot, metatarsals, hallux	Sagittal, coronal, transverse, MLA	3	Uncontrolled (Stage II avg 1.0 m/s)

Abbreviations: IRED; infra-red emitting diode, Hz; hertz, NR; not reported, m/s; metres per second, MLA; medial longitudinal arch angle

Outcomes measured

Spatiotemporal gait characteristics and kinematics for the tibia, hindfoot, midfoot, forefoot and hallux in three planes (sagittal, coronal, transverse) were reported for varying time points during the stance phase of gait (**Appendix 5**). SMDs were calculated for peak angles (**Table 5-6**) and excursion (**Table 5-7**) for each joint where a minimum of two studies reported data (the ankle, hindfoot and forefoot in the sagittal, coronal and transverse planes, hallux in the sagittal plane and the medial longitudinal arch angle). Where SMDs could not be calculated for a specific stance phase, data are reported descriptively.

Main findings

Spatiotemporal characteristics

When walking speed was self-selected (n of studies = 4), meta-analysis showed a large, significant effect for slower walking speed in individuals with TPT compared to controls (SMD (95% CI) -1.4 (-2.2 to -1.0) (**Table 5-5**/**Figure 5-2**). Pooled SMDs from two studies showed that cadence was significantly lower in TPT compared to controls (SMD (95% CI) -1.3 (-2.3 to -0.3)). Individual SMDs showed large effects longer stance duration (% of gait) [128] and shorter stride length [128] in TPT compared to controls ((SMD 95% CI) 1.4 (0.8 to 2.0) and -2.1 (-2.8 to -1.5) respectively) (**Table 5-5**/**Figure 5-2**). Individual SMDs from one study showed large effects for longer stride time in TPT compared to controls (SMD (95% CI) 1.9 (1.0 to 2.9)), [215] but another found no difference between groups for stance time (SMD (95% CI) 0.7 (-0.2 to 1.5)) (**Table 5-5**/**Figure 5-2**). [127]

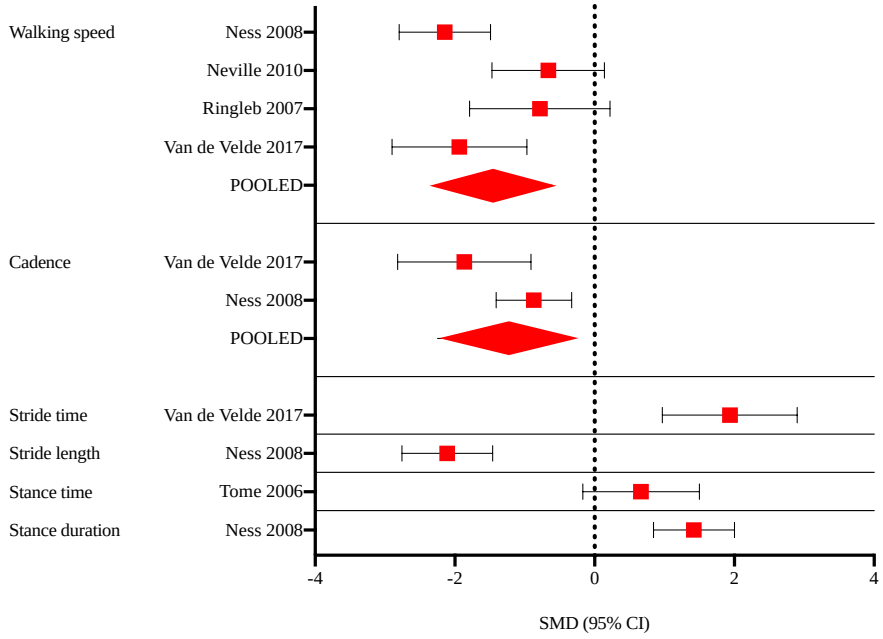


Figure 5-2 *Spatiotemporal characteristics for TPT compared to controls presented as SMD (95% CI) (-SMD indicates smaller values in TPT, +SMD indicates larger values in TPT).*

Table 5-5 *Extracted data (mean, SD, n) and calculated SMDs for spatiotemporal data*

		TPT			Control				
Characteristic	Study	Mean	SD	n	Mean	SD	n	Weight	SMD [95% CI]
Walking speed (m/s)	Ness [128]	0.79	0.18	34	1.12	0.1	25	28.40%	-2.15 [-2.80, -1.49]
	Neville [125]	1.19	0.22	17	1.34	0.22	10	25.90%	-0.66 [-1.47, 0.14]
	Ringleb [214]	1.1	0.2	5	1.2	0.1	20	22.50%	-0.78 [-1.79, 0.22]
	Tome [127]	1.2	0	14	1.3	0	10		Not estimable
	Van de Velde [215]	1	0.2	11	1.3	0.1	15	23.20%	-1.94 [-2.90, -0.97]
	Total (95% CI)			81			80	100.00%	-1.41 [-2.20, -0.61]
	Heterogeneity: $Tau^2 = 0.47$; $Chi^2 = 10.68$, df = 3 (P = 0.01); $I^2 = 72\%$								
	Test for overall effect: Z = 3.46 (P = 0.0005)								
Cadence (steps/min)	Van de Velde [215]	92.9	15.5	11	116.4	9.1	15	41.90%	-1.87 [-2.82, -0.91]
	Ness [128]	96.26	9.75	34	104.2	7.86	25	58.10%	-0.87 [-1.41, -0.33]
	Total (95% CI)			45			40	100.00%	-1.29 [-2.25, -0.32]
	Heterogeneity: $Tau^2 = 0.34$; $Chi^2 = 3.18$, df = 1 (P = 0.07); $I^2 = 69\%$								
	Test for overall effect: Z = 2.62 (P = 0.009)								
Stride time (m/s)	Van de Velde [215]	1.2	0.1	11	1	0.1	15	100.00%	1.94 [0.97, 2.90]
Stride length (m)	Ness [128]	0.98	0.17	34	1.29	0.1	25	100.00%	-2.11 [-2.76, -1.46]
Stance time (s)	Tome [127]	0.772	0.083	14	0.72	0.064	10	100.00%	0.66 [-0.17, 1.50]
Stance duration (% of stride)	Ness [128]	65.79	2.33	34	62.26	2.61	25	100.00%	1.42 [0.84, 2.00]

Table 5-6 *Extracted data (mean, SD, n) and calculated SMDs for peak values (in degrees)for each joint/segment during each phase of stance*

			TPT			Control				
Joint/segment	Phase of stance	Study	Mean	SD	n	Mean	SD	n	Weight	SMD [95% CI]
Ankle plantar flexion/ dorsiflexion	Initial contact	Houck [124]	-1.8	5.3	30	5.9	2.4	15	38.40%	-1.66 [-2.37, -0.94]
		Ness [128]	6.1	10.16	34	19.7	12	25	61.60%	-1.23 [-1.79, -0.66]
		Total (95% CI)			64			40	100.00%	-1.39 [-1.83, -0.95]
		Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.87$, df = 1 (P = 0.35); $I^2 = 0\%$ Test for overall effect: Z = 6.15 (P < 0.00001)								
	Loading response	Houck [124]	-10.5	4.2	30	-2.1	2.5	15	33.20%	-2.21 [-2.99, -1.43]
		Ness [128]	7.97	9.85	34	22.52	11.7	25	39.20%	-1.34 [-1.92, -0.77]
		Ringleb [214]	-10	3	5	-8	3	20	27.50%	-0.64 [-1.64, 0.35]
		Total (95% CI)			69			60	100.00%	-1.44 [-2.23, -0.65]
		Heterogeneity: $Tau^2 = 0.33$; $Chi^2 = 6.25$, df = 2 (P = 0.04); $I^2 = 68\%$ Test for overall effect: Z = 3.59 (P = 0.0003)								
	Midstance	Ness [128]	14.94	11.11	34	28.02	11.9	25	100.00%	-1.13 [-1.69, -0.57]
	Terminal stance	Houck [124]	8	5.4	30	14.8	3.2	15	32.40%	-1.39 [-2.08, -0.70]
		Ness [128]	19.79	13.63	34	31.53	11.8	25	52.20%	-0.90 [-1.44, -0.36]
		Ringleb [214]	5	3	5	7	3	20	15.40%	-0.64 [-1.64, 0.35]
		Total (95% CI)			69			60	100.00%	-1.02 [-1.41, -0.63]
		Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.86$, df = 2 (P = 0.40); $I^2 = 0\%$ Test for overall effect: Z = 5.10 (P < 0.00001)								

	Preswing	Houck [124]	-7.5	8.6	30	-4.2	3.8	15	36.50%	-0.44 [-1.07, 0.19]
		Ness [128]	15.43	15.2	34	27.4	12.1	25	49.20%	-0.85 [-1.39, -0.31]
		Ringleb [214]	-12	3	5	-8	6	20	14.30%	-0.69 [-1.69, 0.31]
		Total (95% CI)			69			60	100.00%	-0.68 [-1.05, -0.30]
		Heterogeneity: Tau² = 0.00; Chi² = 0.93, df = 2 (P = 0.63); I² = 0% Test for overall effect: Z = 3.49 (P = 0.0005)								
Hindfoot inversion /eversion	Initial contact	Houck [124]	-3.4	4	30	-0.7	2.4	15	41.30%	-0.75 [-1.39, -0.10]
		Ness [128]	-4.48	10.34	34	3.64	10.1	25	58.70%	-0.78 [-1.32, -0.25]
		Total (95% CI)			64			40	100.00%	-0.77 [-1.18, -0.36]
		Heterogeneity: Tau² = 0.00; Chi² = 0.01, df = 1 (P = 0.93); I² = 0% Test for overall effect: Z = 3.66 (P = 0.0003)								
	Loading response	Houck [124]	-11.2	4.3	30	-6.1	2.2	15	22.60%	-1.34 [-2.02, -0.65]
		Ness [128]	-6.8	9.7	34	2.04	9.44	25	27.80%	-0.91 [-1.45, -0.37]
		Neville [125]	-12.3	5.9	16	-5.1	1.9	15	18.50%	-1.58 [-2.40, -0.76]
		Ringleb [214]	-4	3	5	-4	4	20	14.70%	0.00 [-0.98, 0.98]
		Tome [127]	-9.6	4.7	14	-3.4	4.6	10	16.40%	-1.28 [-2.19, -0.38]
		Total (95% CI)			99			85	100.00%	-1.06 [-1.51, -0.60]
		Heterogeneity: Tau² = 0.12; Chi² = 7.19, df = 4 (P = 0.13); I² = 44% Test for overall effect: Z = 4.54 (P < 0.00001)								
	Midstance	Ness [128]	-8.81	9.94	34	0.21	9.58	25	44.00%	-0.91 [-1.45, -0.37]
		Neville [125]	-13.2	5	16	-5.5	2	15	28.20%	-1.95 [-2.82, -1.07]

		Tome [127]	-10.4	4.5	14	-5.4	3.6	10	27.70%	-1.16 [-2.05, -0.27]
		Total (95% CI) Heterogeneity: Tau² = 0.14; Chi² = 3.89, df = 2 (P = 0.14); I² = 49% Test for overall effect: Z = 4.10 (P < 0.0001)			64			50	100.00%	-1.27 [-1.88, -0.66]
	Terminal stance	Houck [124]	-9.8	4.3	30	-4.8	2.2	15	21.80%	-1.31 [-1.99, -0.63]
		Ness [128]	-10.53	10.19	34	-0.28	9.26	25	23.50%	-1.03 [-1.58, -0.48]
		Neville [125]	-11.5	4.8	16	-3.8	2.2	15	19.10%	-1.99 [-2.87, -1.11]
		Ringleb [214]	-2	3	5	-4	2	10	16.00%	0.80 [-0.32, 1.92]
		Tome [127]	-9	3.9	14	-6.4	2.9	10	19.60%	-0.71 [-1.55, 0.13]
		Total (95% CI) Heterogeneity: Tau² = 0.46; Chi² = 15.90, df = 4 (P = 0.003); I² = 75% Test for overall effect: Z = 2.58 (P = 0.010)			99			75	100.00%	-0.92 [-1.62, -0.22]
	Preswing	Houck [124]	-1.4	5	30	3.8	2.6	15	22.10%	-1.17 [-1.84, -0.50]
		Ness [128]	-10.51	9.34	34	2.85	6.42	25	23.50%	-1.60 [-2.20, -1.00]
		Neville [125]	-5.1	6	16	3.7	2.7	15	18.90%	-1.82 [-2.68, -0.97]
		Ringleb [214]	10	8	5	9	3	20	16.80%	0.22 [-0.76, 1.21]
		Tome [127]	-3.2	4.7	14	1.1	3.5	10	18.70%	-0.98 [-1.84, -0.11]
		Total (95% CI) Heterogeneity: Tau² = 0.31; Chi² = 12.09, df = 4 (P = 0.02); I² = 67% Test for overall effect: Z = 3.65 (P = 0.0003)			99			85	100.00%	-1.12 [-1.73, -0.52]
Forefoot plantar	Initial contact	Houck [124]	6.3	8.4	30	-1.7	3.5	15	48.10%	1.09 [0.43, 1.76]
		Ness [128]	-27.69	11.49	34	-45.61	7.56	25	51.90%	1.76 [1.15, 2.38]

flexion/ dorsiflexion		Total (95% CI) Heterogeneity: Tau² = 0.12; Chi² = 2.11, df = 1 (P = 0.15); I² = 53% Test for overall effect: Z = 1.66 (P = 0.10)			64			40	100.00%	1.44 [0.79, 2.10]
	Loading response	Houck [124]	12.2	7.9	30	2.4	3.5	15	34.40%	1.42 [0.73, 2.11]
		Ness [128]	-26.11	11.07	34	-43.24	8.63	25	35.70%	1.67 [1.07, 2.27]
		Ringleb [214]	-0.2	5	5	1	3	20	29.90%	-0.34 [-1.32, 0.65]
		Total (95% CI) Heterogeneity: Tau² = 0.72; Chi² = 12.07, df = 2 (P = 0.002); I² = 83% Test for overall effect: Z = 1.83 (P = 0.07)			69			60	100.00%	0.98 [-0.07, 2.04]
	Midstance	Ness [128]	-26.49	9.48	34	-42.4	7.85	25	100.00%	1.78 [1.16, 2.39]
	Terminal stance	Houck [124]	16.4	8.5	30	7.3	4.2	15	34.20%	1.21 [0.54, 1.88]
		Ness [128]	-22.65	9.34	34	-38.83	7.89	25	34.60%	1.82 [1.20, 2.44]
		Ringleb [214]	-3	5	5	0	2	20	31.10%	-1.05 [-2.08, -0.02]
		Total (95% CI) Heterogeneity: Tau² = 1.46; Chi² = 22.07, df = 2 (P < 0.0001); I² = 91% Test for overall effect: Z = 0.98 (P = 0.33)			69			60	100.00%	0.72 [-0.72, 2.16]
	Preswing	Houck [124]	-0.3	9.9	30	-8.5	6	15	38.40%	0.91 [0.26, 1.56]
		Ness [128]	-25.03	11.48	34	-42.14	7.85	25	42.00%	1.67 [1.07, 2.27]
		Ringleb [214]	-8	7	5	-15	6	20	19.60%	1.09 [0.06, 2.13]
		Total (95% CI)			69			60	100.00%	1.27 [0.76, 1.78]

		Heterogeneity: Tau² = 0.07; Chi² = 2.95, df = 2 (P = 0.23); I² = 32% Test for overall effect: Z = 4.87 (P < 0.00001)								
Forefoot inversion /eversion	Initial contact	Ness [128]	4.53	8.55	34	6.41	8.1	25	100.00%	-0.22 [-0.74, 0.30]
	Loading response	Ness [128]	1.48	7.76	34	1.95	7.85	25	57.00%	-0.06 [-0.58, 0.46]
		Ringleb [214]	-6	3	5	-3	2	20	43.00%	-1.31 [-2.37, -0.26]
		Total (95% CI)			39			45	100.00%	-0.60 [-1.82, 0.62]
		Heterogeneity: Tau² = 0.61; Chi² = 4.37, df = 1 (P = 0.04); I² = 77% Test for overall effect: Z = 0.96 (P = 0.34)								
	Midstance	Ness [128]	0.86	6.14	34	2.59	6.73	25	100.00%	-0.27 [-0.79, 0.25]
	Terminal stance	Ness [128]	1.1	6.23	34	4.67	6.77	25	77.60%	-0.55 [-1.07, -0.02]
		Ringleb [214]	3	1	5	3	2	20	22.40%	0.00 [-0.98, 0.98]
		Total (95% CI)			39			45	100.00%	-0.42 [-0.89, 0.04]
		Heterogeneity: Tau² = 0.00; Chi² = 0.92, df = 1 (P = 0.34); I² = 0% Test for overall effect: Z = 1.79 (P = 0.07)								
	Preswing	Ness [128]	2.13	5.82	34	15.4	7.89	25	55.20%	-1.93 [-2.56, -1.30]
		Ringleb [214]	-4	5	5	-2	2	20	44.80%	-0.70 [-1.70, 0.30]
		Total (95% CI)			39			45	100.00%	-1.38 [-2.58, -0.18]
		Heterogeneity: Tau² = 0.58; Chi² = 4.18, df = 1 (P = 0.04); I² = 76% Test for overall effect: Z = 2.25 (P = 0.02)								

Forefoot abduction /adduction	Initial contact	Ness [128]	2.61	10	34	16.44	7.66	25	100.00%	-1.50 [-2.09, -0.91]
	Loading response	Ness [128]	-2.81	9.89	34	7.56	6.29	25	44.50%	-1.20 [-1.76, -0.63]
		Neville [125]	-6.2	4.8	16	-2.4	1.9	15	24.80%	-1.00 [-1.75, -0.25]
		Ringleb [214]	1	1	5	3	2	20	13.30%	-1.04 [-2.07, -0.01]
		Tome [127]	-9.1	3.7	14	-4.4	3.4	10	17.30%	-1.27 [-2.17, -0.37]
		Total (95% CI)			69			70	100.00%	-1.14 [-1.51, -0.76]
		Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.28$, df = 3 (P = 0.96); $I^2 = 0\%$ Test for overall effect: Z = 5.95 (P < 0.00001)								
	Midstance	Ness [128]	-4.68	10.46	34	3.97	5.11	25	52.30%	-0.99 [-1.54, -0.44]
		Neville [125]	-8.1	4.6	16	-5	2.2	15	28.90%	-0.83 [-1.57, -0.09]
		Tome [127]	-10.1	3.1	14	-5.7	3.1	10	18.80%	-1.37 [-2.29, -0.45]
		Total (95% CI)			64			50	100.00%	-1.01 [-1.41, -0.62]
		Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.83$, df = 2 (P = 0.66); $I^2 = 0\%$ Test for overall effect: Z = 5.01 (P < 0.00001)								
	Terminal stance	Ness [128]	-6.44	11.57	34	2.7	5.99	25	28.50%	-0.94 [-1.48, -0.39]
		Neville [125]	-10	4.7	16	-6.6	2.1	15	26.00%	-0.90 [-1.64, -0.16]
		Ringleb [214]	-1	1	5	-2	1	20	22.40%	0.97 [-0.06, 1.99]
		Tome [127]	-11.4	2.8	14	-6.5	2.8	10	23.10%	-1.69 [-2.66, -0.72]
		Total (95% CI)			69			70	100.00%	-0.68 [-1.56, 0.21]
		Heterogeneity: $Tau^2 = 0.64$; $Chi^2 = 15.04$, df = 3 (P = 0.002); $I^2 = 80\%$ Test for overall effect: Z = 1.49 (P = 0.14)								
	Preswing	Ness [128]	-5.08	12.11	34	-0.78	8.73	25	29.60%	-0.39 [-0.91, 0.13]

		Neville [125]	-7.3	5.5	16	1.2	2.9	15	25.20%	-1.86 [-2.73, -1.00]
		Ringleb [214]	3	2	5	9	3	20	21.20%	-2.03 [-3.19, -0.88]
		Tome [127]	-9.2	5.7	14	-0.9	3.8	10	24.00%	-1.60 [-2.55, -0.65]
		Total (95% CI)			69			70	100.00%	-1.40 [-2.29, -0.51]
		Heterogeneity: Tau² = 0.63; Chi² = 13.61, df = 3 (P = 0.003); I² = 78% Test for overall effect: Z = 3.08 (P = 0.002)								
Medial longitudinal arch angle	Loading response	Neville [125]	10.7	8.8	16	0.3	3.1	15	54.20%	1.52 [0.70, 2.33]
		Tome [127]	8.2	8.7	14	0	3.3	10	45.80%	1.13 [0.25, 2.01]
		Total (95% CI)			30			25	100.00%	1.34 [0.74, 1.94]
		Heterogeneity: Tau² = 0.00; Chi² = 0.40, df = 1 (P = 0.53); I² = 0% Test for overall effect: Z = 4.39 (P < 0.0001)								
	Midstance	Neville [125]	12	8.4	16	2.2	2.9	15	54.30%	1.50 [0.69, 2.31]
		Tome [127]	9.8	7.9	14	2.1	4.2	10	45.70%	1.12 [0.24, 2.00]
		Total (95% CI)			30			25	100.00%	1.33 [0.73, 1.92]
		Heterogeneity: Tau² = 0.00; Chi² = 0.38, df = 1 (P = 0.53); I² = 0% Test for overall effect: Z = 4.35 (P < 0.0001)								
	Terminal stance	Neville [125]	13	8.1	16	5.1	3	15	54.40%	1.24 [0.47, 2.02]
		Tome [127]	12.2	6.9	14	7.2	4	10	45.60%	0.82 [-0.03, 1.67]
		Total (95% CI)			30			25	100.00%	1.05 [0.48, 1.62]
		Heterogeneity: Tau² = 0.00; Chi² = 0.52, df = 1 (P = 0.47); I² = 0% Test for overall effect: Z = 3.59 (P = 0.0003)								

	Preswing	Neville [125]	12.5	8.2	16	1.8	4.7	15	55.70%	1.55 [0.73, 2.36]
		Tome [127]	5.3	8.4	14	-4.7	4.4	10	44.30%	1.37 [0.46, 2.29]
		Total (95% CI)			30			25	100.00%	1.47 [0.86, 2.08]
		Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.08$, df = 1 (P = 0.78); $I^2 = 0\%$								
		Test for overall effect: Z = 4.72 (P < 0.00001)								

Table 5-7 *Extracted data (mean, SD, n) and calculated SMDs for total excursion (degrees) at each joint/segment during each phase of stance*

			TPT			Controls				
Joint/segment	Phase of stance	Study	Mean	SD	n	Mean	SD	n	Weight	SMD [95% CI]
Ankle plantar flexion/ dorsiflexion	Initial contact	Ness [128]	6.10	10.16	34	19.70	11.96	25	100.00%	-1.23 [-1.79, -0.66]
	Loading response	Ness [128]	4.92	1.52	34	6.86	1.89	25	51.70%	-1.14 [-1.70, -0.58]
		Van de Velde [215]	4.40	1.90	11	3.70	1.40	15	48.30%	0.42 [-0.37, 1.20]
		Total (95% CI)			45			40	100.00%	-0.39 [-1.91, 1.14]
		Heterogeneity: $Tau^2 = 1.09$; $Chi^2 = 9.99$, df = 1 (P = 0.002); $I^2 = 90\%$								
		Test for overall effect: Z = 0.50 (P = 0.62)								
	Midstance	Ness [128]	9.08	2.73	34	7.38	2.97	25	59.60%	0.59 [0.06, 1.12]
		Van de Velde [215]	10.50	1.80	11	10.70	3.10	15	40.40%	-0.07 [-0.85, 0.70]
		Total (95% CI)			45			40	100.00%	0.32 [-0.32, 0.96]
		Heterogeneity: $Tau^2 = 0.11$; $Chi^2 = 1.92$, df = 1 (P = 0.17); $I^2 = 48\%$								
		Test for overall effect: Z = 0.99 (P = 0.32)								

	Terminal stance	Ness [128]	7.36	4.12	34	6.45	3.47	25	100.00%	0.23 [-0.28, 0.75]
	Pre-swing	Ness [128]	8.81	5.34	34	12.10	5.02	25	63.20%	-0.62 [-1.15, -0.09]
		Van de Velde [215]	16.40	8.50	11	16.80	5.00	15	36.80%	-0.06 [-0.84, 0.72]
		Total (95% CI)			45			40	100.00%	-0.42 [-0.95, 0.12]
		Heterogeneity: $Tau^2 = 0.04$; $Chi^2 = 1.39$, df = 1 (P = 0.24); $I^2 = 28\%$ Test for overall effect: Z = 1.52 (P = 0.13)								
Hindfoot inversion /eversion	Initial contact	Ness [128]	4.48	10.34	34	-3.64	10.10	25	100.00%	0.78 [0.25, 1.32]
	Loading response	Ness [128]	2.76	1.99	34	4.10	2.02	25	53.80%	-0.66 [-1.19, -0.13]
		Van de Velde [215]	4.40	1.90	11	3.70	1.40	15	46.20%	0.42 [-0.37, 1.20]
		Total (95% CI)			45			40	100.00%	-0.16 [-1.22, 0.89]
		Heterogeneity: $Tau^2 = 0.46$; $Chi^2 = 4.95$, df = 1 (P = 0.03); $I^2 = 80\%$ Test for overall effect: Z = 0.30 (P = 0.76)								
	Mid-stance	Ness [128]	2.90	1.14	34	5.10	2.77	25	53.80%	-1.09 [-1.64, -0.53]
		Van de Velde [215]	10.50	1.80	11	10.70	3.10	15	46.20%	-0.07 [-0.85, 0.70]
		Total (95% CI)			45			40	100.00%	-0.62 [-1.61, 0.37]
		Heterogeneity: $Tau^2 = 0.40$; $Chi^2 = 4.33$, df = 1 (P = 0.04); $I^2 = 77\%$ Test for overall effect: Z = 1.22 (P = 0.22)								
	Terminal stance	Ness [128]	4.82	3.85	34	6.90	4.02	25	100.00%	-0.52 [-1.05, 0.00]

	Pre-swing	Ness [128]	6.66	5.28	34	6.22	3.75	25	51.90%	0.09 [-0.42, 0.61]
		Van de Velde [215]	11.40	4.90	11	21.50	4.20	15	48.10%	-2.17 [-3.18, -1.16]
		Total (95% CI)			45			40	100.00%	-1.00 [-3.21, 1.22]
		Heterogeneity: Tau² = 2.40; Chi² = 15.35, df = 1 (P < 0.0001); I² = 93% Test for overall effect: Z = 0.88 (P = 0.38)								
Hindfoot abduction /adduction	Initial contact	Ness [128]	4.88	8.56	34	-2.17	5.39	25	100.00%	0.94 [0.40, 1.49]
	Loading response	Ness [128]	2.57	1.17	34	5.35	2.81	25	52.00%	-1.35 [-1.93, -0.78]
		Van de Velde [215]	3.50	2.50	11	3.50	1.60	15	48.00%	0.00 [-0.78, 0.78]
		Total (95% CI)			45			40	100.00%	-0.70 [-2.03, 0.62]
		Heterogeneity: Tau² = 0.79; Chi² = 7.52, df = 1 (P = 0.006); I² = 87% Test for overall effect: Z = 1.04 (P = 0.30)								
	Mid-stance	Ness [128]	2.61	1.03	34	5.81	4.78	25	52.30%	-0.99 [-1.53, -0.44]
		Van de Velde [215]	3.70	2.50	11	2.90	1.80	15	47.70%	0.37 [-0.42, 1.15]
		Total (95% CI)			45			40	100.00%	-0.34 [-1.66, 0.98]
		Heterogeneity: Tau² = 0.79; Chi² = 7.64, df = 1 (P = 0.006); I² = 87% Test for overall effect: Z = 0.50 (P = 0.61)								
	Terminal stance	Ness [128]	5.70	4.77	34	6.50	2.55	25	100.00%	-0.20 [-0.72, 0.32]
	Pre-swing	Ness [128]	5.45	2.86	34	5.73	3.08	25	51.80%	-0.09 [-0.61, 0.43]
		Van de Velde [215]	3.10	1.60	11	10.30	2.80	15	48.20%	-2.94 [-4.10, -1.77]

		Total (95% CI) Heterogeneity: Tau² = 3.84; Chi² = 19.16, df = 1 (P < 0.0001); I² = 95% Test for overall effect: Z = 1.03 (P = 0.30)			45			40	100.00%	-1.46 [-4.25, 1.32]
Forefoot plantar flexion /dorsiflexion	Initial contact	Ness [128]	-27.69	11.49	34	-45.61	7.56	25	100.00%	1.76 [1.15, 2.38]
	Loading response	Ness [128]	3.70	4.37	34	4.55	2.34	25	69.30%	-0.23 [-0.75, 0.29]
		Van de Velde [215]	3.30	2.10	11	3.60	1.70	15	30.70%	-0.15 [-0.93, 0.62]
		Total (95% CI) Heterogeneity: Tau² = 0.00; Chi² = 0.02, df = 1 (P = 0.88); I² = 0% Test for overall effect: Z = 0.94 (P = 0.35)			45			40	100.00%	-0.21 [-0.64, 0.22]
	Mid-stance	Ness [128]	3.23	2.62	34	5.35	2.54	25	51.50%	-0.81 [-1.35, -0.27]
		Van de Velde [215]	5.40	3.10	11	2.90	1.30	15	48.50%	1.08 [0.24, 1.92]
		Total (95% CI) Heterogeneity: Tau² = 1.66; Chi² = 13.81, df = 1 (P = 0.0002); I² = 93% Test for overall effect: Z = 0.11 (P = 0.91)			45			40	100.00%	0.11 [-1.75, 1.96]
	Terminal stance	Ness [128]	5.53	2.99	34	11.03	4.87	25	100.00%	0.04 [-0.47, 0.56]
	Pre-swing	Ness [128]	7.79	8.36	34	8.73	3.57	25	69.40%	-0.14 [-0.65, 0.38]
		Van de Velde [215]	16.40	8.50	11	16.80	5.00	15	30.60%	-0.06 [-0.84, 0.72]
		Total (95% CI)			45			40	100.00%	-0.11 [-0.54, 0.32]

		Heterogeneity: Tau² = 0.00; Chi² = 0.03, df = 1 (P = 0.87); I² = 0% Test for overall effect: Z = 0.51 (P = 0.61)								
Forefoot inversion /eversion	Initial contact	Ness [128]	-4.53	8.55	34	-6.41	8.10	25	100.00%	0.22 [-0.30, 0.74]
	Loading response	Ness [128]	4.16	2.18	34	7.21	5.16	25	56.40%	-0.80 [-1.34, -0.27]
		Van de Velde [215]	2.20	1.70	11	2.20	1.50	15	43.60%	0.00 [-0.78, 0.78]
		Total (95% CI)			45			40	100.00%	-0.45 [-1.24, 0.33]
		Heterogeneity: Tau² = 0.21; Chi² = 2.78, df = 1 (P = 0.10); I² = 64% Test for overall effect: Z = 1.14 (P = 0.26)								
	Mid-stance	Ness [128]	2.71	1.30	34	6.10	4.58	25	57.90%	-1.07 [-1.62, -0.51]
		Van de Velde [215]	1.50	0.70	11	1.80	0.90	15	42.10%	-0.35 [-1.14, 0.43]
		Total (95% CI)			45			40	100.00%	-0.77 [-1.46, -0.08]
		Heterogeneity: Tau² = 0.14; Chi² = 2.13, df = 1 (P = 0.14); I² = 53% Test for overall effect: Z = 2.17 (P = 0.03)								
	Terminal stance	Ness [128]	5.53	2.99	34	11.03	4.87	25	100.00%	-1.39 [-1.97, -0.82]
	Pre-swing	Ness 2008	8.39	5.59	34	12.91	5.08	25	59.10%	-0.83 [-1.37, -0.29]
		Van de Velde [215]	5.40	1.90	11	10.80	3.60	15	40.90%	-1.74 [-2.67, -0.81]
		Total (95% CI)			45			40	100.00%	-1.20 [-2.08, -0.32]
		Heterogeneity: Tau² = 0.26; Chi² = 2.74, df = 1 (P = 0.10); I² = 64% Test for overall effect: Z = 2.68 (P = 0.007)								

Forefoot abduction /adduction	Initial contact	Ness [128]	-2.61	10.00	34	-16.44	7.66	25	100.00%	1.50 [0.91, 2.09]
	Loading response	Ness [128]	5.94	1.91	34	9.91	6.24	25	68.70%	-0.91 [-1.45, -0.37]
		Van de Velde [215]	1.50	0.70	11	2.50	1.70	15	31.30%	-0.70 [-1.51, 0.10]
		Total (95% CI)			45			40	100.00%	-0.85 [-1.30, -0.40]
		Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.17$, df = 1 (P = 0.68); $I^2 = 0\%$								
		Test for overall effect: Z = 3.68 (P = 0.0002)								
	Mid-stance	Ness [128]	3.29	2.21	34	5.92	2.84	25	51.60%	-1.04 [-1.59, -0.49]
		Van de Velde [215]	3.50	3.00	11	2.20	1.30	15	48.40%	0.58 [-0.22, 1.38]
		Total (95% CI)			45			40	100.00%	-0.26 [-1.84, 1.33]
		Heterogeneity: $Tau^2 = 1.19$; $Chi^2 = 10.72$, df = 1 (P = 0.001); $I^2 = 91\%$								
		Test for overall effect: Z = 0.32 (P = 0.75)								
	Terminal stance	Ness [128]	4.33	2.56	34	8.51	3.66	25	100.00%	-1.34 [-1.92, -0.77]
	Pre-swing	Ness [128]	6.86	3.36	34	13.17	4.68	25	51.90%	-1.57 [-2.16, -0.97]
		Van de Velde [215]	7.20	5.30	11	8.20	2.90	15	48.10%	-0.24 [-1.02, 0.54]
		Total (95% CI)			45			40	100.00%	-0.93 [-2.23, 0.37]
		Heterogeneity: $Tau^2 = 0.76$; $Chi^2 = 7.06$, df = 1 (P = 0.008); $I^2 = 86\%$								
		Test for overall effect: Z = 1.40 (P = 0.16)								
Hallux plantar flexion /dorsiflexion	Initial contact	Ness [128]	12.15	7.96	34	19.38	8.07	25	100.00%	-0.89 [-1.43, -0.35]
		Ness [128]	5.88	3.98	34	10.08	4.99	25	60.20%	-0.94 [-1.48, -0.39]

	Loading response	Van de Velde [215]	7.60	5.90	11	9.30	5.20	15	39.80%	-0.30 [-1.08, 0.48]
		Total (95% CI) Heterogeneity: Tau² = 0.08; Chi² = 1.71, df = 1 (P = 0.19); I² = 41% Test for overall effect: Z = 2.19 (P = 0.03)			45			40	100.00%	-0.68 [-1.29, -0.07]
	Mid-stance	Ness [128]	2.98	2.58	34	5.68	3.15	25	55.90%	-0.94 [-1.49, -0.40]
		Van de Velde [215]	7.80	6.00	11	8.40	4.20	15	44.10%	-0.12 [-0.89, 0.66]
		Total (95% CI) Heterogeneity: Tau² = 0.22; Chi² = 2.90, df = 1 (P = 0.09); I² = 66% Test for overall effect: Z = 1.41 (P = 0.16)			45			40	100.00%	-0.58 [-1.38, 0.23]
	Terminal stance	Ness [128]	14.15	9.03	34	23.03	8.10	25	100.00%	-1.01 [-1.56, -0.46]
	Pre-swing	Ness [128]	15.52	9.38	34	25.55	10.67	25	68.80%	-1.00 [-1.54, -0.45]
		Van de Velde [215]	29.40	11.90	11	37.80	8.20	15	31.20%	-0.82 [-1.64, -0.01]
		Total (95% CI) Heterogeneity: Tau² = 0.00; Chi² = 0.12, df = 1 (P = 0.73); I² = 0% Test for overall effect: Z = 4.05 (P < 0.0001)			45			40	100.00%	-0.94 [-1.40, -0.49]
Medial longitudinal arch angle	Loading response	Van de Velde [215]	2.40	2.00	11	4.10	2.40	15	100.00%	-0.73 [-1.54, 0.07]
	Mid-stance	Van de Velde [215]	4.10	2.70	11	6.70	2.20	15	100.00%	-1.04 [-1.88, -0.20]
	Preswing	Van de Velde [215]	14.40	5.40	11	21.30	7.70	15	100.00%	-0.98 [-1.81, -0.15]

Ankle joint

The ankle joint movement was defined as the relative angle between the tibia and calcaneus for movement in the sagittal plane. Meta-analyses show large significant effects for greater ankle plantar flexion in TPT compared to controls at initial contact (n of studies = 2) (SMD (95% CI) -1.4 (-1.8 to -1.0) and loading response (n of studies = 3) (SMD (95% CI) -1.4 (-2.2 to -0.7), and medium effects at terminal stance (n of studies = 3) (SMD (95% CI) -1.0 (01.4 to -0.6) and pre-swing (n of studies = 3) (SMD (95% CI) -0.7 (-1.1 to -0.3)) (**Table 5-6**/**Figure 5-3**). Medium effects were also found in one study for greater plantar flexion during mid-stance in TPT compared to controls (SMD (95% CI) -1.1 (-1.7 to -0.6) (**Table 5-6**/**Figure 5-3**). There were no differences between groups for excursion except for during initial contact (n of studies = 1) where individuals with TPT had significantly less hindfoot sagittal plane excursion (SMD (95% CI) -1.2 (-1.8 to -0.7) (**Table 5-7**).

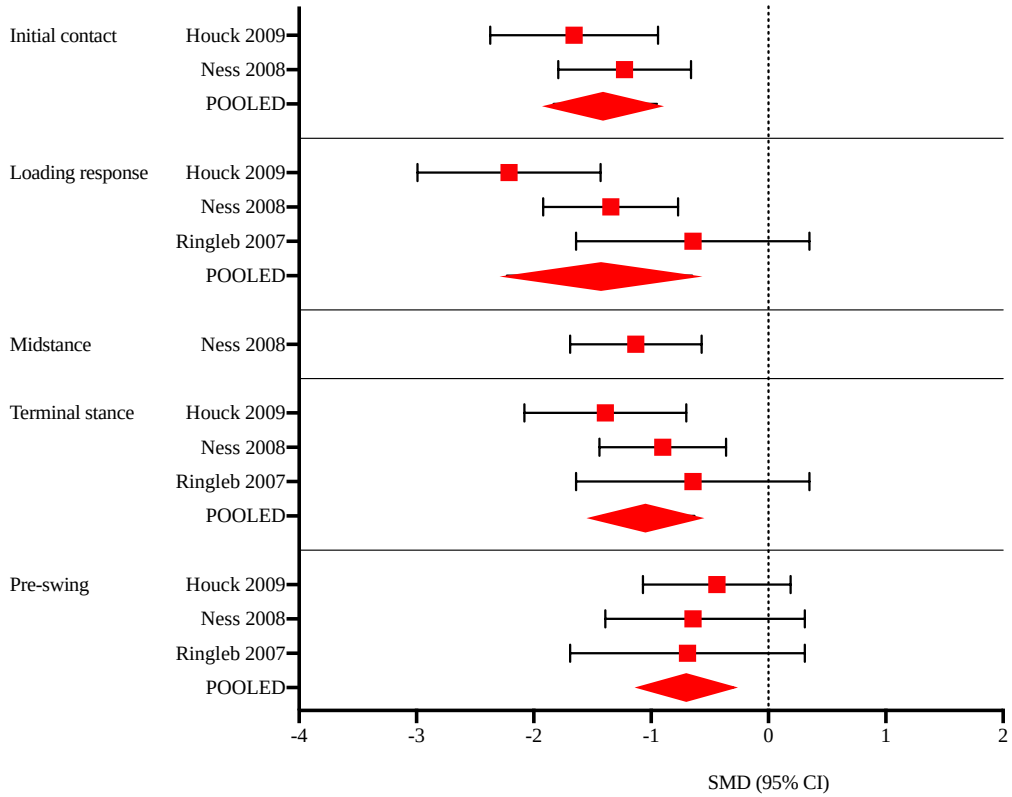


Figure 5-3 *SMD (95% CI) for ankle plantar flexion/dorsiflexion peak values in the sagittal plane (-SMDs indicate greater plantarflexion in TPT compared to controls).*

Hindfoot

For movement of the hindfoot relative to the tibia in the coronal plane, large significant effects were found for greater hindfoot eversion at mid-stance in TPT compared to controls (n of studies = 3)

(SMD (95% CI) -1.3 (-1.88 to -0.66) (**Table 5-6**/**Figure 5-4**). Medium effects were found for greater eversion at initial contact (n of studies = 2) (SMD (95% CI) -0.8 (-1.2 to -0.4), loading response (n of studies = 5) (SMD (95% CI) -1.1 (-1.5 to -0.6), terminal stance (n of studies = 5) (SMD (95% CI) -0.9 (-1.6 to -0.2) and pre-swing (n of studies = 5) (SMD (95% CI) -1.1 (-1.7 to -0.5) in TPT compared to controls (**Table 5-6**/**Figure 5-4**).

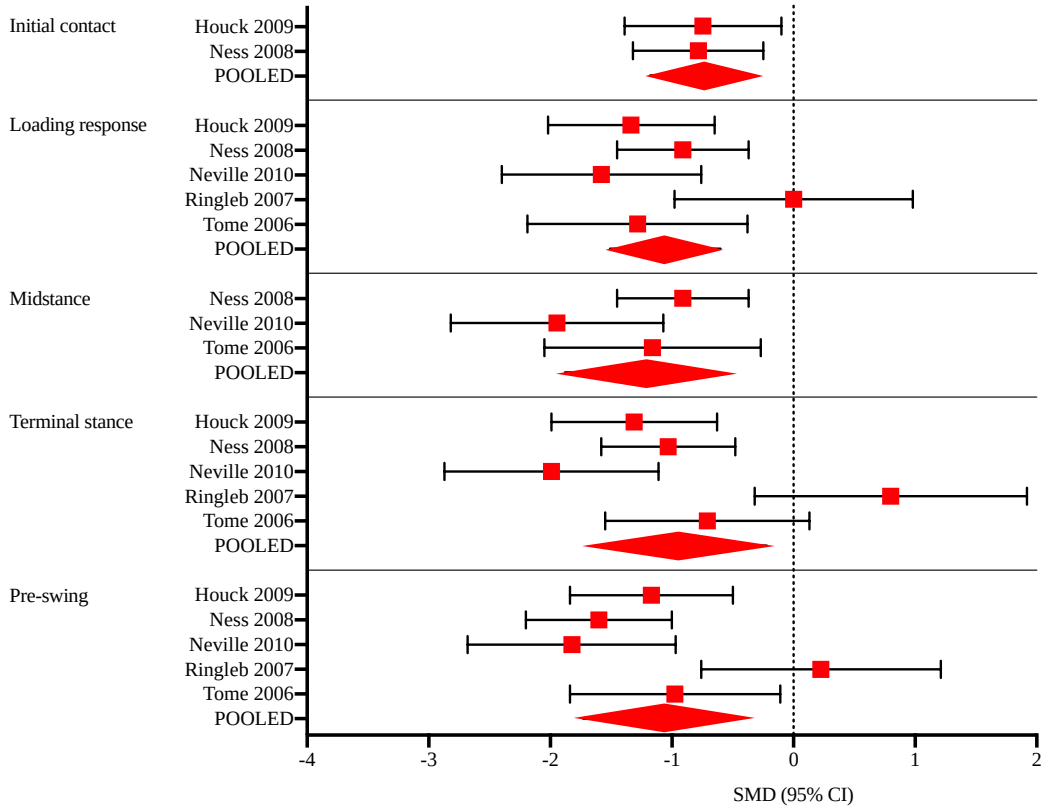


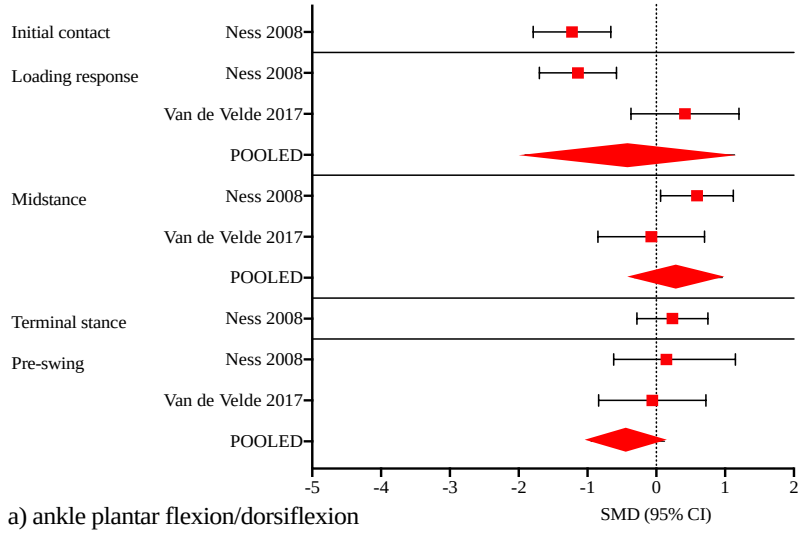
Figure 5-4 *SMD (95% CI) for hindfoot eversion/inversion peak values in the coronal plane (-SMDs indicate greater eversion in TPT compared to controls).*

One study reported peak hindfoot eversion angle, time to peak eversion and total eversion excursion throughout the stance phase [126] and no differences were found between individuals with TPT and controls (**Table 5-8**). At initial contact, there was a medium effect for greater hindfoot eversion excursion in TPT compared to controls (n of studies = 1) (SMD (95% CI) 0.8 (0.3 to 1.3) and there were no other differences in hindfoot excursion between groups in the coronal or transverse planes (**Table 5-7**/**Figure 5-5**).

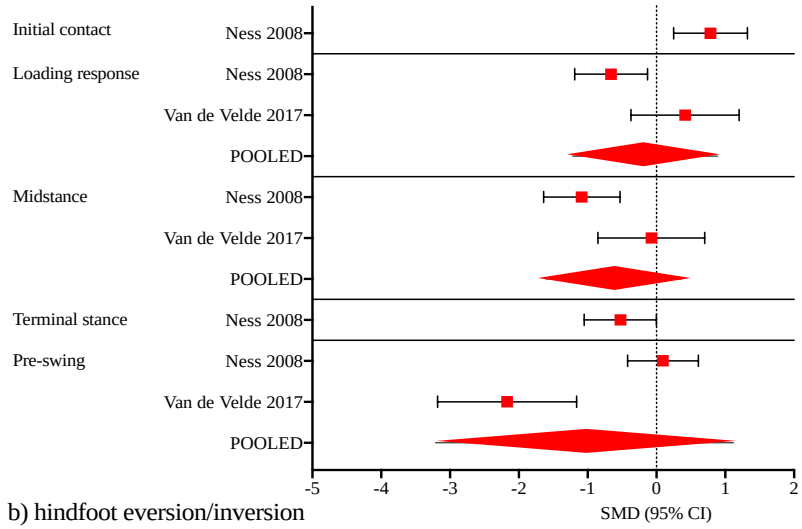
Table 5-8 *Findings for studies reporting kinematic variables unable to be included in forest plots/meta-analyses*

Study	Gait parameter	Event during gait	Mean difference / significant findings between TPT and controls	Effect size (95% CI)
Houck [124]	First metatarsal dorsiflexion (ref: calcaneus)	Entire stance phase	8.8 degrees (4.3 to 13.2) more dorsiflexion in TPT	
	Hindfoot (ref: global)	Initial contact	4 degrees greater plantarflexion in TPT	
		15% stance	4.5 degrees greater plantarflexion in TPT	
	First metatarsal dorsiflexion (ref: global)	Entire stance phase	13.7 degrees (8.4 to 18.9) more dorsiflexion in TPT	
Neville [125]	Hindfoot eversion	Entire stance phase	7.8 (4.1 to 11.5) degrees more everted in TPT	1.45 (0.64 to 2.25)
Rabbito [126]	Peak hindfoot eversion	Entire stance phase	3.1 (0.1 to 6.1) degrees more everted in TPT	0.80 (-0.04 to 1.64)
	Hindfoot eversion excursion	Entire stance phase	0.7 (-1.15 to 2.55) degrees more eversion excursion in TPT	0.29 (-0.51 to 1.10)
	Time to peak eversion	% of stance phase	7.7 (-0.92 to 16.32) % later in TPT	0.69 (-0.14 to 1.52)
	Peak MLA	Entire stance phase	0.5 (-7.48 to 6.48) degrees lower in TPT	-0.06 (-0.86 to 0.75)
Ringleb [214]	Time to peak ankle plantarflexion	% of stance phase	3 (0.06 to 5.94) % earlier in TPT	-0.97 (-1.99, 0.06)
	Time to peak forefoot dorsiflexion	% of stance phase	Earlier in TPT	

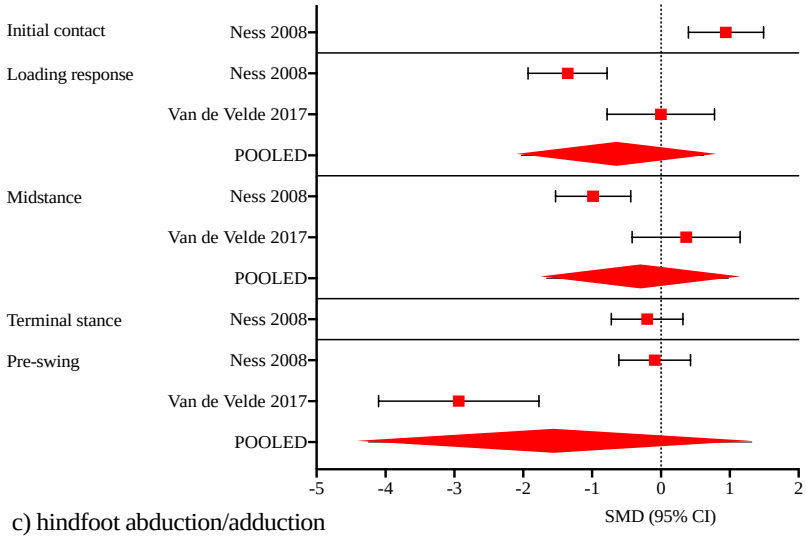
Abbreviations: TPT; tibialis posterior tendinopathy,CI; confidence interval, ref; reference, MLA; medial longitudinal arch



a) ankle plantar flexion/dorsiflexion



b) hindfoot eversion/inversion



c) hindfoot abduction/adduction

Figure 5-5 *SMD (95% CI) for hindfoot excursion in TPT compared to controls (+SMDs indicate greater excursion in TPT).*

Forefoot

For movement of the forefoot relative to the hindfoot (calcaneus) in the sagittal plane, pooled SMDs found a large significant effect for greater forefoot dorsiflexion at initial contact (n of studies = 2) (SMD (95% CI) 1.4 (0.8 to 2.1) and pre-swing (n of studies = 3) (SMD (95% CI) 1.3 (0.8 to 1.8) in TPT compared to controls (**Table 5-6**/**Figure 5-6**). No differences were found during loading response (n of studies = 3) (SMD (95% CI) 1.0 (-0.1 to 2.0)) or terminal stance (n of studies = 2) (SMD (95% CI) 0.7 (-0.7 to 2.2) in TPT compared to controls (**Table 5-6**/**Figure 5-6**). SMDs from one study showed a large effect for greater forefoot dorsiflexion in TPT compared to controls at mid-stance ((SMD (95% CI) 1.8 (1.2 to 2.4) (**Table 5-6**/**Figure 5-6**).

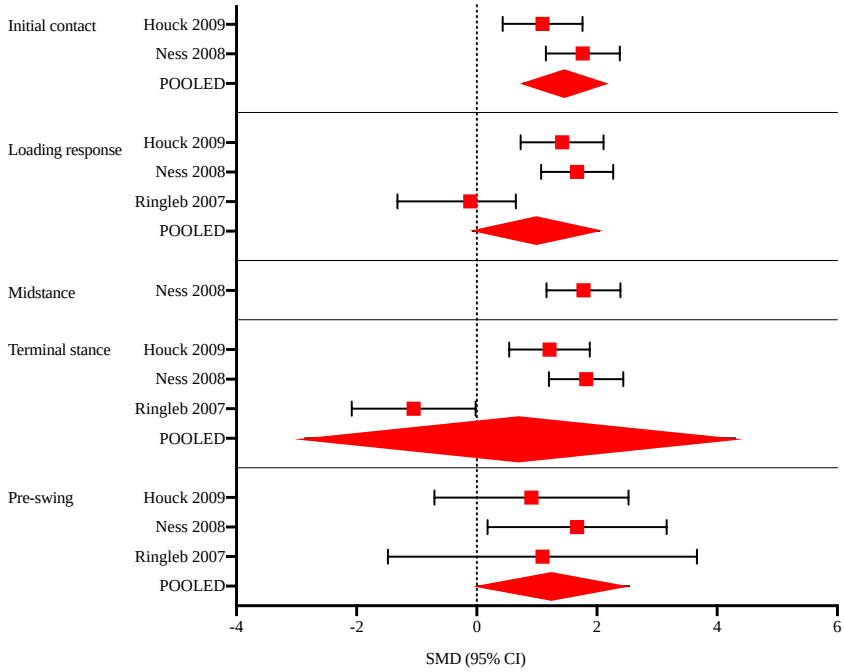
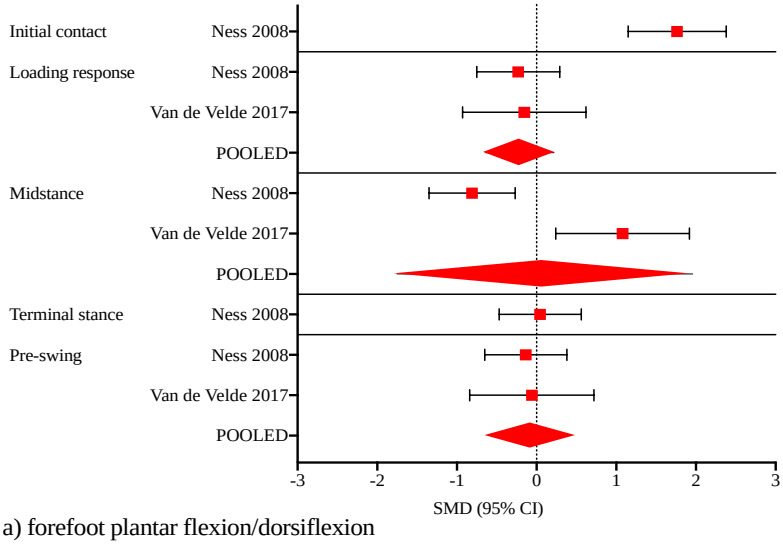
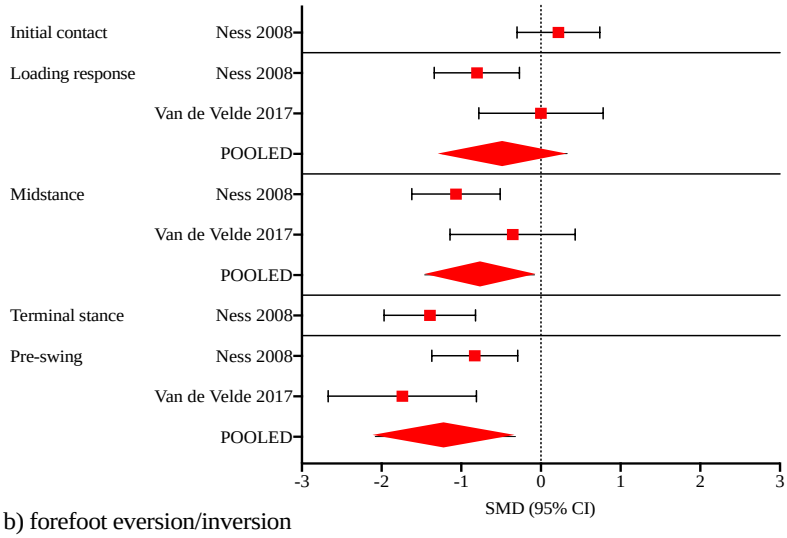


Figure 5-6 *SMD (95% CI) for forefoot plantar flexion/dorsiflexion in the sagittal plane (+SMDs indicate greater dorsiflexion in TPT compared to controls).*

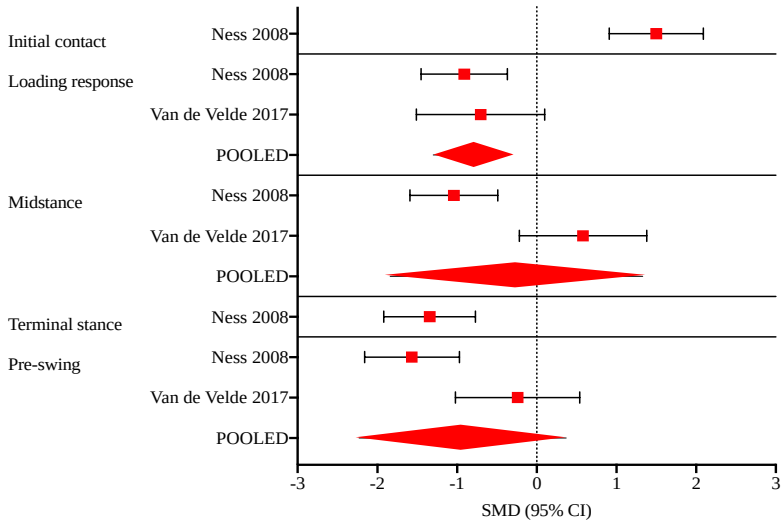
Considering forefoot excursion in the sagittal plane, one study showed a large effect for greater excursion at initial contact in individuals with TPT compared to controls ((SMD (95% CI) 1.8 (1.2 to 2.4) (**Table 5-7**/**Figure 5-7**). There were no other differences between TPT and controls for forefoot sagittal plane excursion (**Table 5-7**/**Figure 5-7**) or coronal plane peak angles during any stance phase (**Table 5-6**/**Figure 5-8**). Medium to large effects (SMD > 0.61) were found for less coronal plane excursion in TPT compared to controls in mid-stance (n of studies = 2) (SMD (95% CI) -0.8 (-1.5 to -0.1), terminal stance (n of studies = 1) (SMD (95% CI) -1.4 (-2.0 to -0.8) and pre-swing (n of studies = 2) (SMD (95% CI) -1.2 (-2.1 to -0.3)) (**Table 5-7**/**Figure 5-7**).



a) forefoot plantar flexion/dorsiflexion



b) forefoot eversion/inversion



c) forefoot abduction/adduction

Figure 5-7 *SMD (95% CI) for forefoot excursion in TPT compared to controls (+SMDs indicate greater excursion in TPT).*

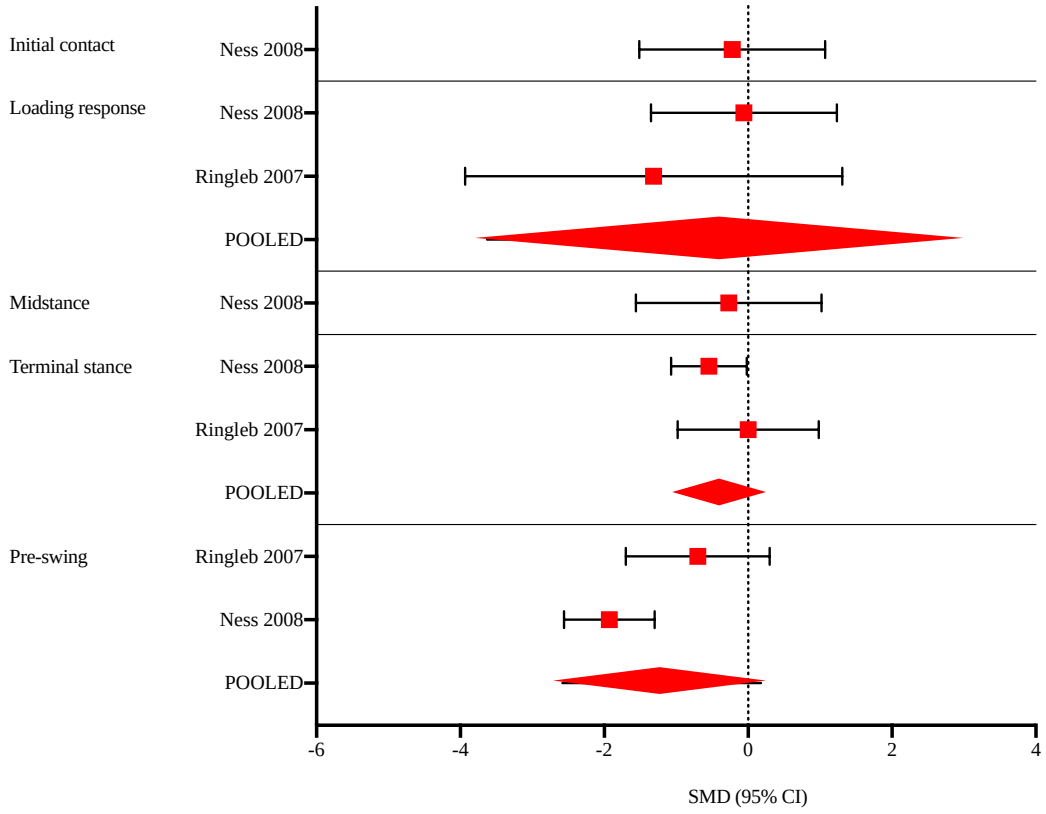


Figure 5-8 *SMD (95% CI) for forefoot eversion/inversion in the coronal plane (-SMDs indicate greater eversion in TPT compared to controls).*

In the transverse plane, pooled SMDs showed medium to large effects for greater forefoot abduction in TPT compared to controls throughout loading response (n of studies = 4) (SMD (95% CI) -1.1 (-1.5 to -0.8), mid-stance (n of studies = 3) (SMD (95% CI) -1.0 (-1.4 to -0.6) and pre-swing (n of studies = 4) (SMD (95% CI)-1.4 (-2.3 to -0.5)) (**Table 5-6**/**Figure 5-9**). Although a medium effect for greater forefoot abduction was found at terminal stance (n of studies = 4), this did not reach statistical significance (SMD (95% CI) -0.7 (-1.6 to 0.2)) (**Figure 5-9**). During loading response, there was a large effect for greater forefoot abduction in TPT compared to controls from one study ((SMD (95% CI) -1.5 (-2.1 to -0.9) (**Table 5-6**/**Figure 5-9**). Medium to large effects for less forefoot excursion in the transverse plane in TPT compared to controls were found during loading response (n of studies = 2) (SMD (95% CI) -0.9 (-1.3 to -0.4) and terminal stance (n of studies = 1) (SMD (95% CI) -1.3 (-1.9 to -0.8). At initial contact, one study found greater forefoot excursion in the transverse plane in TPT compared to controls (SMD (95% CI) 1.5 (0.9 to 2.1) (**Table 5-7**/**Figure 5-7**).

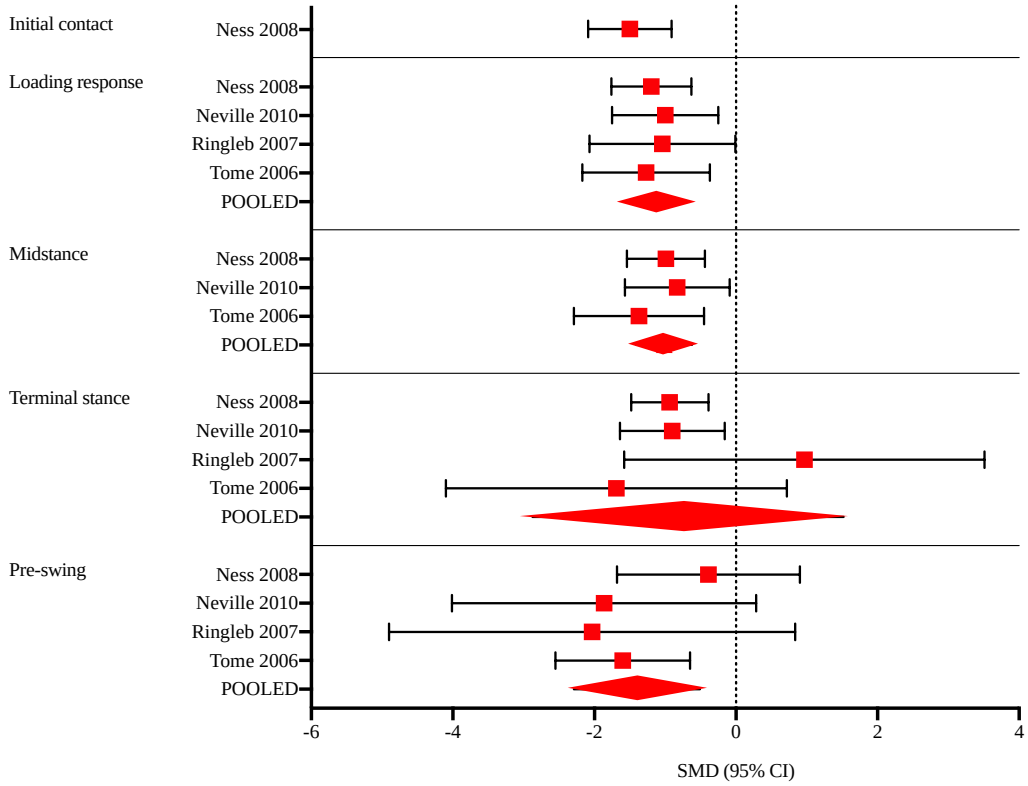


Figure 5-9 *SMD (95% CI) for forefoot abduction/adduction in the transverse plane (-SMDs indicate greater abduction in TPT compared to controls).*

Medial longitudinal arch

The medial longitudinal arch angle was generated from markers on the calcaneus, first metatarsal head and navicular tuberosity. Pooled SMDs from two studies showed large, significant effects for lower medial longitudinal arch height in TPT compared to controls at loading response (SMD (95% CI) 1.3 (0.7 to 1.9), mid-stance (SMD (95% CI) 1.3 (0.7 to 1.9) and pre-swing (SMD (95% CI) 1.5 (0.9 to 2.1), and medium effects at terminal stance (SMD (95% CI) 1.1 (0.5 to 1.6) (**Table 5-6**/**Figure 5-10**). One study reported peak medial longitudinal arch (i.e., lowest value) throughout the gait cycle but this was not different between groups ((SMD (95% CI) -0.06 (-0.86 to 0.75)) (**Table 5-8**). For medial longitudinal arch excursion, one study found medium effects at mid-stance (SMD (95% CI) -1.0 (-1.9 to -0.2) and pre-swing (SMD (95% CI) -1.0 (-1.8 to -0.2) for less medial longitudinal arch excursion in TPT compared to controls but no difference at loading response (SMD (95% CI) -0.7 (-1.5 to 0.1) **Table 5-7**/**Figure 5-11**).

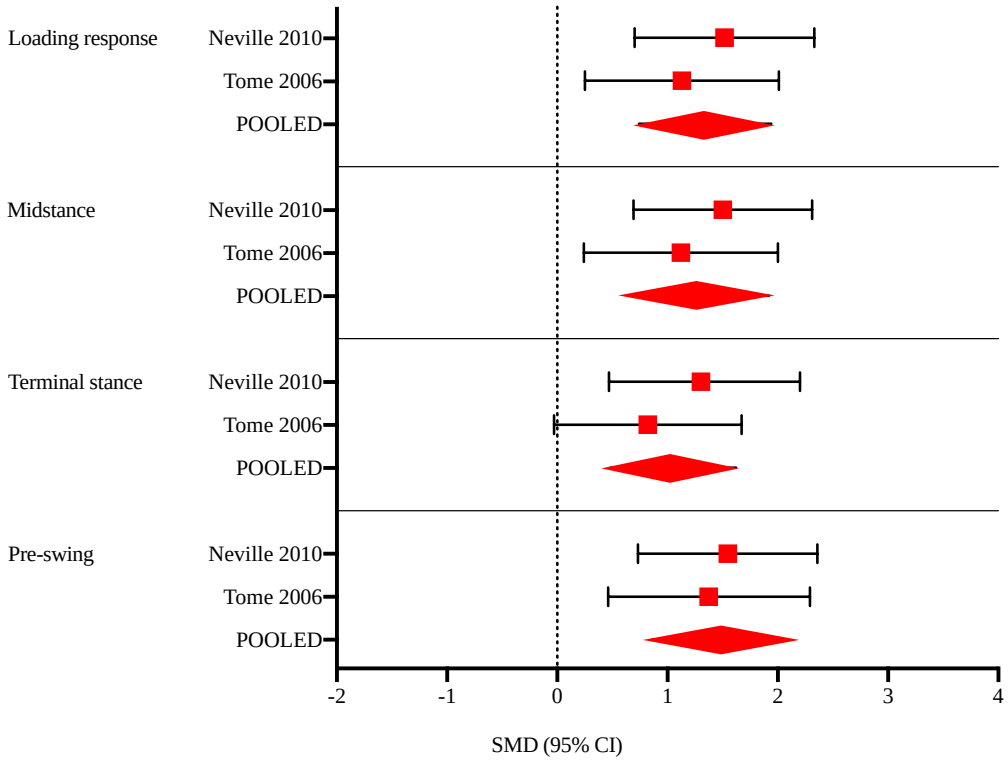
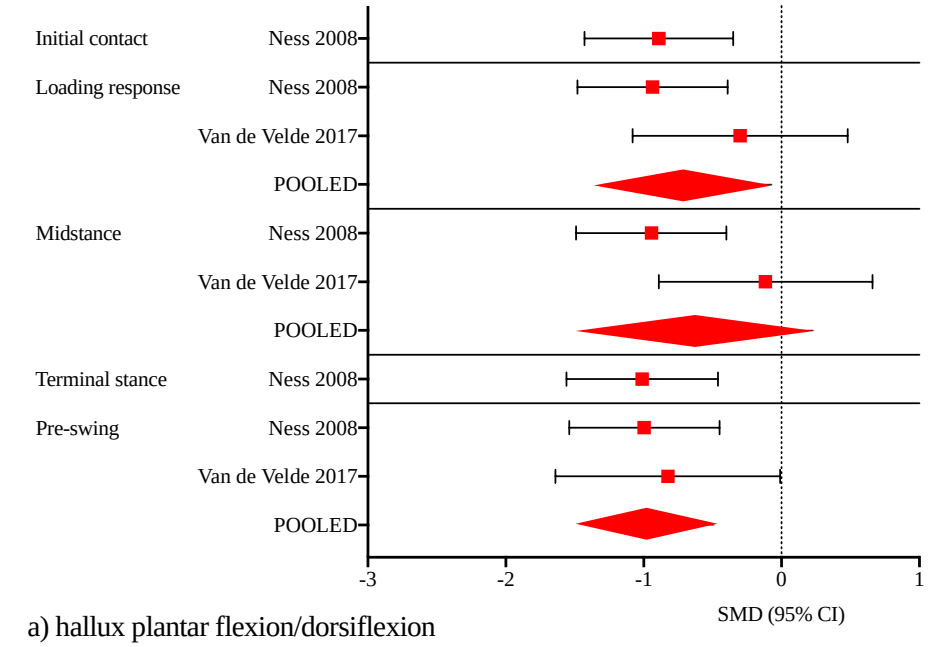


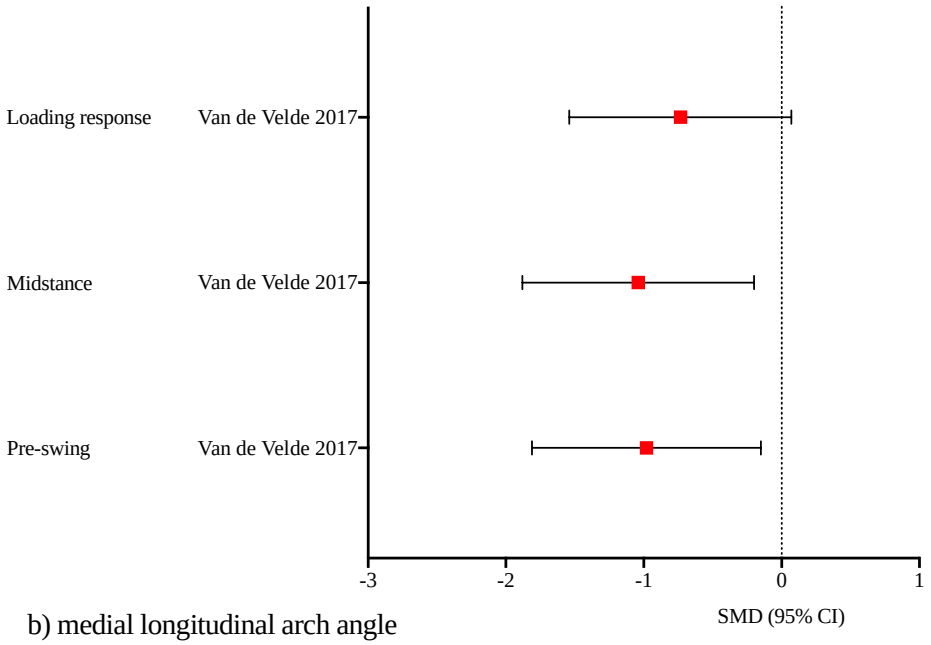
Figure 5-10 *SMD (95% CI) for medial longitudinal arch angle (+SMDs indicate lower medial longitudinal arch height (greater angle) in TPT compared to controls).*

Hallux

Movement of the hallux relative to the forefoot was measured in two studies. [128 215] There were medium effects for less hallux excursion in the sagittal plane during initial contact (n of studies = 1) (SMD (95% CI) -0.9 (-1.4 to -0.4), loading response (n of studies = 2) (SMD (95% CI) -0.7 (-1.3 to -0.1) and terminal stance (n of studies = 1) (SMD (95% CI) -1.0 (-1.6 to -0.5) (**Table 5-7**/**Figure 5-11**).



a) hallux plantar flexion/dorsiflexion



b) medial longitudinal arch angle

Figure 5-11 *SMD (95% CI) for a) hallux plantar flexion/dorsiflexion and b) medial longitudinal arch excursion in TPT compared to controls (+SMDs indicate greater excursion in TPT).*

5.1.4 Discussion

This systematic review provides a comprehensive synthesis of foot and ankle kinematic characteristics of individuals with TPT compared to controls during the stance phase of gait. It is clear that foot kinematics are different in individuals with TPT compared to controls during the stance phase of gait. Meta-analyses demonstrated large effects (SMD >1.2) for greater ankle plantar

flexion, hindfoot eversion, forefoot abduction and lower medial longitudinal arch height, particularly during the loading response and push-off phases of gait.

Differences in kinematics between individuals with TPT and controls were most predominant during the phases of stance in which the TP muscle has the greatest activity in healthy populations. [216] Anatomically, the TP muscle contracts eccentrically to limit hindfoot eversion at the subtalar joint, forefoot abduction, [146] and stabilise the medial longitudinal arch during loading response. Concentric contraction during mid-stance controls pronation and inverts and stabilises the hindfoot locking the midtarsal joint to allow effective propulsion by the plantar flexors during push-off. [216] [217] As such, greater hindfoot eversion and forefoot abduction during loading response, lower medial longitudinal arch height and reduced forefoot plantar flexion during push-off observed in individuals with TPT compared to controls are suggestive of an inefficient TP muscle-tendon unit.

Impaired TP capacity has been demonstrated in studies investigating heel raise height, endurance and plantar flexion inversion force in individuals with TPT compared to controls. [195] Pain and difficulty performing a SLHR is a key clinical feature of TPT. [79] [84] Five of the seven studies in this review included pain or difficulty with a SLHR in the selection criteria for the TPT group. Individuals with TPT have demonstrated lower heel height and ankle plantar flexion with greater forefoot forefoot dorsiflexion and subtalar eversion during a SLHR task compared to age-matched controls. [67] These findings are consistent with the foot and ankle kinematics found during the push-off phase of gait in this systematic review. Previous research has identified that the biomechanical characteristics and TP muscle activity required during the push-off phase of gait are similar to those during a SLHR. [218]

Alterations in muscle activity and coordination occur in the presence of musculoskeletal pain [219-221] and may be related to changes in movement patterns which occur when there is pain and dysfunction. Electromyographic (EMG) studies investigating muscle activity during walking in TPT are limited. One study has measured EMG simultaneously with kinematics in 5 individuals with TPT compared to 5 healthy controls and provides preliminary insight into TP muscle activity during gait. [214] There was greater TP EMG amplitude during the second half of stance and greater forefoot abduction in TPT during this phase. This suggests kinematic patterns indicative of a dysfunctional TP occur with greater muscle activity (motor recruitment) in individuals with TPT i.e. this increased motor recruitment strategy does not maintain normal kinematics. Greater EMG activity has previously been demonstrated in muscles of the lower limb when there is weakness. [222] Ringleb et al [214] also found impaired plantar flexor power during push-off with a lower degree of ankle plantar flexion range. While these findings provide some insight into TP muscle activity and

foot and ankle kinematics in TPT, further EMG studies with larger sample sizes are required to investigate timing and amplitude of muscle activity in TPT during gait.

Due to the role of the TP in supporting the medial longitudinal arch, alterations in arch height and foot posture have been frequently investigated in the literature. [195] There is strong evidence for lower arch height in individuals with TPT compared to controls. [195] Of the studies that investigated arch angle during gait, only one [126] did not find MLA to be lower in TPT compared to controls during gait, but it was the only one not to have flatfoot posture as an eligibility criteria. Furthermore, an association between foot posture and lower limb kinematics has been demonstrated in asymptomatic flatfoot populations. A systematic review has shown greater hindfoot eversion and forefoot abduction in low-arch foot posture compared to normal foot posture, and an association between increasing flatfoot posture and increased rearfoot eversion, and total range of motion. [208] Therefore it is unclear whether alterations in kinematics of the foot found in this systematic are related to the condition or the foot posture.

Whereas synthesis of the available evidence confirms the characteristic foot and ankle deformity and altered movement patterns proposed to be associated with TPT, the available evidence provides little insight into proximal movement patterns. Included papers did not collect or report kinematic characteristics of the hip or knee. One study was identified during full-text screening stage that reported hip and knee kinematics but was excluded from the review as it did not report foot/ankle data. Maeda (2018) found that individuals with TPT had increased knee internal rotation during the loading response of gait compared to controls. However, these findings are difficult to interpret with no foot/ankle data. [223] As alterations in movement patterns at the foot are likely to be accompanied by alterations proximally at the knee, femur, hip and/or pelvis, [114 116 120 224] future research should include kinematic analysis of the whole lower limb in TPT populations.

A key finding of this systematic synthesis was the variability in methodology for collecting, analysing and reporting kinematic data. A number of different models, with varying marker placement, definition of segments, and definitions of joint axes were used. While careful consideration was made before pooling data to ensure accuracy and homogeneity, there was still substantial heterogeneity (>75%) for some pooled SMDs. This needs to be considered when interpreting results. Sample size and subsequent power issues also need to be considered in interpretation, as sample size for pooled SMDs ranged between 55 and 184. Some papers were not able to be pooled due to differences between studies in definitions of joints and movements, angles reported (i.e. peak versus average) and time points during stance phase of gait that were used. This limits the overall sample size of the meta-analysis. Standardised and consistent models, methodology and reporting in future studies would permit replication and increase overall

confidence in kinematic findings. Consistency would also increase robustness of future meta-analyses as accuracy, measurement error and sample size are frequent limitations for individual kinematic studies.

5.1.5 Conclusion

Differences in foot and ankle kinematics between individuals with TPT and controls include greater ankle plantar flexion, hindfoot eversion, forefoot abduction and lower medial longitudinal arch height, particularly during the loading response and push-off phases of gait. Interventions aimed at supporting the medial longitudinal arch during loading activities and improving dynamic stability may assist with symptom modification.

PART B:

Experiments to better understand TPT

This section consists of three lab studies designed to contribute to the understanding of the clinical presentation of TPT by addressing gaps identified in Part A.

CHAPTER 6 Diagnostic utility of clinical tests for tibialis posterior tendinopathy

6.1 Diagnostic accuracy of clinical tests to diagnose ultrasound-confirmed tibialis posterior tendinopathy in patients presenting with medial foot/ankle pain

Part A has critically appraised and evaluated the literature for TPT. Chapter three provided recommendations for selection criteria for stage I and II PTTD (i.e TPT). This chapter explores the diagnostic accuracy of four clinical tests (selected based on the findings in Chapter three) compared to ultrasound (US) confirmation of TP tendon pathology. The aim of this chapter is to determine how well commonly used clinical tests can identify grey scale changes within the TP tendon using US as the reference standard. Of all tests, single leg heel raise (SLHR) was most likely to identify grey scale changes within the TP tendon.

Ross MH, Smith MD, Durbridge, G, Vicenzino B. The diagnostic accuracy of clinical tests to diagnose ultrasound-confirmed tibialis posterior tendinopathy in patients presenting with medial foot/ankle pain. *Submitted to BJSM.*

Contributor	Statement of contribution
Megan H Ross (Candidate)	Conception and design (50%) Data acquisition (50%) Analysis and interpretation (70%) Drafting and production (60%)
Dr Michelle D Smith	Conception and design (15%) Analysis and interpretation (15%) Drafting and production (15%)
Dr Rebecca Mellor	Conception and design (15%) Drafting and production (15%)
Dr Gail Durbridge	Conception and design (5%) Data acquisition (50%)
Professor Bill Vicenzino	Conception and design (15%) Analysis and interpretation (15%)

	Drafting and production (10%)

6.1.1 Introduction

Tibialis posterior tendinopathy (TPT) presents as pain on the medial side of the mid- to rear-foot and/or ankle and is associated with difficulties during activities that load the tibialis posterior tendon. [84] TPT is considered to occur on a continuum from disordered tendon to joint destruction, [48 51 133] and is regarded to be the most common cause of acquired flatfoot deformities in adults. [45 129] Current literature suggests that TPT is often misdiagnosed, or goes undiagnosed, until significant and prolonged symptoms severely interfere with function. [47 70]

The 2019 International Consensus Statement defined tendinopathy as persistent tendon pain and loss of function related to mechanical loading. [64] We recently conducted a systematic review of selection criteria for TPT in primary research papers. [84] Tenderness on palpation, swelling along the tendon, poor plantar flexion-inversion (PF/INV) strength and difficulties performing a single leg heel raise (SLHR) were identified as the most frequently reported clinical features of TPT used for study inclusion.[84] These clinical signs are specifically thought to be indicative of TPT, but to date there is a lack of data supporting their validity.

The diagnostic utility of clinical findings for identifying TPT when it is shown on imaging has not been tested. Diagnostic ultrasound (US) is commonly used to assess tendon changes. High-resolution US is a cost effective, readily accessible and clinically available tool, [182] that has shown good sensitivity and specificity for diagnosing TPT when using MRI as the reference standard. [182 225-227] It is a reliable method for assessing greyscale tendon changes (e.g. hypoechogencity, fibrillar disruption) [228-230] and can reliably measure tendon size. [231]

Determining clinical tests that are reliable and can assist clinicians to identify TPT in individuals presenting with medial ankle pain will assist appropriate diagnosis and management of the condition. The aim of this study was to determine the reliability and utility of clinical tests in detecting tibialis posterior tendon pathology on US in individuals presenting with medial foot/ankle pain.

6.1.2 Methods

Study design

We conducted a diagnostic utility study in which individuals with medial foot/ankle pain underwent an US examination (reference standard) by a sonographer and a clinical examination (index tests) performed by physiotherapists. All examiners were blind to each other's findings.

Participants

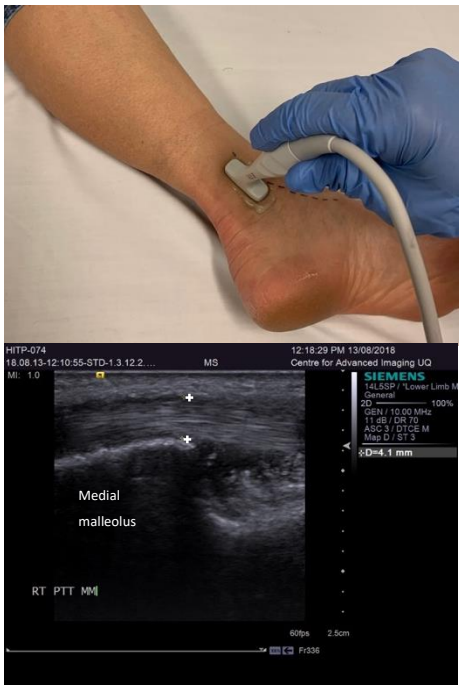
Participants were recruited through local advertisements (social media, websites) within a 50 kilometre radius of the Brisbane area between November 2017 and March 2019. Eligibility was determined via a preliminary online screening survey and subsequent phone screening. Participants were eligible if they were aged between 18 and 70 years and reported average medial ankle/foot pain greater than 2 out of 10 on an 11 point Numerical Rating Scale (NRS) (where 0 = no pain and 10= worst pain imaginable) that had been present on most days for a minimum of 3 months and were able to attend both the clinical and US exam sessions. The presence of medial foot/ankle pain was determined based on the participant's reporting of the location of their pain. Participants were excluded if self-reported (and clinician confirmed) location of pain was not on the medial aspect of the foot/ankle, if they had any known neurological disorders or other known medical conditions (i.e. gout, fibromyalgia, rheumatoid or psoriatic arthritis).

Reference standard

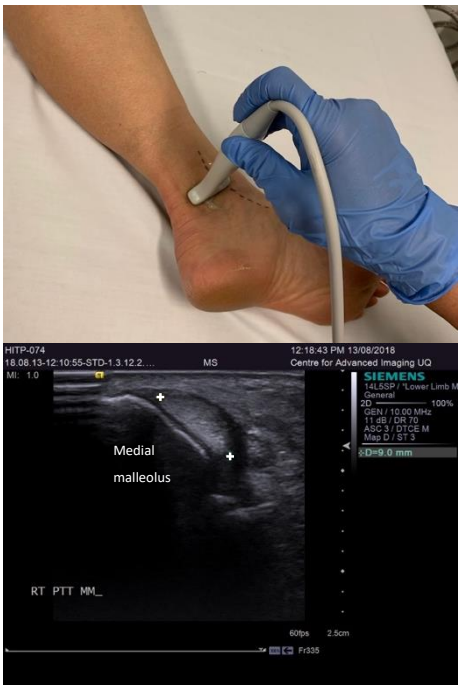
Diagnostic US imaging was used as the reference standard as it has been shown to be reliable for detecting echogenicity, fibrillar disruption, and changes in tendon size. [228-231] These US changes are considered to represent TPT.[139 175 232] The US scans were performed by an experienced sonographer. Participants were recumbent during testing, with the ankle in neutral. The sonographer performed a standardised assessment of the tibialis posterior tendon in both longitudinal and transverse views using a Siemens/Acuson S3000 14MHz linear array 'hockey stick' probe (**Figure 6-1**). Based on current literature, the standardised assessment included evaluation of the tendon for greyscale changes (including hypoechoic changes in the tendon, fibrillar disruption and tendon thickening) [233,234] which were rated as positive (present) or negative (absent). The reference standard was considered positive when there was at least one greyscale finding within the tendon present on US examination.

To increase our confidence that these findings were clinically relevant, we surveyed health care professionals on their views of which US features were most important in diagnosing TPT (**Appendix 6**). The health care professionals ranked greyscale changes on US as being most important in diagnosing TPT.

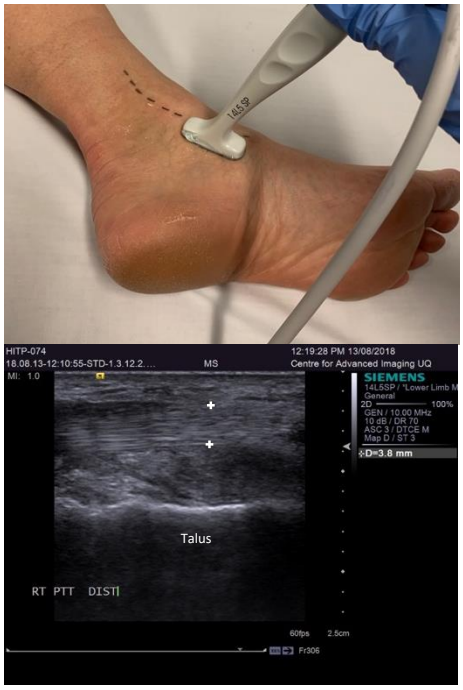
Measurements of the antero-posterior and transverse tendon diameters and hypoechoic areas were reported (where present) from longitudinal and transverse views both posterior to the medial malleolus (posterior to the most prominent aspect of the medial malleolus) and mid-way between the medial malleolus and navicular tuberosity (**Figure 6-1**).



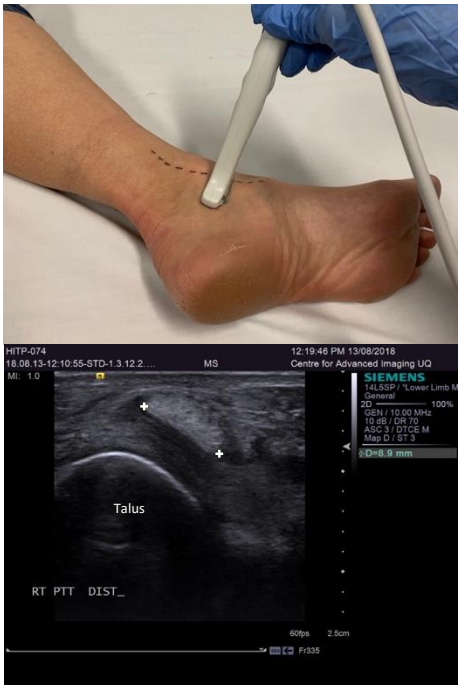
a) Longitudinal measurement at the level of the medial malleolus



b) Antero-posterior measurement at the level of the medial malleolus



c) Longitudinal measurement at the midpoint between the medial malleolus and the navicular tuberosity



d) Antero-posterior measurement at the midpoint between the medial malleolus and the navicular tuberosity

Figure 6-1 *Ultrasound measurements of the tibialis posterior tendon*

Index tests

We studied four index tests (palpation, observation, manual resisted contraction, weight bearing) that we found from a systematic review of the literature. [84] The index tests were rated as positive if there was: tenderness on palpation along the course of the tibialis posterior tendon (from the musculotendinous junction to insertion on the navicular tuberosity), palpable or visible swelling of the tendon sheath along the course of the tendon, pain or weakness on manually resisted isometric contraction of ankle PF/INV in neutral, and pain on or inability performing one SLHR. The SLHR test was performed barefoot, with light fingertip support from the examiner as required. Participants were asked to perform one SLHR to their maximum height in a controlled manner. We also tested a combination of palpation plus one of the two loading tests (PF/INV, SLHR) in order to replicate what seems to be common clinical practice of using palpation and loading in diagnosing tendinopathy. [64]

Procedure

Participants were invited to attend a testing session during which two physiotherapists (minimum 7 years clinical experience) independently screened for eligibility and assessed the index tests for TPT (based on the criteria above). US imaging was conducted within 2 weeks of the clinical examination (assessment of index tests) with sonographer and physiotherapists blind to each other's findings.

Analysis

Sample characteristics

Participant characteristics between those with and without US defined TPT or the combined clinical tests (palpation plus a loading test) were analysed with independent t-tests for continuous data and the chi-square statistic for categorical data. Pairwise comparisons were used to evaluate group differences and expressed as mean differences (MDs) and standardised mean differences (SMDs) with 95% CIs. Effect sizes were interpreted as: < 0.2 trivial effect, 0.2 - 0.6 small effect, 0.61 – 1.2 moderate effect, and > 1.2 large effect. [88]

Reliability of the index tests

Statistical analysis was performed using IBM SPSS V24 (SPSS Chicago, Illinois, USA). Inter-rater agreement for the reliability of each index test (positive, negative) was calculated using the κ-statistic (95% confidence interval (CI)). A κ of < 0.00 was interpreted as poor agreement, 0.00-0.20 slight agreement, 0.21 – 0.40 fair agreement, 0.41 – 0.60 moderate agreement, 0.61 – 0.80 substantial agreement or 0.81 to 1.00 almost perfect agreement. [89]

Diagnostic utility analyses

A series of 2x2 contingency tables were constructed to cross-tabulate the positive and negative results of the index tests (including the clinical diagnosis (as defined above for this study)) with the reference standard of diagnostic US.

Sensitivity (i.e. the probability that the index test is positive when US is positive), specificity (i.e. the probability that the index test is negative when US is negative), positive predictive value (PPV) (i.e. probability that US is positive when then index test is positive), negative predictive value (NPV) (i.e. the probability that US is negative when the index test is negative) and their 95% CIs were calculated for each index test and for the clinical diagnosis overall (i.e. tender on palpation plus one positive loading index test). [235] Positive likelihood ratios (LR+) (i.e. the ratio between the probability of a positive index test when US is positive and the probability of a positive index test when US is negative) and negative likelihood ratios (LR-) (i.e. the ratio between the probability of a negative test when US is positive and the probability of a negative test when US is negative) were calculated to provide an estimate of the shift in probability of the condition being present based on a positive or negative index test.[236] Likelihood ratios between 0 and 1 decrease the probability of the reference standard being positive, likelihood ratios greater than 1 increase the probability and ratios close to 1 have little effect on the post-test probability. 95% CIs were calculated and the LR was considered statistically significant if the CIs did not contain 1. [236]

6.1.3 Results

Participant features

Fifty-two participants (42 (80.8%) females) with a mean (SD) age of 46.2 (12.3) years and worse medial foot/ankle pain over the previous week of 6.5/10 (2.2) were included in this study (**Table 6-1**). There were no differences in sex, body mass index and pain levels between positive and negative clinical diagnosis or presence of TPT as per the reference standard. Interestingly, the positive US group was approximately a decade older than the negative US group (**Table 6-1**).

Figure 6-2 outlines the flow of participants through the study and the results of the clinical and US assessments. Twenty-two participants (42.3%) had greyscale changes in the tibialis posterior tendon on US, and 28 (54%) had a positive clinical diagnosis (i.e. tenderness on palpation of the tibialis posterior tendon and one positive loading index test) (**Table 6-1**/**Figure 6-2**). There were no adverse events related to the clinical or US assessments.

Table 6-1 *Participant demographics. All data are presented as mean (SD) or n (%).*

	All (n = 52)	Clinical +ve (n = 28)	Clinical -ve (n = 24)	p-value	US +ve (n = 22)	US -ve (n = 30)	p-value
Women n	42 (80.8)	23 (82.1)	19 (79.2)	0.79	18 (81.8)	24 (80.0)	0.87
Left study side, n	29 (55.8)	14 (50.0)	15 (62.5)	0.37	14 (63.6)	15 (50.0)	0.33
Age, years	46.2 (12.3)	47.0 (13.7)	45.3 (10.9)	0.62	51.2 (12.1)	42.5 (11.4)	*0.01*
Height, m	1.67 (0.09)	1.66 (0.08)	1.69 (0.10)	0.15	1.65 (0.09)	1.68 (0.09)	0.19
Mass, kg	84.7 (22.0)	87.1 (25.0)	81.2 (17.7)	0.35	86.8 (21.5)	82.6 (22.4)	0.50
Body mass index, kg/m^2	30.1 (7.6)	30.4 (6.7)	29.7 (8.7)	0.74	31.5 (8.0)	29.1 (7.2)	0.26
Average pain /10	4.4 (1.9)	4.4 (2.1)	4.3 (1.7)	0.96	4.3 (2.0)	4.4 (1.8)	0.93
Worst pain /10	6.5 (2.2)	6.6 (2.4)	6.3 (2.0)	0.57	6.7 (2.4)	6.3 (2.1)	0.58

Abbreviations: +ve; positive, -ve; negative, US; ultrasound

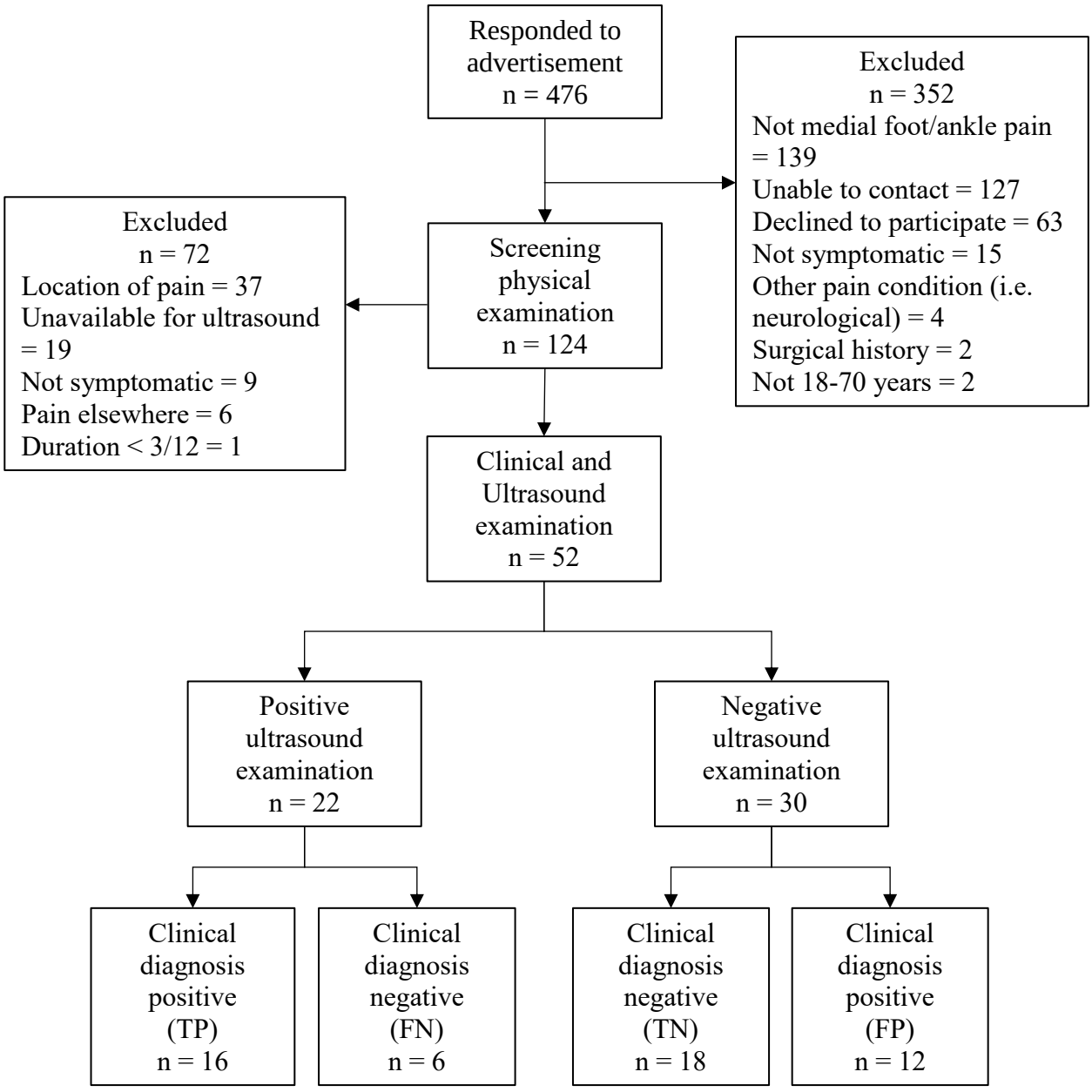


Figure 6-2 *Participant flow through the study and results of the US and clinical examinations*

Reliability of index tests

There were 4 participants for whom a second rater was not available to perform the index test examination, which leaves 48 participants in the reliability analysis. Pain or inability to perform a SLHR had the highest inter-rater agreement (κ 0.74 (95% CI 0.54 to 0.93), with the two physiotherapists agreeing in 42 of 48 cases (87.5%) (**Table 6-2**). There was moderate inter-rater agreement for swelling of the tibialis posterior tendon (77.1% agreement, κ 0.54 (95% CI 0.30 to

0.78), pain/weakness with resisted PF/INV (72.9% agreement, κ 0.46 (95% CI 0.21 to 0.71) and tenderness on palpation (75.0% agreement, κ 0.44 (95% CI 0.18 to 0.69).

Table 6-2 *Inter-rater agreement for index tests (n = 48)*

Index test	Kappa statistic	Standard error	95% CI		p-value
Pain/inability to SLHR	0.74	0.099	0.54	0.93	<0.001
Swelling along tendon course	0.54	0.121	0.30	0.78	<0.001
Pain/weakness with resisted PF/INV	0.46	0.127	0.21	0.71	0.001
Tenderness on palpation	0.44	0.129	0.18	0.69	0.002

Abbreviations: CI; confidence interval, PF/INV; plantar flexion-inversion, SLHR; single leg heel raise

Diagnostic utility of the index tests

Of the individual index tests, the SLHR (pain or inability to perform) had the highest sensitivity (77.3%), identified 17 true cases of TPT (positive index test and positive US) and had the lowest number of false negatives (5 TPT on US not picked up by the index tests). Specificity was 63.3%, identifying 19 (over 80%) true negatives, and this index test had the highest accuracy rate (69.2%), PPV (60.7%) and NPV (79.2%) (**Table 6-3**). Pain or inability to perform a SLHR had the largest positive and negative LR and was the only individual index test for which the CIs did not include 1. This indicates that pain or inability to perform a SLHR is the single most useful index test for ruling TPT both in and out i.e. if SLHR is positive there is a greater likelihood that TPT is present on US, or if SLHR is negative there is a lower likelihood that TPT is present on US (approximately 20% shift in probability, see **Table 6-4**).

For the combination of palpation plus one positive loading index test, there were 16 true positives (positive clinical diagnosis and positive US), 18 true negatives (negative clinical diagnosis and negative US), 12 false positives (positive clinical diagnosis and negative US) and 6 false negatives (negative clinical diagnosis and positive US) (**Table 6-3**/**Figure 6-2**) The clinical examination had a reasonable sensitivity (72.7%), specificity (60.0 %) and accuracy rate (i.e. the overall probability that a participant was correctly classified using the clinical diagnosis was 65.4%) (**Table 6-3**/**Figure 6-2**). The LR+ and LR- (95% CI) for the clinical diagnosis were 1.8 (1.1 to 3.0) and 0.5 (0.2 to 1.0) respectively.

Table 6-3 *Index test results and indices of clinical utility in the diagnosis of tibialis posterior tendinopathy using US as the reference standard*

Index test	TP	TN	FP	FN	Sens (%) (95% CI)	Spec (%) (95% CI)	PPV (%) (95% CI)	NPV (%) (95% CI)	LR+ (95% CI)	LR- (95% CI)	Accuracy (%) (95% CI)
Clinical diagnosis of TPT^	16	18	12	6	72.7 (49.8 to 89.3)	60.0 (40.6 to 77.3)	57.1 (44.5 to 68.9)	75.0 (58.8 to 86.3)	1.82 (1.09 to 3.02)	0.45 (0.22 to 0.95)	65.4 (50.9 to 78.0)
Tender on palpation	15	14	16	7	68.2 (45.1 to 86.1)	46.7 (28.3 to 65.7)	48.4 (37.7 to 59.3)	66.7 (49.3 to 80.5)	1.3 (0.8 to 2.0)	0.7 (0.3 to 1.4)	55.8 (41.3 to 69.5)
Swelling along tendon course	12	18	12	10	54.6 (32.2 to 75.6)	60.0 (40.6 to 77.3)	50.0 (35.9 to 64.1)	64.3 (51.1 to 75.6)	1.4 (0.8 to 2.44)	0.8 (0.4 to 1.3)	57.7 (43.2 to 71.3)
Pain/weakness with resisted PF/INV	10	19	11	12	45.5 (24.2 to 67.8)	63.3 (43.9 to 80.1)	47.6 (32.1 to 63.7)	61.3 (49.8 to 71.7)	1.2 (0.6 to 2.4)	0.9 (0.5 to 1.4)	55.8 (41.3 to 69.5)
Pain/inability to SLHR	17	19	11	5	77.3 (54.6 to 92.2)	63.3 (43.9 to 80.1)	60.7 (47.8 to 72.3)	79.2 (62.6 to 89.6)	2.1 (1.25 to 3.55)	0.4 (0.2 to 0.8)	69.2 (54.9 to 81.3)

Abbreviations: TP; true positive, TN; true negative, FP; false positive, FN; false negative, Sens; sensitivity, Spec, specificity, LR+; likelihood ratio positive, LR-; likelihood ratio negative. Key: ^ Positive clinical diagnosis of TPT = positive tender on palpation, and positive on at least one loading test

Table 6-4 *Interpreting Likelihood Ratios (LR) of clinical (index) tests and clinical implications assuming pre-test probability of 42% based on reference standard (greyscale changes on US).*

Index Test	Result	LR	Post-test Probability %	Change %	Implications
Pain or inability to SLHR*	+ve	2.1	60.3	18.3	If the patient experiences pain or cannot do a SLHR, probability of greyscale findings on US increases by 18% to 60%, if negative, probability of greyscale findings on US decreases by 20% to 23%.
	-ve	0.4	22.5	-19.5	
Clinical diagnosis^	+ve	1.8	56.6	14.6	If the patient is tender on palpation plus has pain/weakness with resisted PF/INV or pain/inability to SLHR, probability of greyscale findings on US increase by 15% to 57% and reduce to 27% if negative.
	-ve	0.5	26.6	-15.4	
Palpation	+ve	1.3	48.5	6.5	Almost no change in probability of greyscale findings on US with a positive or negative test
	-ve	0.7	33.6	-8.4	
Swelling along tendon	+ve	1.4	50.3	8.3	Almost no change in probability of greyscale findings on US with a positive or negative test
	-ve	0.8	36.6	-5.4	
Pain or weakness with isometric PF/INV contraction	+ve	1.2	46.5	4.5	Almost no change in probability of greyscale findings on US with a positive or negative test
	-ve	0.9	39.5	-2.5	

*Abbreviations: LR; likelihood ratio, +ve; positive, -ve; negative, PF/INV; plantar flexion/inversion, SLHR; single leg heel raise, US; ultrasound^ tender on palpation plus 1 of loading tests, * tests with LR CIs that did not contain 1.*

True and false positives and negatives for tenderness on palpation, swelling of the posterior tibial tendon sheath and pain or weakness with resisted PF/INV are provided in **Table 6-3**. For tenderness

on palpation, specificity and PPV were low (fewer true positives than false positives) indicating that isolated tenderness on palpation of the tibialis posterior tendon may have minimal clinical utility in ruling out TPT (i.e. identified on index test when there is no TPT on US). PPV for swelling was 50.0%, indicating that the presence of swelling has no/minimal clinical utility in ruling out the presence of TPT (as many true positives as false positives). The PPV for pain or weakness with resisted PF/INV was 47.6%, indicating that less than half of those who tested positive had TPT on US. Twelve participants who tested negative to this index test were positive on US (highest number of false negatives of all index tests and lowest NPV (61.3%)).

Measurements of tendon diameter

We also compared tendon diameter as measured on US between true positives (positive clinical and US) and true negatives (negative clinical and US) and observed TPT to have greater diameter (**Table 6-5**). There was a large SMD (effect) for anteroposterior tendon diameter at the medial malleolus, moderate effect for greater transverse tendon diameter at the medial malleolus, and moderate effect for anteroposterior diameter at the midpoint between the medial malleolus and the navicular insertion of the tendon (**Table 6-5**).

Table 6-5 *Ultrasound measurements of tendon diameter and hypoechoic regions for true positives compared to true negatives*

	Positive on Clinical + US			Negative Clinical + US			Positive v Negative					
Measurement (mm)	n	Mean	SD	n	Mean	SD	MD	95% CI		p-value	SMD	95% CI	
AP tendon at medial malleolus	16	5.21	1.26	18	3.92	0.69	1.29	0.56	2.02	0.00	1.26	0.53	2.00
Transverse tendon at medial malleolus	16	9.62	1.85	18	8.09	2.17	1.53	0.11	2.95	0.04	0.74	0.04	1.43
AP tendon at MP	16	4.91	1.90	18	3.39	0.51	1.52	0.49	2.56	0.01	1.10	0.38	1.82
Transverse tendon at MP	16	9.89	2.90	18	8.36	2.21	1.53	-0.26	3.33	0.09	0.58	-0.10	1.27
Hypoechoic region in longitudinal^	5	5.84	2.60	0	-	-	-	-	-	-	-	-	-
Hypoechoic region in transverse^	5	3.88	1.97	0	-	-	-	-	-	-	-	-	-

Key: ^; only measured if present, -; cannot be computed because at least one of the groups was 0

Abbreviations: US; ultrasound (reference standard) SD; standard deviation, MD; mean difference, CI; confidence interval, AP; anteroposterior measurement, MP; midpoint between medial malleolus and navicular insertion

6.1.4 Discussion

To our knowledge, this is the first study in patients with medial foot/ankle pain that investigates the diagnostic utility and reliability of commonly used clinical tests for TPT. [84] We used grey scale changes seen in the tibialis posterior tendon on US as the reference standard. Overall our findings indicate that commonly used clinical examination tests have low diagnostic utility in identifying those patients who have grey scale changes on US in the tibialis posterior tendon. This should be viewed in light of the reasonably low prevalence rate of US identified TPT in our sample (22/52, 42%).

SLHR found to have best clinical utility

Of the 22 individuals presenting with US identified TPT, over 70% were correctly identified clinically by either having pain or an inability to perform a SLHR (17, 77%) or a clinical diagnosis that was a combination of positive findings on palpation and one of the active contraction tests of the tibialis posterior muscle (16, 73%). Considering both reliability and diagnostic utility of the individual index tests, SLHR appears the most useful index test when greyscale changes in the tibialis posterior tendon are present with US as the reference standard. SLHR had the highest inter-rater agreement ($\kappa = 0.74$) and largest effects across all indices of diagnostic utility (**Table 6-3**). Pain or inability to perform a SLHR appears to be slightly more useful in ruling out the presence of TPT on US, as it had highest sensitivity and negative likelihood ratios of all indices, including when combined with palpation in the clinical diagnosis test. Negative SLHR almost halved the probability of the patient having grey scale changes on US (see **Table 6-4**).

Despite the SLHR index test having the greatest diagnostic utility of those examined in this study (the only test with CI not containing the null), there were still a significant proportion of participants who tested positive to the SLHR test that did not have signs of TPT on US (11 false positives). This suggests that a SLHR may also be painful in individuals presenting with other causes of medial foot/ankle pain, and may not help to differentially diagnose TPT from other medial ankle pathologies. For example, the lower limb in a SLHR experiences 100% of the body mass in load, which conceivably loads the mid-tarsal joints or other nearby tendons (e.g., flexor hallucis longus). Alternatively, the US examination evaluated only greyscale changes, which may not be sufficiently sensitive to detect earlier pathological changes in the tendon or paratendon that could conceivably be a source of pain in this area. [237]

Loading in clinical examination tests of tendinopathy

Tendinopathies are characterised by pain localised to the tendon that increases with loading. [238] The SLHR test is frequently described as a key component of the examination for TPT, [51] due to the role

of the tibialis posterior muscle in plantar flexion, inversion and stabilising and lifting the medial longitudinal arch. [239] The forces acting on the lower limb during a SLHR (due to 100% body mass) plausibly places more load through the tibialis posterior tendon than those during a clinician's manually resisted PF/INV isometric contraction. This may explain the greater sensitivity and accuracy of the SLHR index test than the resisted PF/INV test (i.e. fewer false negatives for SLHR than resisted PF/INV). In another lower limb tendinopathy (gluteal tendinopathy), we showed that a test that included weight bearing on a single limb had better clinical utility than manually resisted isometric contractions of the involved muscles. [240] Together with our data, this suggests that manual resistance may not provide sufficient load to elicit a positive response and that for lower limb tendinopathies, bodyweight loading is probably more useful in identifying when there are signs of tendinopathy on imaging.

Our physiotherapists applied manual resistance to an isometric contraction of PF/INV muscles with the rearfoot in an anatomically neutral position. That is, we did not test in a position of dorsiflexion and eversion, which would additionally stress the tibialis posterior tendons where it passes from posterior the medial malleolus to its primary destination at the navicular bone. [107] In our study of gluteal tendinopathy, we found that manually resisted isometric contractions in positions of the hip that added compression load to the tendons were diagnostically more useful. [240] It is compelling to speculate that performing resisted PF/INV in a dorsiflexed and everted position, thereby adding compression and tensile stresses to the tendon, may increase the diagnostic utility of this manually limited isometric PF/INV test.

Palpation

Tenderness on palpation has historically been a key component of the clinical examination for differentiating lower limb musculoskeletal conditions. [241] In this study, sensitivity of palpation was moderate (68%) and specificity was low (50%). This indicates there were as many true negatives as false positives, limiting the utility of palpation for ruling out TPT. The inter-rater reliability for tenderness on palpation of the tibialis posterior tendon was moderate ($\kappa = 0.41$), which is likely to have influenced the diagnostic utility of the test. The clinical utility of palpation for accurately predicting pathology in tendons as seen on imaging must be interpreted with consideration of the comparator group (i.e. asymptomatic or pain group) and the reliability of the test. For example, compared to an asymptomatic cohort, inter-rater reliability of palpation for Achilles tendinopathy was substantial to almost perfect ($\kappa = 0.72$ to 0.86), specificity was high (85% (75 to 91)) and sensitivity was moderate (58% (39 to 75)). [242] Reliability of palpation is likely influenced by palpation skills/technique of the clinician and the specific area. That is, close proximity of other

anatomical structures that might be sensitized/painful (e.g., as in conditions such as tarsal tunnel syndrome or posterior impingement). [241]

Low specificity values indicate that tenderness on palpation may be present in tendons that do not have US-identified tendinopathy (i.e. high number of false positives; positive results when there is no tendinopathy on US). When all participants in diagnostic utility studies present with pain, the specificity of palpation for diagnosing tendinopathy on imaging is lower than compared to when the cohort includes asymptomatic participants (e.g., 47% in gluteal tendinopathy, [240] and between 6% [243] and 70% [244] in patellar tendinopathy compared to 85% when the comparator is asymptomatic [242]). In our study, there were 16 false positives (47% specificity) which suggests that other structures in the area are responsible for the symptoms. Alternatively, it is possible that some tendons that do not have US changes are tender on palpation. [245]

Clinical implications

Our data suggest that the index tests selected in this study may be more useful for ruling out TPT in patients presenting with medial foot/ankle pain. Table 4 provides a clinical example of this. The probability of a patient presenting with medial ankle pain being diagnosed as having TPT from this study is 42%. A positive SLHR index test would increase this probability to 60% (18% change), but if the test was negative, the post-test probability would decrease to 22% (19% change). These findings suggest that clinicians need to be cautious using palpation alone to make a diagnostic decision. While palpation forms an integral component of the physical examination and may be important to determine the location of pain, adding a loading test improves likelihood of correctly diagnosing when there is a TPT. Thus, adding a loading test to palpation improves the diagnostic utility of palpation alone. Of the two loading tests used in this study, loading with body weight has greater diagnostic utility. As such, clinicians should consider using the SLHR test in preference to manually resisted PF/INV for clinically diagnosing TPT.

Clinical signs of tendinopathy, specifically localised tendon pain that increases with load, can be present in the absence of degenerative pathological changes in the tendon. [246-248] The association between clinical signs and symptoms of tendinopathy and structural abnormalities is poor, [249] with abnormal imaging signs present in up to 50% of asymptomatic tendons. [250-253] Additionally, improvements in pain and function in tendinopathy are not mediated by changes in pathologic tendon structure. [254] Considering this disconnect between tendon pathology and clinical symptoms, [255] it is important for clinicians to consider imaging findings in conjunction with clinical signs of tendinopathy and presenting impairments to help guide management.

Limitations

There are limitations to consider when interpreting the results of this study. The first potential limitation is using US as the reference standard. While this means the findings are dependent on the inherent accuracy of US, it has been shown to be accurate and reliable when compared to magnetic resonance imaging [182 225-227] and is correlated with surgical findings. [139] Another potential limitation is that a single examiner performed all US assessments, where two clinicians performed the index test assessment. We only had access to one sonographer for this study and previous studies have shown better intra- than inter-rater reliability. [229] Second, the sample size is small and the indices of diagnostic utility (LRs) are small, lack precision (i.e., large CI), and (except for SLHR) all CIs contained 1 (i.e., null). As such, we were unable to confidently report shifts in post-test probability for three of the four index tests. Stronger conclusions may have been possible with a larger sample size, however this is the first study to investigate the reliability and utility of clinical tests for TPT that were identified by a systematic review of all primary research on the condition. Further research should seek ways to increase sample size so that estimates of diagnostic utility are more precise and also so that clinical prediction rules might be developed. Third, it must be considered that PPV and NPV are influenced by the prevalence of the disease in the population being tested (i.e. 42% in this case), and as such, the values reported in this study are only applicable when considering those presenting with medial ankle pain, not the general population. That said, the omission of asymptomatic participants in this study ensures there was no overestimation of the accuracy and sensitivity of the clinical tests in detecting tendinopathy. [246] This study reflects the use of clinical tests to diagnose tendinopathy in the clinical setting (i.e. to differentiate TPT from another cause of medial ankle pain).

6.1.5 Conclusion

Overall, the selected clinical tests for TPT have low diagnostic utility. In individuals with medial foot/ankle pain, pain or inability to perform a SLHR is likely to have the greatest utility in assisting a clinician to make a diagnosis of TPT. Common clinical tests such as palpation, manually resisted PF/INV and observing swelling along the tendon when applied as single tests are not useful in determining if TPT is present on US. Combining palpation with either SLHR or manually resisted PF/IN marginally improves the diagnostic utility of palpation, but it is still inferior to SLHR alone.

CHAPTER 7 Distinguishing features of tibialis posterior tendinopathy

7.1 Pronated foot posture, foot mobility and single leg heel raise capacity are distinguishing features of tibialis posterior tendinopathy

Chapter four investigated clinical impairments, pain and disability reported in the current TPT literature. The review highlighted that outcome measures were predominantly focussed on local tendon dysfunction and foot posture and that 9/10 studies had eligibility criteria relating to foot posture, which makes findings about altered foot posture in TPT difficult to interpret. The primary aim of this chapter was to determine if there were differences in a range of common clinical foot and ankle measures between individuals with medial foot/ankle pain that was attributed to TPT, those who had TPT plus concomitant pain, those with medial foot/ankle pain that was not attributed to TPT and pain-free controls.

Ross MH, Smith MD, Mellor, R, Vicenzino B. Heel raise capacity plus foot mobility and pronated posture distinguish individuals with tibialis posterior tendinopathy from those with concomitant pain, medial foot/ankle pain and pain-free: a cross sectional study.

Contributor	Statement of contribution
Megan H Ross (Candidate)	Conception and design (50%) Data acquisition (100%) Analysis and interpretation (70%) Drafting and production (70%)
Dr Michelle D Smith	Conception and design (25%) Analysis and interpretation (15%) Drafting and production (15%)
Professor Bill Vicenzino	Conception and design (25%) Analysis and interpretation (15%) Drafting and production (15%)

7.1.1 Introduction

Lower arch height and altered foot posture are frequently reported as key features of tibialis posterior tendinopathy. [84 195] Due to the path of the tendon on the posteromedial aspect of the ankle joint and its tendinous insertions to the plantar aspect of the tarsals and metatarsals, [256 257] dysfunction of the tibialis posterior is often implicated as the most common cause of an adult acquired flatfoot deformity. [46 258]

Literature suggests that tendinopathy is the early stage on a continuum of progressive failure of the tendon and osseoligamentous structures of the foot that maintain the medial longitudinal arch (e.g. the plantar calcaneonavicular ligament) which can progress to an acquired flatfoot deformity. [130] Flatfoot, and acquired flatfoot deformities have several eitiologies other than tibialis posterior tendinopathy, including congenital, neurological and traumatic causes. [132]

A recent systematic review found large, significant effects for lower arch height index (AHI; the height of the dorsum of the foot at 50% total foot length, divided by truncated foot length) [259] in individuals with tibialis posterior tendinopathy compared to controls. [195] This finding should be interpreted with caution as eligibility criteria for 9 out of 10 included studies required participants to demonstrate signs of flatfoot deformity, and specified control participants demonstrate AHI 1 standard deviation (SD) above normative values. [260] Subsequently, it is not currently clear whether flatfoot is a key feature of the presentation when there are clinical signs of tendinopathy of the tibialis posterior tendon.

Literature suggests that tibialis posterior tendinopathy is often misdiagnosed, or not diagnosed until the later stages when there is associated ligamentous failure and significant deformity and disability is present. [70] Identifying clinical features of tibialis posterior tendinopathy that are distinct from medial foot pain that is not attributable to tibialis posterior tendinopathy may assist with earlier diagnosis and developing targeted interventions. Due to the dearth of high quality randomised clinical trials for conservative management of tibialis posterior tendinopathy, the literature suggests management should be guided by presenting impairments. [65] Management strategies for pain in the medial foot and ankle regions vary considerably and a greater understanding of any differences in presenting impairments between those attributable to tibialis posterior tendinopathy and others may assist with the development of tailored management approaches for tibialis posterior tendinopathy.

The first aim of this cross sectional study was to determine if there were differences in a range of commonly used clinical foot and ankle measures between individuals who had medial foot/ankle pain that we attributed to tibialis posterior tendinopathy (TPT), those who had TPT plus concomitant pain (TPTplus), those with medial foot/ankle pain that is not attributable to TPT (non-

TPTMFP) and controls. A secondary aim was to evaluate if there were differences between the symptomatic and asymptomatic sides of individuals with TPT, TPTplus and non-TPTMFP and the asymptomatic side compared to controls. The reasons for including this analysis were two-fold; first, unilateral musculoskeletal conditions often manifest with bilateral impairments or deficits, [261] and side to side comparisons are common clinical practice in evaluating musculoskeletal conditions.

7.1.2 Methods

Participants

Participants were recruited from the Brisbane area between July 2017 and March 2019 for this cross sectional study. Participants between 18 and 70 years of age, reporting pain on the medial aspect of the foot and/or ankle and no history of lower limb surgery in the preceding 12 months, responded to online and print advertisements and completed an online screening survey. Potential participants invited to undergo a physical screening and testing session at the University of Queensland, Brisbane, Australia.

On physical examination, those volunteers who had medial foot/ankle pain were classified as TPT if they had pain on the medial aspect of the foot/ankle greater than 2/10 on a numerical rating scale (NRS) on most days for the preceding three months and pain or inability to perform a single leg heel raise (SLHR). These selection criteria were based on a diagnostic utility study of index tests for TPT (Study 5) and performed by two separate examiners to improve the confidence in the selection process. Of the participants meeting selection criteria for the TPT group, those who also had pain elsewhere in the lower limbs or back, including bilateral TPT symptoms, were further classified into the TPTplus group. Participants with medial foot/ankle pain greater than 2/10 on a NRS on most days for the preceding three months who tested negative to the SLHR test were classified as having non-TPTMFP. Where participants had bilateral TPT or non-TPTMFP, the most symptomatic side was considered the 'study side'. Participants were excluded if pain was not greater than 2/10 on most days in the preceding three months, or if pain was not in the medial aspect of the foot/ankle on physical screening. Control participants responded to an online screening survey and were eligible if they had no history of lower limb or back pain in the last 12 months and no history of lower limb surgery. Participants with neurological or inflammatory arthritic diseases were excluded from all groups.

Measures

To characterise foot posture and mobility, a range of commonly used clinical outcome measures were collected for all participants. Static foot posture was quantified visually using the Foot Posture Index (FPI). This simple and reliable [262] tool contains six criterion-based observations of the

rearfoot and forefoot which are used to classify foot posture. Observations are graded on a scale from -2 to 2 with more supinated positions receiving a negative value, and more pronated positions receiving a positive value with final aggregate scores ranging between -12 to +12 (**Figure 7-1**). [263] Arch height index (AHI) is another commonly reported measure of foot posture, and was calculated as the height of the arch at 50% of truncated foot length. [259] To measure foot mobility, the Foot Mobility Magnitude (FMM) was used to calculate change in midfoot height (DiffAH) and width (DiffMFW) between weight bearing (**Figure 7-1**) and non-weight bearing conditions. [264] Total foot length, midfoot height and width at 50% of total foot length and forefoot width were measured in standing and unsupported sitting and the FMM was calculated as $\sqrt{(DiffAH)^2 + (DiffMFW)^2}$ as previously described in the literature. [264]

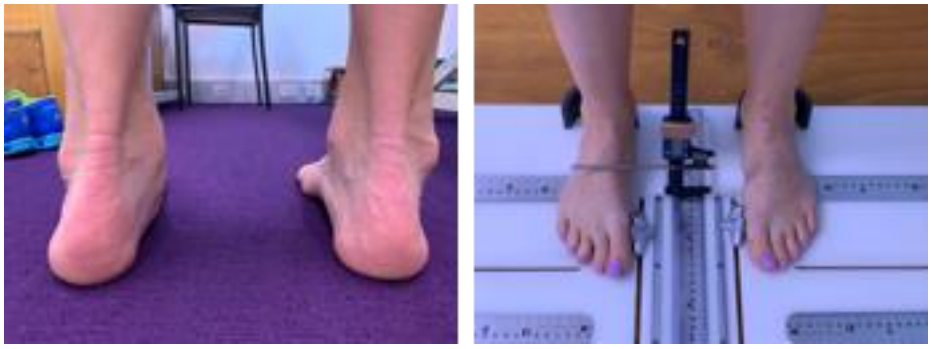


Figure 7-1 *Left: Position for visual observation of foot posture for FPI, right: measurement position for AHI and weight bearing arch height measurement of FMM.*

Weight bearing dorsiflexion (WBDF) was measured using a lunge ankle dorsiflexion measurement device previously shown to have high intra- and inter-rater reliability in clinical population. [265] Linear measurement of the horizontal distance between the anterior knee and the fixed reference block at the longest toe was recorded (mm) (**Figure 7-2**) as well as the inclination (degrees) of the tibia using an inclinometer placed at the midpoint of the anterior border of the tibia at the end of WBDF range. Tibial inclination (degrees) during ankle dorsiflexion in knee extension was also measured with the central line on the lunge ankle dorsiflexion measurement device bisecting the foot between the second and third toe and centre of the calcaneus consistent with the positioning for the WBDF measurement. [265]

Ankle plantar flexor endurance was assessed using a single leg heel raise (SLHR) test in knee extension, which has been widely used for assessing people with tibialis posterior tendinopathy. [133] Participants performed as many repetitions as possible at maximal SLHR height determined on a single repetition prior to beginning the test (**Figure 7-2**). The test was terminated when the knee flexed, the height of the heel raise diminished (i.e. participant was unable to reach the horizontal bar set at the maximal heel raise height determined on a single repetition prior to the test), excessive

weight was placed through the hands or the participant was unable to perform another repetition due to pain. Number of successful SLHRs and pain intensity during and following the test was recorded on a NRS.

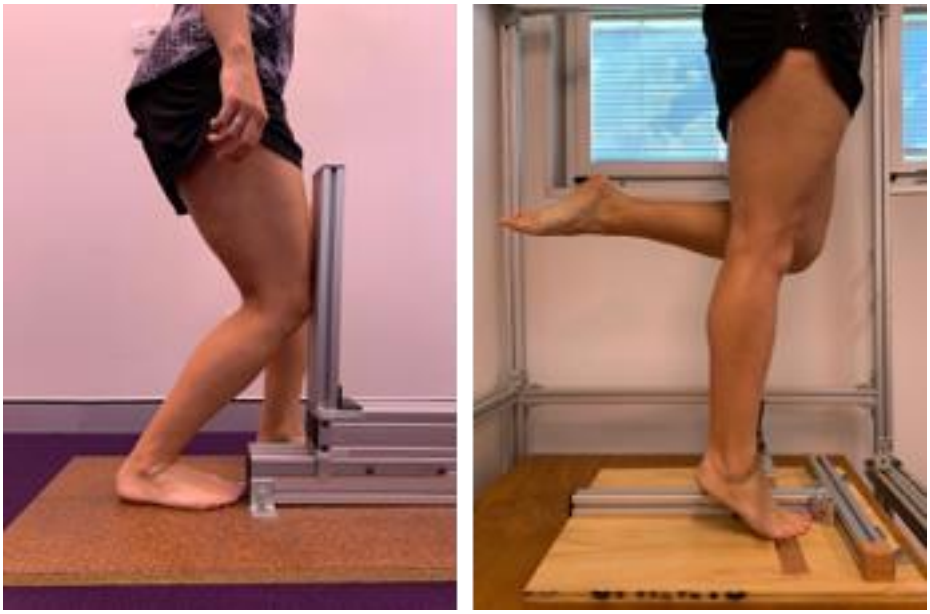


Figure 7-2 *Left: Measurement position for WBDF, right: SLHR test position*

Five self-report measures were used to better understand the impact of medial foot/ankle pain on those with TPT, TPTplus and non-TPTMFP. Health-related foot function and foot-health related quality of life were assessed using the Foot Function Index-Revised. This is a valid and reliable self-report questionnaire consisting 68 questions in relation to pain, stiffness, difficulties, activity limitations, social restrictions. [266] [267] Responses to each question were given on 5-point likert scales and summed to give scores for each subscale and an overall score, with higher values indicating poor foot health and poor foot-related quality of life. [268] Multi-dimensional health-related quality of life was assessed using the Assessment of Quality of Life (6 domains) (AQoL-6D). The self-report questionnaire has appropriate levels of construct, concurrent and convergent validity with other generic measures of health related quality of life [269] [270] and consists of 20 questions pertaining to six domains (independent living, relationships, mental health, coping, pain and senses). [270] For each item there are 4-6 response options, with higher scores representing greater impairment in quality of life. [269] Catastrophic thinking related to pain was measured using the Pain Catastrophisation Scale (PCS), which has demonstrated adequate to excellent internal consistency, [271] and moderate reliability overall. [272] The PCS consists of 13 items scored on a 5-point scale from 0 (not at all) to 4 (all the time), [271] and total score is calculated by summing the responses to all 13 items (ranges from 0 to 52 where 52 represents a high level of catastrophizing). [271] Fear of movement or (re)-injury related to pain fear of movement was assessed using the Tampa Scale of Kinesiophobia (TSK). The

TSK is a self-administered questionnaire with 17 items scored on a 4-point Likert scale from 'strongly disagree' (1 point) to 'strongly agree' (4 points). A final score is calculated by first inversing the scores from items 4, 8, 12 and 16 and then summing the total which ranges from 17 or 68 with higher scores indicating greater levels of fear of movement. [273] The TSK has demonstrated high internal consistency and subsequently high reliability [274] in addition to good responsiveness, concurrent validity and predictive validity. [275]

Procedures

Following physical screening, demographic and anthropometric data were collected for all participants prior to undergoing the physical testing session. Self-report measures were completed online following the physical testing session.

Statistical analysis

All data were examined for normality prior to analyses using SPSS version 25 (IMB, New York, NY). Continuous, normally distributed descriptive data were expressed as mean (SD) and compared between groups using an analysis of variance (ANOVA) with an alpha level of $p = 0.05$. Descriptive data that was not normally distributed was reported as median (interquartile range (IQR)) and compared using the Krustal-Wallis (>2 groups) or Mann Whitney-U (2 groups) tests. Descriptive categorical data was reported as n (%) for each group and compared using Pearson's chi-square statistic ($\chi 2$). For outcomes with bilateral data, the left and right sides of control participants were pooled to give one average value. Where there were bilateral medial foot/ankle symptoms for the TPTplus and non-TPTMFP groups, as the most symptomatic side was considered the 'study side' and the other, less painful side, was excluded from analyses of the 'asymptomatic side'.

Multivariate analyses of variance and covariance (MANOVA and MANCOVA) were run to compare TPT, TPTplus and non-TPTMFP groups for foot measures on the symptomatic side (after controlling for body mass index (BMI) (MANCOVA) and self-report outcomes (MANOVA). A second MANOVA was run to compare foot measures between the symptomatic and asymptomatic side for the three pain groups (TPT, TPTplus and non-TPTMFP) and a second MANCOVA was run to compare the symptomatic and asymptomatic sides for each pain group to control participants after controlling for BMI. Pairwise comparisons were expressed as mean differences (MDs) and 95% confidence intervals (CIs) for between group and side differences (for TPT and non-TPTMFP groups).

Standardised mean differences (SMDs) were calculated as the difference between group means, divided by the pooled SD [197] and visualised on forest plots as SMDs and 95% CIs. SMDs were

interpreted based on Hopkins, as follows; < 0.2 trivial effect, 0.2 - 0.6 small effect, 0.61 – 1.2 medium effect, and > 1.2 large effect. [88]

7.1.3 Results

Participants

Seventy-one participants with medial foot/ankle pain met eligibility criteria and were compared to 27 age and sex matched controls (**Figure 7-3**). Of participants presenting with medial foot/ankle pain, a 15 (21.1%) cases were classified as TPT, 27 (38.0%) cases as TPTplus and 29 (40.8%) cases as non-TPTMFP. All groups were similar in terms of age, proportion of females, height, pain medication use (in the previous 48 hours), hormonal status, diabetes and physical activity (**Table 7-1**).

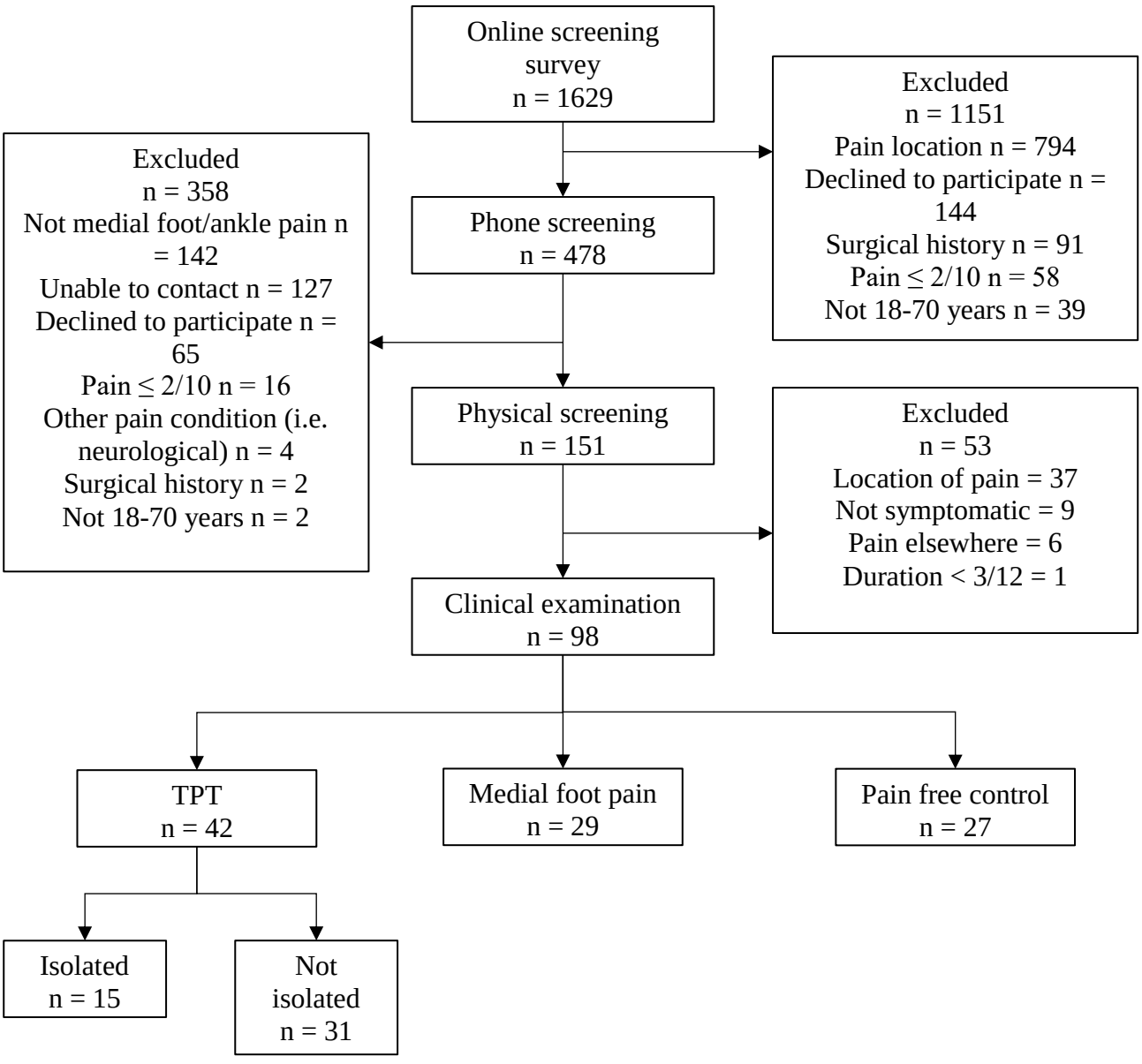


Figure 7-3 *Participant flow through the study*

All participants with medial foot/ankle pain regardless of tissue attribution had significantly higher body mass and body mass index (BMI) than control participants ($p<0.01$). Duration of symptoms and worst pain in the previous week were similar between participants with TPT, TPTplus and non-TPTMFP (**Table 7-1**). A greater proportion of participants with TPT plus concomitant pain than isolated TPT and controls were taking regular prescription medication, but there was no difference compared to non-TPTMFP participants ($p<0.01$). There was a greater proportion of participants in the TPTplus and control groups who were post-menopausal compared to the TPT only group (**Table 7-1**). Physical activity in the previous week was not different between the four groups overall, however participants with isolated TPT reported a greater total time than participants with TPT plus concomitant pain, of whom a lesser proportion were sufficiently active compared to controls (**Table 7-1**).

Table 7-1 *Demographic characteristics of included participants (n=98). Data are number (%) of participants or mean (SD) unless otherwise specified.*

Characteristic	TPT[1] n=15	TPTplus[2] n=27	non-TPTMFP[3] n=29	Control[4] n=27	p-value
Age, years	43.8 (11.6)	47.6 (14.6)	43.5 (11.1)	43.7 (15.6)	0.64
Female	12 (80.0)	23 (85.2)	24 (82.8)	25 (92.6)	0.65
Left study foot	3 (20.0)[2,3]	19 (70.4)[1,4]	16 (55.2)[1]	9 (33.3)[2]	<0.01
Bilateral MFP	-	9 (33.3)	6 (20.7)	-	0.29~
Height, m	1.7 (0.1)[2,3,4]	1.6 (0.1)	1.7 (0.1)	1.7 (0.1)	0.08
Mass, kg	83.4 (19.5)	86.0 (21.9)	79.3 (21.7)	63.7 (13.6)[1,2,3]	<0.01
Body mass index kg/m^2	28.2 (7.1)	31.4 (6.5)	28.8 (8.1)	23.0 (4.6)[1,2,3]	<0.01
Symptom duration, months^	13 (42, 3-60)	34 (54, 3-240)	30 (90, 3-312))	-	0.37[#]
3-6	2 (13.3)	5 (18.5)	3 (10.3)	-	0.89
6-12	4 (26.7)	5 (18.5)	6 (20.7)	-	
>12	9 (60.0)	15 (63.0)	20 (69.)	-	
Worst pain^ /10	7 (4, 4-9)	7 (3, 2-10)	6 (3, 2-10)	-	0.44[#]
Number of patients with pain elsewhere	-	25 (92.6)	24 (82.8)	-	0.27~
Number of additional pain locations^	-	1 (1, 0-7)	1 (1, 0-7)	-	0.84~

Used pain medication in last 48 hours	1 (6.7)	7 (25.9)	8 (27.6)	3 (11.1)	0.19
Regular medication use	4 (26.7)[2]	17 (63.0)[1,4]	14 (48.3)[4]	5 (18.5)[2]	<0.01
Diabetes	1 (6.7)	0 (0.0)	0 (0.0)	0 (0.0)	0.13
Hormonal status					0.24
Premenopausal	5 (33.3)	9 (33.3)	11 (37.9)	14 (51.9)	
Perimenopausal	6 (40.0)	5 (18.5)	9 (31.0)	5 (18.5)	
Postmenopausal	0 (0.0)[2,4]	8 (29.6)[1]	4 (13.8)	6 (22.2)[1]	
Not applicable	4 (26.7)	5 (18.5)	5 (17.2)	2 (7.4)	
Total physical activity over the last week, hrs	14.6 (9.7)[2]	7.2 (6.1)[1]	11.3 (9.6)	12.4 (8.1)	0.10
Rating of physical activity^					0.20
Inactive	0 (0.0)	2 (11.8)	1 (4.0)	0 (0.00)	
Insufficiently active	1 (6.7)	3 (17.6)	4 (16.0)	1 (3.70)	
Sufficiently active	14 (93.3)	12 (70.6)[4]	20 (80.0)	26 (96.30)[2]	

Superscript numbers denote groups that are different at the 0.05 level based on pairwise comparisons, ~ = Comparison between TPT+pain and non-TPTMFP groups only, ^ = median (IQR, range), # = comparison between 3 pain groups only

Main outcomes

A MANCOVA was conducted to determine if there were statistically significant differences between isolated TPT, TPT plus concomitant pain, non-TPTMFP and controls on foot posture and mobility measures on the symptomatic side after controlling for BMI (**Table 7-2**).

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Table 7-2 *Foot posture and mobility data for participants with TPT, non-TPTMFP and controls. Data are mean (SD).*

	TPT		TPTplus		Non-TPTMFP		Control
	Symptomatic (n=15)	Asymptomatic (n=15)	Symptomatic (n=26)	Asymptomatic (n=18^)	Symptomatic (n=28)	Asymptomatic (n=22^)	Average (n=27)
Characteristic	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
FPI (-12 to 12)	6.67 (3.13)	4.00 (3.03)	7.00 (3.37)	4.27 (3.46)	3.53 (2.69)	1.18 (2.66)	1.98 (3.19)
AHI	0.31 (0.03)	0.31 (0.03)	0.30 (0.04)	0.31 (0.04)	0.32 (0.03)	0.32 (0.03)	0.32 (0.03)
Foot mobility magnitude	17.89 (3.42)	19.07 (3.31)	17.77 (3.68)	17.37 (3.78)	15.83 (2.94)	16.10 (2.91)	16.93 (3.48)
WBDF (mm)	87.04 (33.63)	111.24 (32.56)	86.01 (36.22)	97.14 (37.14)	93.29 (28.88)	107.3 (28.62)	112.72 (34.26)
Tibial inclination in knee flexion (degrees)	37.98 (8.44)	42.84 (8.17)	35.01 (9.09)	39.42 (9.32)	38.57 (7.25)	42.15 (7.18)	42.77 (8.6)
Tibial inclination in knee extension (degrees)	31.60 (5.70)	34.67 (5.51)	30.2 (6.13)	31.17 (6.29)	31.5 (4.89)	34.3 (4.85)	35.26 (5.80)
SLHR height (cm)	8.73 (1.99)	8.96 (1.93)	7.18 (2.15)	8.48 (2.2)	8.55 (1.71)	9.15 (1.70)	9 (2.03)
SLHR repetitions	9.48 (6.09)	14.28 (5.90)	8.41 (6.56)	12.84 (6.73)	12.21 (5.23)	15.76 (5.19)	19.57 (6.21)
SLHR pain during /10	4.73 (2.33)	1.07 (2.26)	4.86 (2.51)	1.82 (2.58)	3.33 (2.00)	0.37 (1.99)	-0.08 (2.38)

Evaluated with BMI as a covariate at 28.33, ^ = asymptomatic side excluded due to pain

Between groups

There were no differences between participants with isolated TPT and TPTplus on the symptomatic side (**Table 7-3**). Participants with TPTplus fewer repetitions (~4 repetitions, p = 0.01) on the symptomatic side compared to those with non-TPTMFP (**Table 7-3**/**Figure 7-4-c**). Considering foot posture, there were significant differences between non-TPTMFP participants and TPT (TPT and TPTplus) for FPI with participants with TPT (TPT and TPTplus) having significantly more pronated foot posture than non-TPTMFP (**Table 7-3**/**Figure 7-4-b,c**). Participants with TPTplus also had significantly greater foot mobility (FMM) than the non-TPTMFP group (**Table 7-3**/**Figure 7-4-c**). There were no differences in ankle dorsiflexion or AHI between any pain groups (**Table 7-3**/**Figure 7-4-a,b,c**).

Table 7-3 *Symptomatic side comparisons between groups for foot posture and mobility outcomes. Data are mean (SD).*

Comparison	TPT v TPTplus	TPT v non-TPTMFP	TPTplus v non-TPTMFP
Characteristic	MD (95% CI), p	MD (95% CI), p	MD (95% CI), p
FPI (-12 to 12)	-0.33 (-2.29 to 1.62), 0.74	3.15 (1.23 to 5.06), <0.01*	3.48 (1.84 to 5.12), <0.01*
AHI	0.01 (-0.01 to 0.03), 0.31	-0.01 (-0.03 to 0.01), 0.59	-0.02 (-0.03 to 0), 0.07
Foot mobility magnitude	-0.08 (-2.2 to 2.04), 0.94	1.94 (-0.11 to 3.99), 0.06	2.02 (0.2 to 3.84), 0.03*
WBDF (mm)	3.55 (-17.3 to 24.4), 0.74	-4.77 (-24.95 to 15.41), 0.64	-8.32 (-26.19 to 9.55), 0.36
Tibial inclination in knee flexion (degrees)	3.99 (-1.22 to 9.21), 0.13	-0.06 (-5.1 to 4.99), 0.98	-4.05 (-8.52 to 0.42), 0.08
Tibial inclination in knee extension (degrees)	1.73 (-1.79 to 5.26), 0.33	0.26 (-3.15 to 3.68), 0.88	-1.47 (-4.5 to 1.55), 0.34
SLHR repetitions	2.11 (-1.66 to 5.88), 0.27	-2.13 (-5.78 to 1.51), 0.25	-4.25 (-7.47 to -1.02), 0.01*

*Evaluated with BMI as a covariate at 28.33, * = mean difference significant at 0.05*

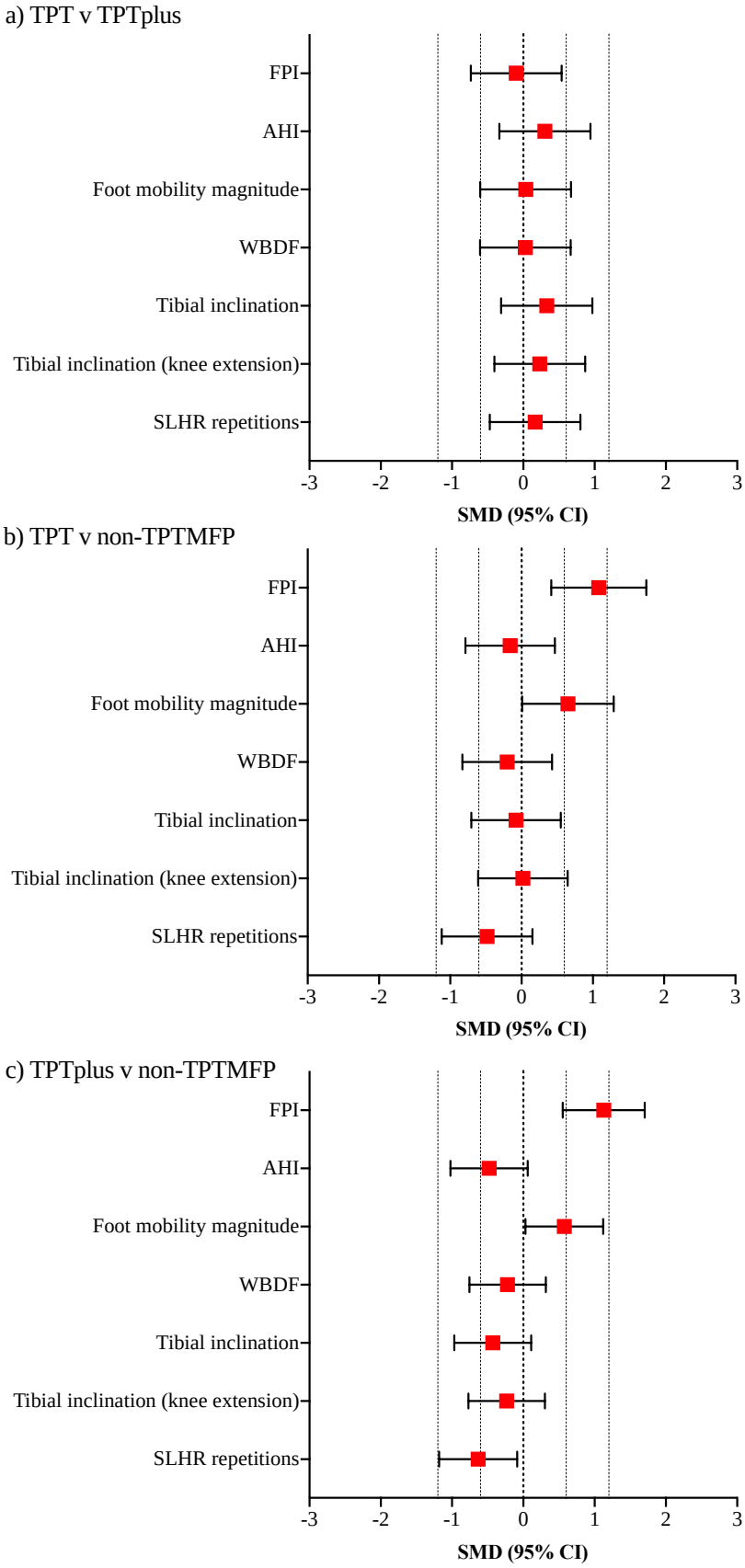


Figure 7-4 *SMD (95% CI) for the symptomatic side between pain groups. Positive SMDs indicate greater values in a) TPT group, b) TPT group and c) TPTplus group.*

Compared to controls, all participants with medial foot/ankle pain had significantly poorer foot-related function and quality of life on the FFI-R (**Table 7-4**) poorer quality of life overall, and in relation to the independent living and pain subscales of the AQoL6D (**Table 7-4**). There were no differences between TPT, TPTplus or non-TPTMFP for self-reported foot function, quality of life, pain catastrophizing or kinesiophobia (**Table 7-4**). Only participants with TPTplus had significantly poorer quality of life compared to controls in relation to the relationships, mental health and coping subscales (**Table 7-4**).

Table 7-4 *Self report outcomes for isolated TPT and TPT with concomitant pain. Data are mean (SD) unless otherwise specified.*

Characteristic	TPT (n = 15) [1] Mean (SD)	TPTplus (n = 17) [2] Mean (SD)	non-TPTMFP (n = 25) [3] Mean (SD)	Control (n=27) [4] Mean (SD)	p-value
Foot Function Index-Revised	45.77 (14.03) [4]	46.03 (11.75) [4]	42.09 (9.08) [4]	25.37 (1.2) [1, 2, 3]	<0.01
Pain	56.41 (13.5) [4]	54.50 (14.48) [4]	52.76 (10.71) [4]	25.21 (1.07) [1, 2, 3]	<0.01
Stiffness	49.26 (18.86) [4]	52.70 (17.15) [4]	50.46 (14.51) [4]	25.36 (1.36) [1, 2, 3]	<0.01
Difficulties	47.06 (14.86) [4]	48.53 (15.83) [4]	43.86 (14.15) [4]	25 (0) [1, 2, 3]	<0.01
Activity limitations	35.57 (13.82) [4]	33.42 (10.28) [4]	31.58 (8.31) [4]	25 (0) [1, 2, 3]	<0.01
Social restrictions	41.72 (17.44) [4]	42.35 (14.16) [4]	36.21 (11.36) [4]	25.96 (3.6) [1, 2, 3]	<0.01
AQoL6D	36.60 (9.88) [4]	38.94 (11.08) [4]	36.36 (7.8) [4]	27.89 (4.77) [1, 2, 3]	<0.01
Independent living	6.47 (2.07) [4]	6.94 (2.88) [4]	6.60 (2.36) [4]	4.15 (0.36) [1, 2, 3]	<0.01
Relationships	4.13 (1.64)	4.29 (1.9) [4]	4.00 (1.35)	3.33 (0.56) [2]	0.09
Mental health	8.07 (2.74)	8.76 (3.27) [4]	7.76 (1.79)	6.74 (2.23) [2]	0.06
Coping	5.93 (1.67)	7.12 (2.47) [4]	6.28 (1.82)	5.70 (1.61) [2]	0.11
Pain	7.13 (2.23) [4]	7.18 (2.24) [4]	6.72 (1.79) [4]	3.41 (0.75) [1, 2, 3]	<0.01
Senses	4.87 (1.6)	4.65 (1.32)	5.00 (1.29)	4.56 (1.22)	0.65
Pain Catastrophizing Scale	8.73 (11.38)	6.53 (7.33)	5.28 (4.77)	6.26 (11.13)	0.70
Tampa Scale of Kinesiophobia[#]	35.00 (6.57)	32.35 (10.51)	36.32 (4.88)	-	0.24

Superscript numbers denote groups that are different at the 0.05 level based on pairwise comparisons, # = comparison between 3 pain groups only. Abbreviations: AQoL6D; Assessment of Quality of Life (6 domains)

Between sides

A MANOVA was conducted to see if there were statistically significant differences between the symptomatic and asymptomatic side for each of the three pain groups, excluding the asymptomatic side for those who had bilateral pain.

Table 7-5 *Foot posture and mobility outcomes between symptomatic and asymptomatic sides for pain groups*

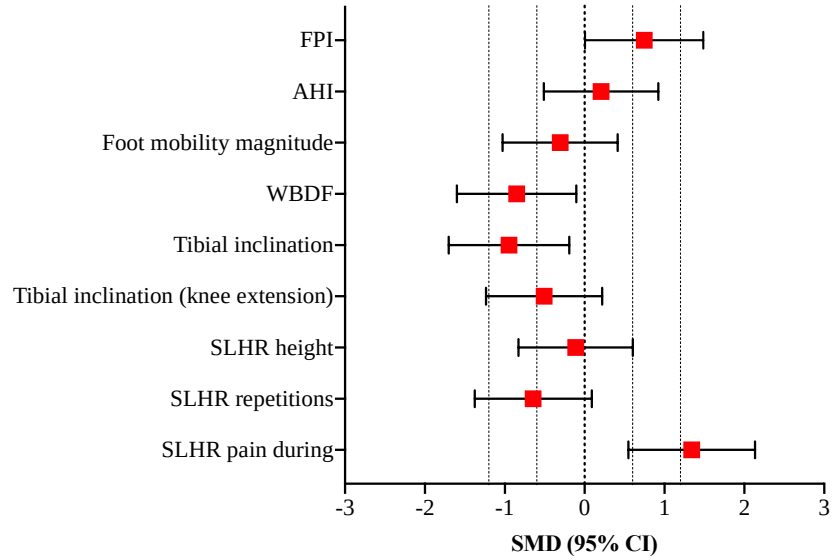
	TPT between sides	TPTplus between sides	non-TPTMFP between sides
Characteristic	MD (95% CI), p	MD (95% CI), p	MD (95% CI), p
FPI (-12 to 12)	2.67 (0.48 to 4.85), 0.02*	2.74 (0.91 to 4.58), <0.01*	2.35 (0.65 to 4.06), <0.01*
Arch height index	0.01 (-0.02 to 0.03), 0.59	-0.01 (-0.03 to 0.01), 0.18	0 (-0.02 to 0.02), 0.96
Foot mobility magnitude	-1.18 (-3.59 to 1.23), 0.34	0.44 (-1.58 to 2.47), 0.67	-0.24 (-2.12 to 1.64), 0.8
WBDF (mm)	-24.2 (-47.7 to -0.7), 0.04*	-11.34 (-31.08 to 8.39), 0.26	-14.17 (-32.5 to 4.17), 0.13
Tibial inclination in knee flexion (degrees)	-4.87 (-10.85 to 1.11), 0.11	-4.53 (-9.55 to 0.5), 0.08	-3.67 (-8.34 to 0.99), 0.12
Tibial inclination in knee extension (degrees)	-3.07 (-7.03 to 0.9), 0.13	-0.97 (-4.3 to 2.37), 0.57	-2.79 (-5.89 to 0.3), 0.08
SLHR height (cm)	-0.23 (-1.73 to 1.26), 0.76	-1.36 (-2.62 to -0.11), 0.03*	-0.65 (-1.81 to 0.52), 0.27
SLHR repetitions	-4.8 (-9.59 to -0.01), 0.05	-4.67 (-8.69 to -0.65), 0.02*	-3.73 (-7.46 to 0.01), 0.05
SLHR pain	3.67 (2.04 to 5.29), <0.01*	3.03 (1.66 to 4.4), <0.01*	2.96 (1.69 to 4.23), <0.01*

** = mean difference significant at 0.05*

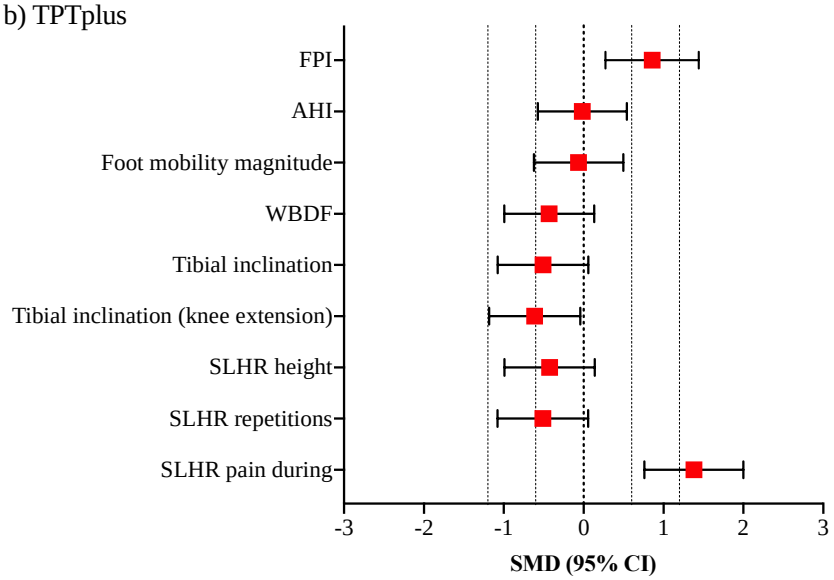
All participants with medial foot/ankle pain had significantly more pronated foot posture on the symptomatic side compared to the asymptomatic side with moderate to large effects (SMD 0.61 to >1.2) (**Table 7-5**/**Figure 7-5**). Only participants with isolated TPT had significantly less WBDF range of motion on the symptomatic side than the asymptomatic side (**Table 7-5**/**Figure 7-5-b**). In participants with non-TPTMFP, there was a moderate effect for restricted tibial inclination in knee extension (**Figure 7-5-c**), but this did not reach statistical significance (**Table 7-5**). All participants with medial foot/ankle pain reported significantly greater pain on the symptomatic side compared to

the asymptomatic side during the SLHR test, but only those with TPT plus concomitant pain performed significantly fewer repetitions on the symptomatic side (**Table 7-5**/**Figure 7-5-a,b,c**). There was also a difference between height of SLHR on the symptomatic compared to asymptomatic side for the TPTplus group, however the CIs for the effect contained 0 (**Table 7-5**/**Figure 7-5-a**).

a) TPT



b) TPTplus



c) non-TPTMFP

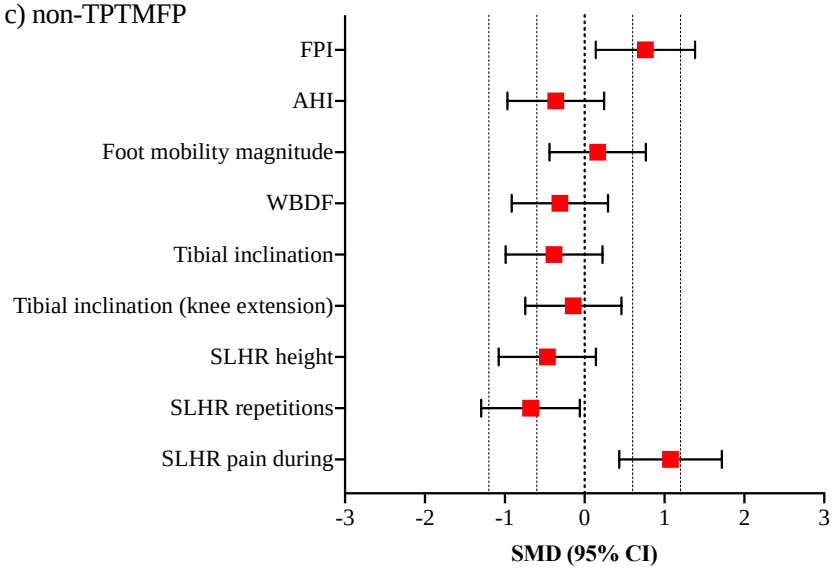


Figure 7-5 *Between side differences for a) isolated TPT, b) TPTplus, c) non-TPTMFP. Positive SMDs indicate greater values on the symptomatic side.*

Compared to controls

Both TPT groups, but not those with non-TPTMFP had significantly more pronated foot posture compared to controls on both the symptomatic and asymptomatic side (**Table 7-6**/**Figure 7-6**). Participants with TPTplus, but not those with TPT or non-TPTMFP had significantly smaller AHI on the symptomatic side compared to controls (**Table 7-6**/**Figure 7-6-a,c,e**). There was significantly less WBDF range of motion on the symptomatic compared to controls for all groups (**Table 7-6**/**Figure 7-6-a,c,e**), tibial inclination in knee flexion and extension for the TPTplus group (**Figure 7-6-c**) and tibial inclination in knee extension only for the non-TPTMFP group (**Figure 7-6-e**). Dorsiflexion in knee extension was also restricted on the asymptomatic side for the TPTplus group (**Table 7-6**/**Figure 7-6-d**)

Single leg heel raise endurance was significantly poorer compared to controls for both the symptomatic and asymptomatic sides for all participants with medial foot/ankle pain (**Table 7-6**/**Figure 7-6**), with a greater magnitude of deficit for the symptomatic side (moderate to large SMDs; **Figure 7-6-a,c,e**).

There were no differences between non-TPTMFP participants and controls for foot posture or mobility outcomes on the symptomatic or asymptomatic sides (**Table 7-6**/**Figure 7-6-e,f**). There were no differences between the asymptomatic side for the non-TPTMFP group and controls except for SLHR endurance (**Table 7-6**/**Figure 7-6-f**).

Table 7-6 *Foot posture and mobility outcomes for pain groups compared to controls for the symptomatic and asymptomatic side. Data are mean (SD).*

	Symptomatic v control		
	TPT	TPTplus	non-TPTMFP
Characteristic	MD (95% CI), p	MD (95% CI), p	MD (95% CI), p
FPI (-12 to 12)	4.7 (2.73 to 6.66), <0.01*	5.03 (3.27 to 6.78), <0.01*	1.55 (-0.12 to 3.22), 0.07
AHI	-0.01 (-0.03 to 0.01), 0.2	-0.02 (-0.04 to -0.01), 0.01*	-0.01 (-0.03 to 0.01), 0.39
Foot mobility magnitude	0.85 (-1.252to 2.94), 0.43	0.92 (-1.02 to 2.87), 0.35	-1.1 (-2.92 to 0.73), 0.24
WBDF (mm)	-24.28 (-44.91 to -3.66), 0.02*	-27.84 (-46.96 to -8.71), <0.01*	-19.52 (-37.43 to -1.61), 0.03*
Tibial inclination in knee flexion (degrees)	-4.31 (-9.47 to 0.85), 0.1	-8.3 (-13.09 to -3.52), <0.01*	-4.26 (-8.74 to 0.22), 0.06
Tibial inclination in knee extension (degrees)	-3.52 (-7.009 to -0.03), 0.05	-5.25 (-8.49 to -2.02), <0.01*	-3.78 (-6.81 to -0.75), 0.01*
SLHR repetitions	-9.54 (-13.266 to -5.812), <0.01*	-11.65 (-15.11 to -8.19), <0.01*	-7.41 (-10.64 to -4.17), <0.01*
	Asymptomatic v control		
	TPT	TPTplus	non-TPTMFP
Characteristic	MD (95% CI), p	MD (95% CI), p	MD (95% CI), p
FPI (-12 to 12)	2.03 (0.06 to 3.99), 0.04*	2.30 (0.39 to 4.20), 0.02*	-0.79 (-2.56 to 0.97), 0.37
AHI	-0.02 (-0.04 to 0), 0.07	-0.01 (-0.03 to 0.01), 0.33	-0.01 (-0.03 to 0.01), 0.46
Foot mobility magnitude	2.14 (0 to 4.29), 0.05	0.44 (-1.64 to 2.53), 0.67	-0.83 (-2.75 to 1.1), 0.4
WBDF (mm)	-1.56 (-22.66 to 19.54), 0.88	-15.71 (-36.21 to 4.81), 0.13	-5.51 (-24.44 to 13.43), 0.57
Tibial inclination in knee flexion (degrees)	0.02 (-5.25 to 5.3), 0.99	-3.43 (-8.56 to 1.7), 0.19	-0.67 (-5.41 to 4.06), 0.78
Tibial inclination in knee extension (degrees)	-0.61 (-4.18 to 2.96), 0.74	-4.12 (-7.59 to -0.65), 0.02*	-0.98 (-4.18 to 2.22), 0.55
SLHR repetitions	-5.33 (-9.14 to -1.52), <0.01*	-6.8 (-10.5 to -3.09), <0.01*	-3.86 (-7.28 to -0.44), 0.03*

*Evaluated with BMI as a covariate at 28.33, * = mean difference significant at 0.05*

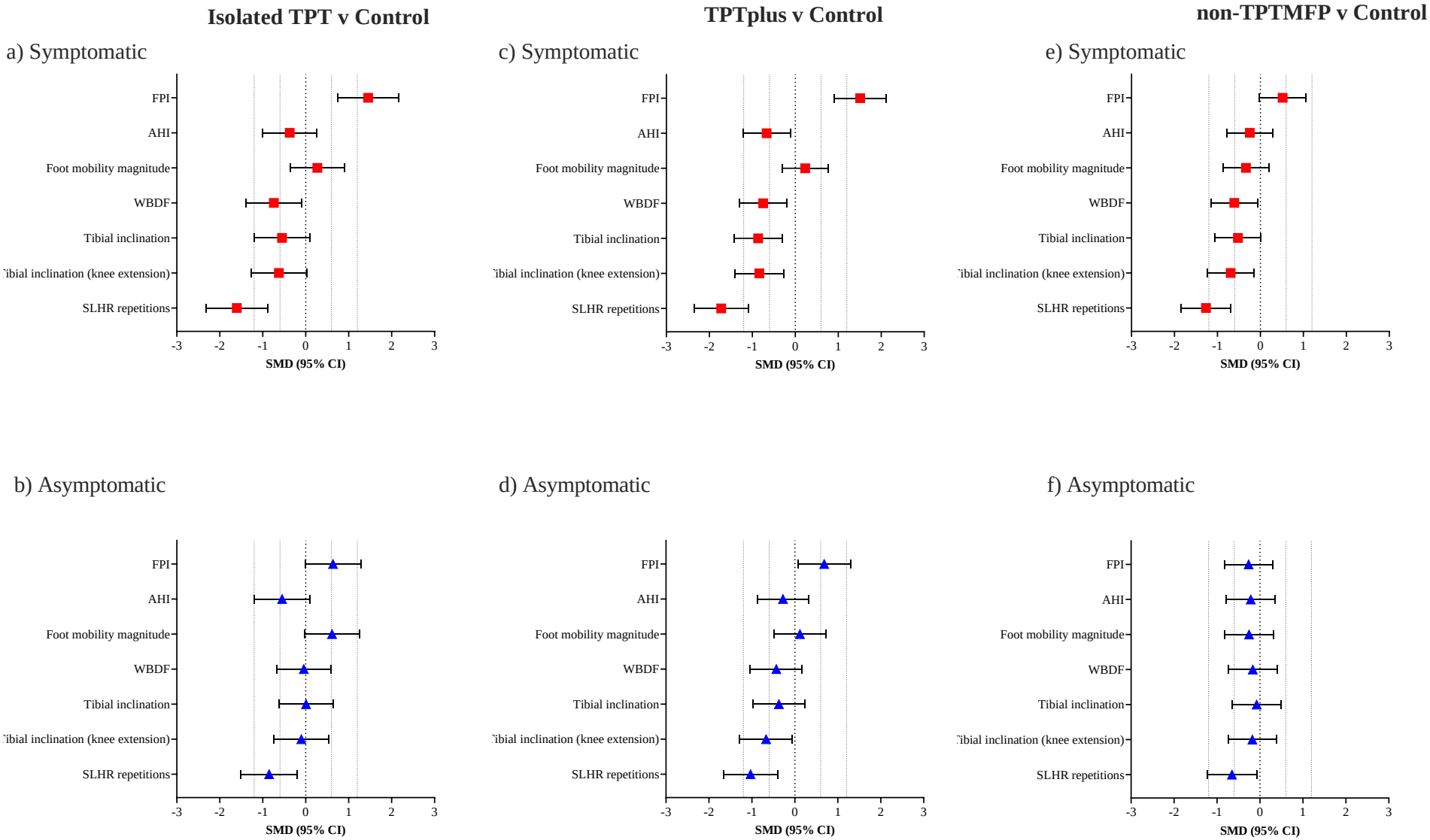


Figure 7-6 SMD (95% CI) for the symptomatic and asymptomatic side for pain groups compared to controls. Positive SMDs indicate greater values in the TPT group compared to controls.

7.1.4 Discussion

This cross-sectional study is the first to investigate and report differences in the clinical presentation of medial foot/ankle pain that is attributable to tibialis posterior tendinopathy based on pain location and pain or difficulties with raising the heel on one foot standing (TPT), when compared to TPT plus concomitant pain (TPTplus), medial foot/ankle pain that is not attributable to the tibialis posterior tendon (nonTPTMFP) and to controls. We classified medial foot/ankle pain being attributable to tibialis posterior by using the SLHR. We based this on a comprehensive systematic review [84] and diagnostic utility study (Study 5) that showed it to have the highest likelihood ratio (both positive and negative) of identifying US greyscale features of tibialis posterior tendinopathy. Of 71 participants with medial foot/ankle pain included in the present study, 39% (28) could not be attributed to the tibialis posterior on the classification criteria we used. Of the 41 (58%) participants who had a positive SLHR test, only 15 (37%, or 21% of the total sample of 71) did not have concomitant pains elsewhere in the lower body.

Results suggest that there are some clinical features that distinguish between individuals with TPT, TPTplus, non-TPTMFP and controls. Participants with TPT and concomitant pain were more likely to be taking regular medications, be post-menopausal and participate in approximately 7 hours of moderate to vigorous physical activity less than those with isolated TPT. Considering foot posture, individuals with medial foot/ankle pain that was attributed to the tibialis posterior tendon had bilaterally pronated foot posture and in terms of SLHR capacity, those with TPTplus had greater deficits in height, endurance and pain compared to those with medial foot/ankle pain that was not attributed to the tibialis posterior tendon.

The SLHR test was used to quantify evidence of impaired capacity of the tibialis posterior muscle. Findings from this study are comparable to previously published literature demonstrating impaired heel raise performance [66 67] in tibialis posterior tendinopathy compared to healthy controls. Unique to this study, individuals with TPTplus (i.e., additional pain sites) had greater deficits in SLHR endurance compared to MFP not attributable to tibialis posterior tendinopathy, and deficits in endurance were greater in, but not limited to, the symptomatic side in all pain groups compared to controls. Bilaterally impaired SLHR endurance has been demonstrated previously for TPT. [66] Results from this study indicate that bilaterally impaired SLHR endurance is a clinical feature of tibialis posterior tendinopathy, despite unilateral symptoms. Interestingly, non-TPTMFP was associated with similar endurance deficits compared to controls on the symptomatic side only, although to a lesser magnitude than TPT. Together, these findings suggest that the SLHR test is a provocative test for individuals with medial foot/ankle pain (not just TPT) but is considerably more difficult for individuals with pain that was attributed to TPT on clinical testing, particularly when

there are concomitant pain sites (greatest magnitude of deficit). Clinically this suggests that individuals presenting with medial foot/ankle pain, regardless of differential diagnosis, may benefit from treatment directed at improving functional capacity of the ankle plantar flexors and may require management bilaterally.

Research has consistently shown that individuals with TPT have altered foot posture compared to healthy, asymptomatic controls. [195] Flatfoot deformity has been implicated as both a risk factor for, [276 277] and a sequelae of, tibialis posterior tendinopathy, [130] with lowering of the medial longitudinal arch, forefoot abduction and calcaneal eversion characteristic features of the deformity. [191] Results from this study are consistent with the previous research; individuals with medial foot/ankle pain that was attributed to the tibialis posterior tendon have pronated foot posture on both feet compared to controls, which is greater on the symptomatic than asymptomatic side. As this was a cross-sectional study design no causal direction can be inferred and as such it is not known whether greater pronation on the symptomatic side preceded symptoms or is a result of osseoligamentous failure. [278] Pronated foot posture, quantified in this study using the FPI, may be useful however, in distinguishing TPT from other medial foot/ankle pain that is not attributable to TPT. Foot posture was not different between those with non-TPTMFP and controls on the symptomatic or asymptomatic side, and those with TPT (both isolated and with concomitant pain) had significantly more pronated foot posture on the symptomatic side compared to the non-TPTMFP group.

Restrictions in range of motion at the ankle were also present in participants with medial foot/ankle pain compared to controls. On the symptomatic side, all pain participants had similar deficits in WBDF range of motion compared to pain free controls. Maximal dorsiflexion at the ankle increases compressive and tensile loads [107] on the tibialis posterior tendon as it runs posteriorly to the medial malleolus and is likely to be provocative for individuals with tibialis posterior tendinopathy. As dorsiflexion range of motion with the knee extended may be limited by the gastrocnemius-achilles complex before compression occurs, it is possible that participants with TPTplus and non-TPTMFP were limited by this rather than pain from compression. Previous research has suggested that Achilles tendon contracture may at times, occur concurrently with TPT. [192 193] Evidence of impaired dorsiflexion in knee flexion, and extension, may support this association, although further research is warranted.

There are some limitations that need to be considered when interpreting the findings from this study. First is that classification criteria for TPT were based on clinical tests for TPT with moderate ability to identify when there were greyscale changes on ultrasound. The SLHR test had the best diagnostic utility and was chosen as the key selection criteria in this study (in addition to medial ankle pain). While selection into the TPT and non-TPTMFP groups was not based on imaging

findings, the criteria for TPT were based on a clinical diagnosis of tendinopathy (persistent tendon pain and pain with mechanical loading). [64] Second, sample size for each group is small, and the 'asymptomatic' side was reduced where participants had bilateral pain, which may have further increased the potential for type two errors.

Overall, this study has several clinical implications. Firstly, findings from this study suggest that considering local foot posture and mobility measures and self-report measures of pain, function and quality of life, a distinction may not need to be made between isolated cases of TPT and cases plus concomitant pain sites. This finding also has research implications. Isolated TPT is difficult to recruit; it is not clear from previous research whether small sample sizes have been limited by the presence of additional pain, [66 127 214] however the findings from this study may permit larger sample sizes to be recruited in the future, thus affording a greater understanding of the condition. This study did not investigate impairments proximal to the ankle. Future research should investigate potential differences between isolated TPT and TPT plus concomitant pain with regard to global function in order to determine whether these two groups can be considered together on the whole. The second clinical implication is that pronated foot posture, rather than lowered arch height, may be a distinguishing feature when there is tendinopathy of the TP, and that the FPI (a quick, simple and reliable tool) [263] may be useful in differentiating TPT from other causes of non-TPTMFP.

7.1.5 Conclusion

This is the first study to compare the presentation of isolated TPT, TPT plus concomitant pain, other causes of non-TPTMFP and controls. Pronated foot posture, and not lower arch height, appears to be a characteristic feature of TPT, that is not present with other causes of non-TPTMFP compared to pain free controls. Compared to other causes of medial foot/ankle pain, participants with TPT have significantly more pronated and mobile feet and have poorer SLHR capacity and participants with TPT plus concomitant pain have the greatest deficits in SLHR capacity.

CHAPTER 8 Considering tibialis posterior tendinopathy under the ICF framework

8.1 Considering tibialis posterior tendinopathy under the ICF framework: a cross-sectional study identifying bilateral hip extension muscle weakness and psychosocial components of the condition

Chapter four investigated clinical impairments, pain and disability reported in the current TPT literature. The review highlighted that outcome measures were predominantly focussed on local impairments with some indication of changes in hip strength, walking, balance and function in TPT. In order to advance the current knowledge and address the gaps in the literature, this chapter explores a range of clinical measures (both locally and proximally) and self report outcome measures under each domain of the ICF framework in individuals clinically diagnosed with TPT compared to asymptomatic controls.

Ross MH, Smith MD, Vicenzino B. Considering tibialis posterior tendinopathy under the ICF framework: a cross-sectional study identifying bilateral hip extension muscle weakness and psychosocial components of the condition

Contributor	Statement of contribution
Megan H Ross (Candidate)	Conception and design (60%) Data acquisition (100%) Analysis and interpretation (70%) Drafting and production (70%)
Dr Michelle D Smith	Conception and design (20%) Analysis and interpretation (15 %) Drafting and production (15%)
Professor Bill Vicenzino	Conception and design (20%) Analysis and interpretation (15%) Drafting and production (15%)

8.1.1 Introduction

Tibialis posterior tendinopathy (TPT) is characterised by pain around the medial aspect of the foot and ankle, and difficulty with activities that load the tendon. [84] In some cases, these symptoms may be accompanied by an acquired flatfoot deformity. The prevalence of this progressive condition is unknown but estimated to reach up to 10% [70] and most frequently affects mid-late aged females. [47] Studies of impairments associated with TPT have primarily focussed on structure and function at the foot and ankle, with reports of lower arch height, plantar flexion inversion strength and endurance, and heel raise height in individuals with TPT compared to controls (Study 4). [195]

The International Classification of Functioning, Disability and Health (ICF) framework is used to describe health and wellbeing in terms of body structure and function, activity, and participation. [7] Considering body structure and function, in addition to impairments in strength and endurance of the tibialis posterior, kinematic analysis has shown greater rearfoot eversion,[124-128] lower medial longitudinal arch [125 127] and more forefoot abduction [124 127 128 214] during walking in individuals with TPT compared to controls. There is minimal research investigating impairments in structure or function beyond the foot and ankle. Research suggests TPT is associated with overall reductions in function. Individuals with TPT have been shown to have reduced walking speeds [128 214] and distances, [66] and report pain, [66] difficulties and social limitations due to foot problems. [195] Considering the ICF, these issues are likely to have a negative effect on performance of activities of daily living, participation and overall quality of life for those affected.

The aim of this study is to characterise TPT using the ICF framework; specifically, to compare impairments at the body structure and function level more broadly than the foot and ankle, activity limitations and participation restrictions between individuals with TPT and asymptomatic controls. It is hypothesised that participants with TPT will have impairments beyond the foot and ankle under all three domains of the ICF.

8.1.2 Methods

Participants

Participants aged between 18 and 70 years were recruited from the community between July 2017 and March 2019 in two groups: those who presented with clinical signs of TPT and asymptomatic age and sex matched controls. Participants were screened online and via phone prior to attending one physical screening and subsequent testing session at the University of Queensland, Brisbane, Australia. Participants were eligible for the TPT group if they presented with medial foot/ankle pain on most days for at least three months, with an average pain in the previous week greater than 2/10 on a Numeric Rating Scale (NRS) anchored with “no pain” at 0 and “worst pain imaginable” at 10,

and pain or inability to perform a single leg heel raise (SLHR) on physical screening. Selection criteria were based on a clinical definition of tendinopathy [64] and the diagnostic utility of clinical tests for TPT (Study 5) where the SLHR test had the highest likelihood ratio (positive and negative) for predicting when there would be greyscale changes within the tendon on ultrasound imaging. Participants in the TPT group were permitted to have pain in other locations provided that their medial foot/ankle pain was their predominant pain.

Asymptomatic control participants were eligible providing they had no lower extremity pain in the previous three months. Participants with a history of lower limb surgery in the previous year and systemic, neurological or arthritic diseases were excluded from both groups. The study was approved by the institutional Human Research Ethics Committee and each participant provided written informed consent prior to participation.

Procedures

Measures of body structure and function

Foot Posture Index (FPI) was used as a simple and reliable method of visually classifying static foot postures.[262] Arch height index (AHI) and the Foot Mobility Magnitude (FMM) (change in arch height and midfoot width between weight bearing and non-weight bearing positions) were measured and calculated in accordance with previously published protocols (as per Study 7). [259 260 264] Ankle dorsiflexion in weight bearing was measured using a Lunge Ankle Dorsiflexion device in accordance with a previously published protocol shown to have high intra- and inter-rater reliability. [265] Tibial inclination (°) was measured using an inclinometer in both knee flexion and extension to record the angle of the lower leg relative to the horizontal position in maximal dorsiflexion.

Ankle plantar flexor endurance was assessed with a single leg heel raise (SLHR) with knee extended and light hand support on a horizontal rail for balance. This test has been widely used in individuals with TPT. [133] Participants performed as many repetitions as possible at 100% of maximal SLHR height (determined by a single repetition prior to beginning the test). The test was terminated if the knee flexed, the height of the heel raise diminished, excessive weight was placed through the hands, the participant was unable to lift the heel off the ground, or when they reached upper limit of 25 repetitions (selected based on population norms for females between 40 and 60 years of age). [279] The number of complete SLHRs was recorded in one trial. Worst pain experienced before, during and after the test was recorded on a NRS.

Combined ankle plantar flexion-inversion muscle strength was measured with the participant lying supine in 90° hip and knee flexion (with the leg supported) and the ankle in 45° plantar flexion (**Figure 8-1**). The centre of the hand held dynamometer (HHD) (Nicholas, Lafayett, IN47903 USA) was secured to the medial side of the first metatarsal head. The participant was instructed to maintain plantar flexion and to push isometrically against the HHD into inversion/forefoot adduction. Participants were given one practice trial at 50% effort, followed by three experimental trials of maximal voluntary contraction, with the maximal force (N) value used for analysis.

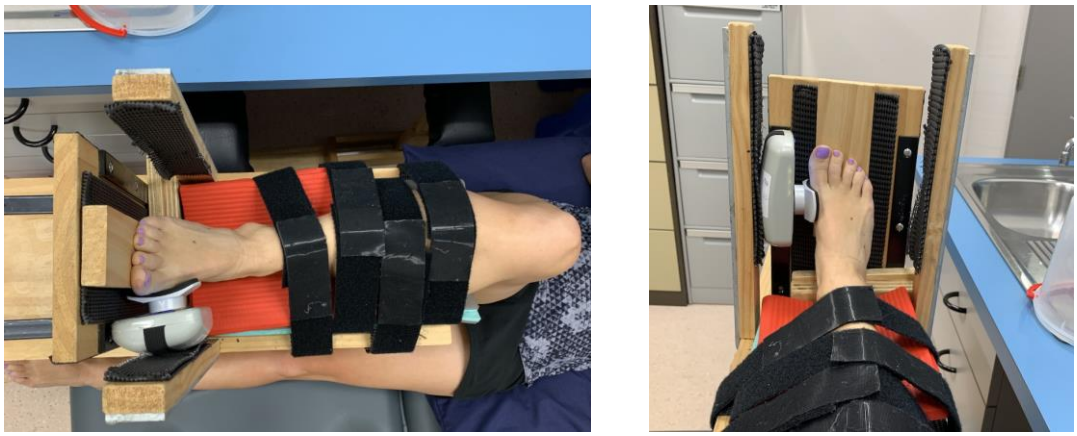
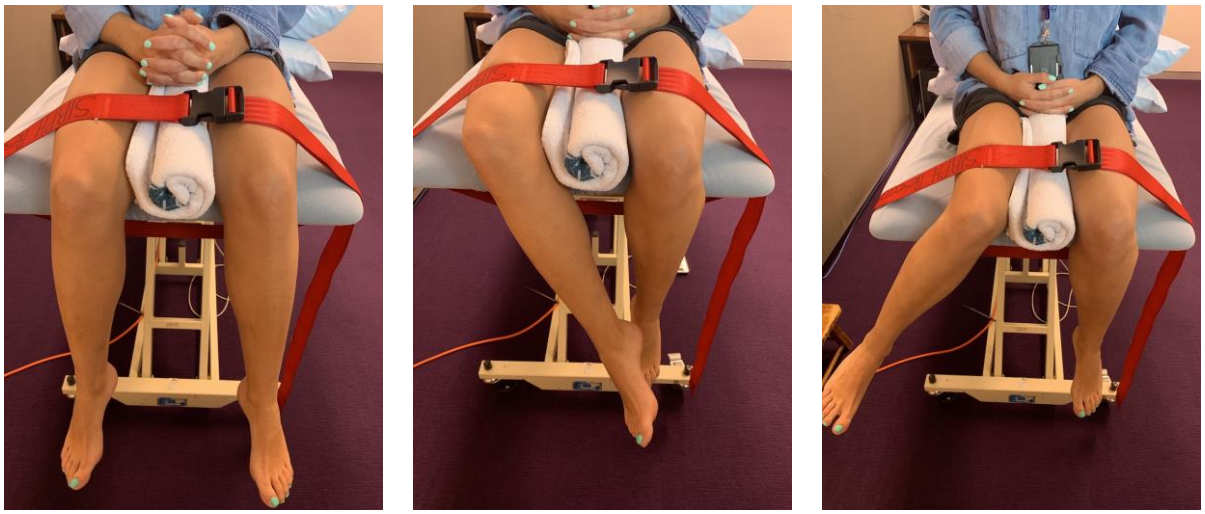


Figure 8-1 *Test position for plantar flexion-inversion force with fixed hand held dynamometer*

Passive and active hip internal rotation (IR) and external rotation (ER) range of motion (ROM) were measured in 90° hip and knee flexion using a pleurometer (**Figure 8-2**). [280 281] Hip IR and ER lag was calculated as the difference between passive and active ROM for each direction.



a) Start position b) End position hip ER c) End position hip IR

Figure 8-2 *Test positions for passive and active hip rotation range*

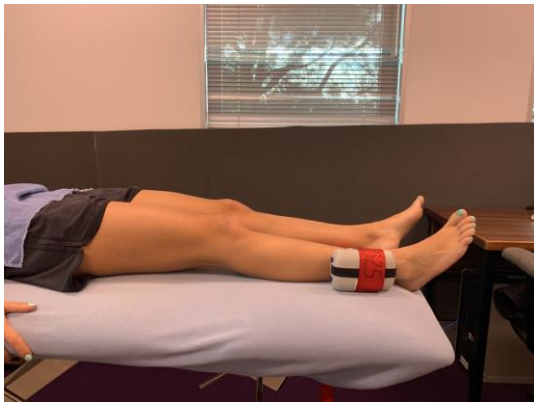
Maximal isometric muscle strength of the hip abductor, adductor, flexor, extensor and external and internal rotation muscle groups was measured using a HHD (

Figure *8-3*). Dynamometry is reported to be a reliable and valid measure of muscle strength [282] in both older adults [283] and healthy strong populations. [284] A strap was placed around the dynamometer and the plinth during testing to stabilize the HHD and provide resistance to muscle contraction. [285] Hip abductor and adductor muscle torque were measured with the participant lying supine, with both legs extended. The centre of the HHD was positioned above the lateral malleolus for abduction or the medial malleolus for adduction. The distance between the centre of the HHD and the anterior superior iliac spine (ASIS) was measured (m) as lever arm length.

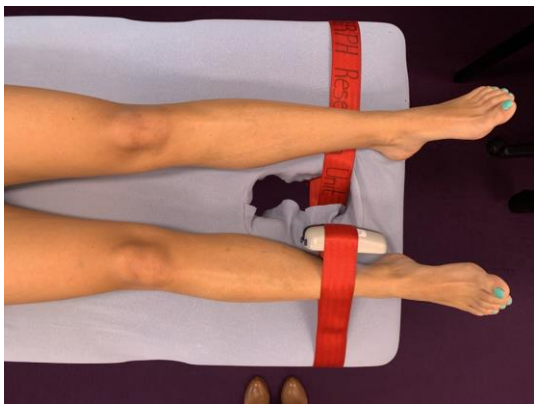
Hip extension and flexion were performed in side lying, with the test hip at 30° and the knee at 45° flexion. The HHD was placed on the posterior aspect of the thigh just proximal to the knee crease for extension, and 5cm above the patella on the anterior aspect for flexion. The lever length was measured as the distance between the ASIS and the point 5cm above the base of the patella.

Hip external and internal rotation were measured with the participant lying supine, hips flexed to 30° and the knees flexed to 90° over a wedge. The HHD was positioned 5cm proximal to the distal tip of the medial malleolus for ER and the lateral malleolus for IR. The lever arms were measured as the distance between the medial/lateral condyle of the femur to the point 5cm above the medial/lateral malleoli of the ankle, with the axis of rotation through the centre of the knee joint, along the length of the femur and perpendicular to the tibia. The examiners hand was placed lightly on the test thigh to discourage compensatory thigh movements.

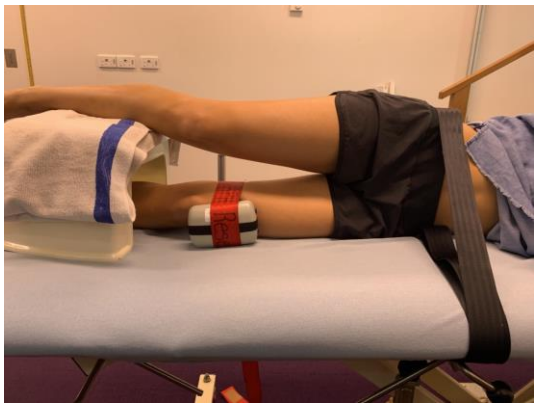
For all muscle groups, participants were given one practice trial at 50% effort, followed by three experimental trials of maximal voluntary contraction. Fifteen seconds rest was allowed between each contraction. The participants were asked to increase the force gradually, and then maintain a maximal contraction for 5 seconds. Peak force (N) was recorded for each contraction, and the maximal value achieved over the three repetitions was used for analysis. Torque (Nm) was calculated by the equation *Torque (Nm) = Force (N) x Lever arm length (m)*, and then standardized to body mass (Nm/kg).



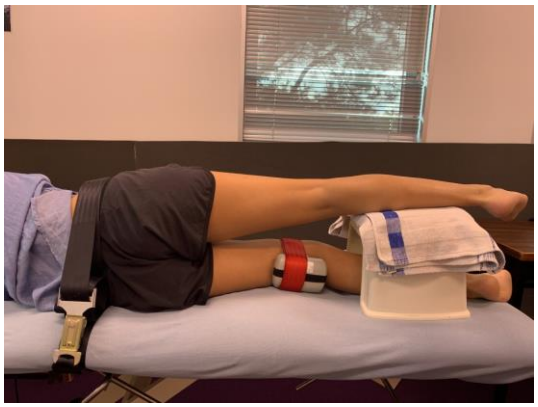
a) Hip abduction



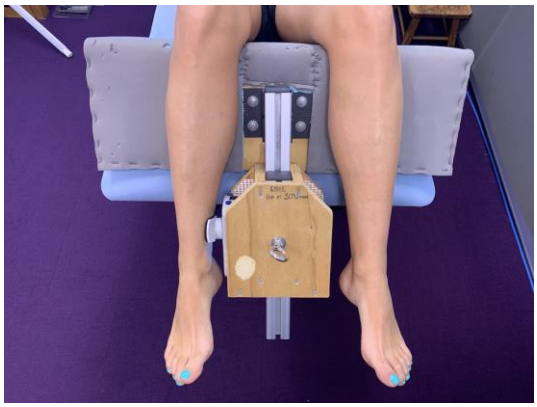
b) Hip adduction



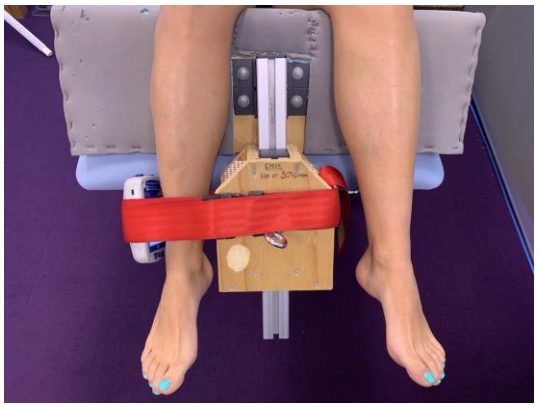
c) Hip flexion



d) Hip extension



e) Hip external rotation



f) Hip internal rotation

Figure 8-3 *Test positions for hip muscle torque measurements*

To characterise catastrophic thinking related to pain, the Pain Catastrophization Scale (PCS) was administered to both groups. The PCS consists of 13 items pertaining to three domains; rumination, magnification and helplessness. [271] Total scores range from 0 to 52 where 52 represents a high level of catastrophizing. [271] The Tampa Scale of Kinesiophobia (TSK) was used to measure fear of

movement or (re)-injury related to pain in the TPT group only. Total scores range between 17 and 68. Higher scores indicate greater levels of fear of movement.[273] A total score >37 indicates significant fear of movement.[273]

Measures of activity

Participants descended and then ascended a flight of 20 stairs (not assisted by placing hands on the railing) and time taken to complete the test was recorded. The intensity of pain before, during and after the test (using the NRS) was recorded.

The Active Australia Survey (AAS) was used to measure total number of minutes of physical activity in the preceding week, and to classify participants as inactive (0 minutes) or participating in insufficient (<150 minutes) or sufficient (>150 minutes) amounts of moderate to vigorous physical activity. [286]

Measures of participation

The Foot Function Index-Revised (FFI-R) questionnaire was used to measure health-related foot function and foot-related quality of life. An overall index (percentage score) and indices for each sub-scale (pain, stiffness, difficulties, activity limitations, social issues) were calculated by summing responses and dividing by the maximum possible scores. Scores range from 0-100% with higher scores indicating worse foot health and poorer foot-related quality of life. The questionnaire has been shown to be valid and reliable in assessment of patients with foot problems. [266 267] Scores for subscales of the FFI-R falling under the body structure and function and activity domains of the ICF are reported in the relevant section in the results.

The Assessment of Quality of Life (AQoL) was used to obtain health-related quality of life information under six domains; independent living, relationships, mental health, coping, pain and senses. Domains are scored separately and combined for an overall 'utility' score with higher scores representing greater impairment in quality of life. [269 270] Scores for the domains of the AQoL falling under the body structure and function and activity domains of the ICF are reported in the relevant section in the results.

Statistical analysis

Statistical Package for the Social Sciences (SPSS) version 25 (IMB, New York, NY) was used for data analysis. All data were examined for normality. Continuous descriptive data were expressed as mean (SD) or median (IQR) and group differences examined using independent t-tests or Mann-Whitney U tests for normally and nonnormally distributed data respectively. Categorical descriptive

data were expressed as n (%), with between group differences examined using Pearsons Chi-square ($\chi 2$).

For outcomes with data from both limbs, a multivariate analysis of variance (MANOVA) with three groups (TPT symptomatic, TPT asymptomatic and control) was used to test for differences between sides in the TPT group and between the TPT group and controls. Where TPT participants had bilateral pain, only the most symptomatic side was used in the analysis. For control participants, a mean of the two sides was used in the analysis. For self-report data and the stairs task, group differences were examined using MANOVA with two groups (TPT and control). In the presence of group main effects, pairwise comparisons were completed and reported as mean differences (MD) and 95% confidence intervals (CIs). Standardised mean differences (SMDs) were calculated as the difference between TPT and control group means divided by the pooled SD. [197] SMDs and 95% CIs were visualised on forest plots and interpreted as follows; < 0.2 trivial effect, 0.2 - 0.6 small effect, 0.61 – 1.2 medium effect, and > 1.2 large effect. [88]

A two-way analysis of variance (ANOVA) was used to analyse differences in pain during the functional tasks for the TPT group. The two factors were task (two levels: SLHR and stairs) and time (three levels: before, during and after) and pairwise comparisons were completed to explore main effects.

8.1.3 Results

Participants

Twenty-two participants (19 (86%) females) met selection criteria for TPT and were compared to 27 (25 (93%) females) asymptomatic controls (**Figure 8-4**/**Table 8-1**).

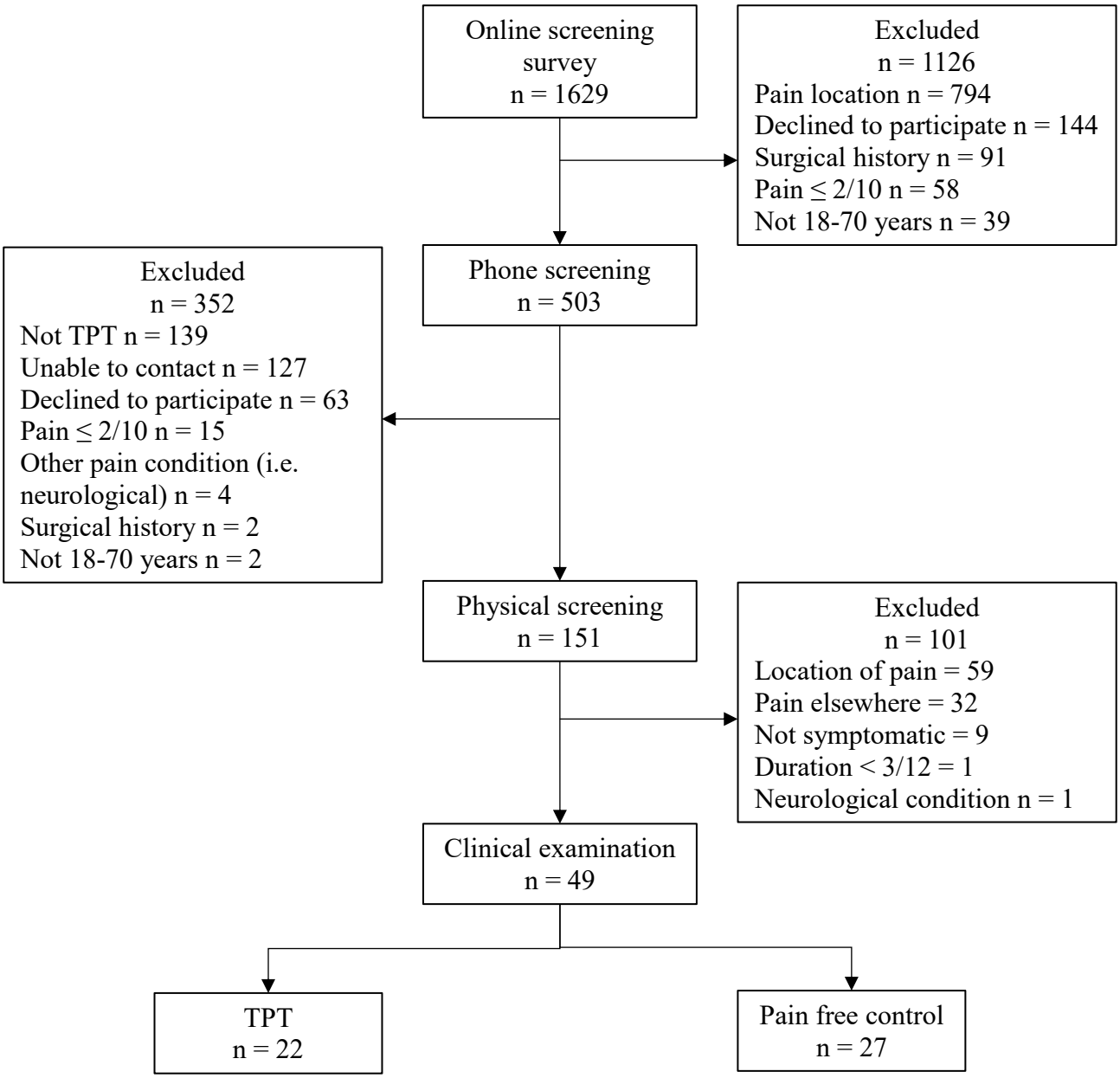


Figure 8-4 *Participant flow through the study*

Participants were similar in age and sex, but weight and BMI were significantly higher in the TPT group compared to controls ($p<0.01$) (**Table 8-1**). Participants in the TPT group had a median (IQR) symptom duration of 13 (45) months and an average and worst pain over the last week of 4 (3) and 7 (3) out of 10 respectively on the NRS. Five participants (23%) with TPT had pain in another location (which was not their predominant pain) and 3 participants (13%) had bilateral medial ankle pain. There were no differences between groups with regards to pain medication use in the previous 48 hours, regular medication use, diabetes or hormonal status ($p > 0.1$).

Table 8-1 *Demographic characteristics of participants by group. Data are number of participants (%) or mean (SD) unless otherwise specified.*

Characteristic	TPT (n = 22)	Control (n = 27)	p
Age, years	43.3 (12.7)	43.7 (15.6)	0.91
Sex, female	19 (86.4)	25 (92.6)	0.47
Study foot, left	5 (22.7)	9 (33.3)	0.41
Height, m	1.70 (0.1)	1.66 (0.1)	0.19
Mass, kg	80.6 (20.5)*	63.7 (13.6)	<0.01
Body mass index, kg/m^2	27.9 (6.9)*	23.0 (4.6)	<0.01
Symptom duration, months^	13 (45)	-	-
3-6	3 (13.6)	-	-
6-12	7 (31.8)	-	-
>12	12 (54.5)	-	-
Average pain^	4 (3)	-	-
Worst pain ^	7 (3)	-	-
Used pain medication in last 48 hours	3 (13.6)	3 (11.1)	0.80
Regular medication use	7 (31.8)	5 (18.5)	0.28
Diabetes	1 (4.5)	0 (0.0)	0.26
Hormonal status			0.19
Premenopausal	10 (45.5)	14 (51.9)	
Perimenopausal	7 (31.8)	5 (18.5)	
Postmenopausal	1 (4.5)	6 (22.2)	
Not applicable	4 (18.2)	2 (7.4)	

**; p <0.05, ^; median (IQR)*

Measures of body structure and function

Foot and ankle

Participants with TPT had a significantly more pronated foot posture on the symptomatic compared to asymptomatic side (p = 0.01) and on both sides compared to controls (p = 0.01) (**Table 8-2**/**Figure 8-5**). Weight-bearing ankle dorsiflexion was significantly lower on the symptomatic compared to the asymptomatic side for TPT (p = 0.04) and compared to controls (p = 0.01). Compared to controls, individuals with TPT produced significantly less plantar flexion inversion force on the symptomatic side (p<0.01) and performed significantly fewer SLHR repetitions on both sides (p < 0.01) (**Figure 8-5**).

Table 8-2 *Body structure and function impairment measures by side and group. Data are presented as mean (SD).*

Foot / ankle					TPT symptomatic v asymptomatic	TPT symptomatic v control	TPT asymptomatic v control
Characteristic	Symptomatic (n = 22)	Asymptomatic (n = 19)~	Control (n = 27)	p	Mean difference (95% CI), p	Mean difference (95% CI), p	Mean difference (95% CI), p
Foot Posture Index	6.64 (2.36)	4.16 (4.15)	1.85 (1.97)	<0.01	2.48 (0.70 to 4.6)*, <0.01	4.79 (3.15 to 6.42)*, <0.01	2.30 (0.60 to 4.01)*, <0.01
Arch Height Index	0.31 (0.03)	0.30 (0.03)	0.32 (0.03)	0.20	0.01 (-0.01 to 0.02), 0.61	-0.01 (-0.03 to 0.01), 0.22	-0.02 (-0.03 to 0.00), 0.09
Difference in arch height	13.73 (2.93)	14.79 (2.64)	13.38 (1.90)	0.16	-1.07 (-2.62 to 0.49), 0.18	0.35 (-1.08 to 1.77), 0.63	1.42 (-0.07 to 2.90), 0.06
Difference in midfoot width	10.78 (3.46)	10.74 (4.20)	9.25 (3.60)	0.27	0.04 (-2.30 to 2.40), 0.98	1.53 (-0.61 to 3.67), 0.16	1.50 (-0.74 to 3.73), 0.19
Foot Mobility Magnitude	17.70 (3.36)	18.54 (3.79)	16.55 (3.01)	0.14	-0.84 (-2.94 to 1.26), 0.43	1.15 (-0.77 to 3.01), 0.24	1.99 (-0.01 to 4.00), 0.05
Ankle dorsiflexion (mm)	89.74 (26.85)	109.47 (29.40)	114.79 (31.91)	0.01	-19.73 (-38.28 to -1.18)*, 0.04	-25.01 (-42.06 to -8.03)*, <0.01	-5.32 (-23.05 to 12.42), 0.55
Tibial inclination (°)	38.59 (5.50)	42.37 (6.34)	43.93 (6.53)	0.01	-3.78 (-7.63 to -0.07), 0.06	-5.34 (-8.87to -1.80)*, <0.00	-1.56 (-5.24 to 2.13), 0.40
Dorsiflexion range of motion (°)	32.27 (4.78)	34.37 (6.01)	35.17 (4.54)	0.14	-2.10 (-5.26 to 1.07), 0.19	-2.89 (-5.80 to 0.01), 0.05	-0.80 (-3.83 to 2.23), 0.60
Plantar flexion inversion force (N)	47.28 (21.48)	62.21 (24.31)	66.91 (27.34)	0.02	-14.93 (-30.40 to 0.54), 0.06	-19.63 (-33.82 to -5.45)*, <0.01	-4.70 (-19.49 to 10.09), 0.53
SLHR height	8.74 (1.88)	8.97 (1.70)	9.59 (1.39)	0.18	-0.24 (-1.27 to 0.79), 0.65	-0.85 (-1.80 to 0.09), 0.08	-0.61 (-1.60 to 0.37), 0.22
SLHR repetitions	10.46 (7.12)	14.00 (6.50)	21.89 (4.18)	<0.01	-3.55 (-7.25 to 0.16), 0.06	-11.43 (-14.83 to -8.04)*, <0.01	-7.89 (-11.43 to -4.35)*, <0.01
Hip					TPT symptomatic v asymptomatic	TPT symptomatic v control	TPT asymptomatic v control
Characteristic	Symptomatic (n = 21)^	Asymptomatic (n = 18)^~	Control (n = 27)	p	Mean difference (95% CI), p	Mean difference (95% CI), p	Mean difference (95% CI), p
Passive External Rotation (°)	44.53 (7.53)	42.79 (4.61)	45.97 (5.54)	0.21	1.15 (-2.67 to 4.97), 0.55	-1.99 (-5.45 to 1.48), 0.26	-3.14 (-6.76 to 0.48), 0.09

Passive Internal Rotation (°)	35.76 (9.34)	36.67 (10.41)	40.78 (7.38)	0.09	-0.39 (-6.08 to 5.31), 0.89	-5.13 (-10.29 to 0.02), 0.05	-4.75 (-10.14 to 0.65)
Active External Rotation (°)	37.17 (7.71)	33.70 (8.83)	37.42 (4.18)	0.23	3.07 (-1.42 to 7.55), 0.18	-0.49 (-4.55 to 3.57), 0.81	-3.55 (-7.80 to 0.69)
Active Internal Rotation (°)	34.20 (8.40)	34.77 (6.12)	35.85 (7.53)	0.79	-0.56 (-5.42 to 4.30), 0.82	-1.48 (-5.88 to 2.92), 0.50	-0.92 (-5.52 to 3.68)
External Rotation Lag (°)	7.36 (6.40)	8.02 (4.80)	12.15 (5.74)	0.01	-0.86 (-4.55 to 2.83), 0.64	-5.11 (-8.45 to -1.76)*, <0.01	-4.25 (-7.74 to -0.75)*
Internal Rotation Lag (°)	1.56 (6.33)	1.26 (4.93)	4.94 (4.55)	0.02	0.29 (-3.11 to 3.68), 0.87	-3.65 (-6.73 to -0.58)*, 0.02	-3.94 (-7.15 to -0.73)*
Adduction (Nm/kg)	1.06 (0.46)	1.07 (0.36)	1.14 (0.37)	0.69	-0.01 (-0.27 to 0.24), 0.96	-0.09 (-0.33 to 0.14), 0.44	-0.08 (-0.33 to 0.16)
Abduction (Nm/kg)	1.09 (0.46)	1.12 (0.47)	1.15 (0.44)	0.86	-0.02 (-0.31 to 0.27), 0.88	-0.07 (-0.34 to 0.19), 0.59	-0.05 (-0.33 to 0.23)
Flexion (Nm/kg)	0.99 (0.50)	0.98 (0.50)	1.14 (0.54)	0.42	0.02 (-0.31 to 0.36), 0.89	-0.16 (-0.47 to 0.14), 0.29	-0.19 (-0.50 to 0.13)
Extension (Nm/kg)	0.75 (0.46)	0.80 (0.46)	1.16 (0.68)	0.01	-0.05 (-0.40 to 0.30), 0.79	-0.46 (-0.77 to -0.14)*, 0.01	-0.41 (-0.74 to -0.08)*
External Rotation (Nm/kg)	0.38 (0.15)	0.40 (0.14)	0.45 (0.17)	0.17	-0.03 (-0.13 to 0.07), 0.61	-0.08 (-0.18 to 0.01), 0.07	-0.06 (-0.15 to 0.04)
Internal Rotation (Nm/kg)	0.55 (0.18)	0.59 (0.22)	0.58 (0.23)	0.71	-0.04 (-0.17 to 0.10), 0.59	-0.05 (-0.17 to 0.07), 0.42	-0.01 (-0.14 to 0.11)

Self-report measures			TPT v control
Characteristic	TPT (n = 22)	Control (n = 27)	Mean difference (95% CI), p
FFI-R - Pain	54.28 (12.37)	25.21 (1.07)	29.08 (23.89 to 34.26)*, <0.01
FFI-R - Stiffness	49.92 (16.86)	25.36 (1.36)	24.56 (12.02 to 31.09)*, <0.01
AQoL - Pain	6.91 (2.20)	3.41 (0.75)	3.50 (2.59 to 4.41)*, <0.01
AQoL - Senses	4.64 (1.47)	4.56 (1.22)	0.08 (-0.69 to 0.85), 0.83
Pain catastrophizing scale	6.45 (8.55)	6.26 (11.13)	0.20 (-5.62 to 6.01), 0.95

Tampa scale of kinesiophobia[#]	8 (36.4)	-	-

*~; 3 participants with bilateral pain were excluded from 'asymptomatic', *; p<0.05, ^; one TPT participant was excluded from the hip torque due to missing data (testing caused pain which limited maximal voluntary contraction), [#]; n (%) greater than 37. Abbreviations: SLHR; single leg heel raise, FFI-R; Foot function index - revised, AQoL; Australian Quality of Life*

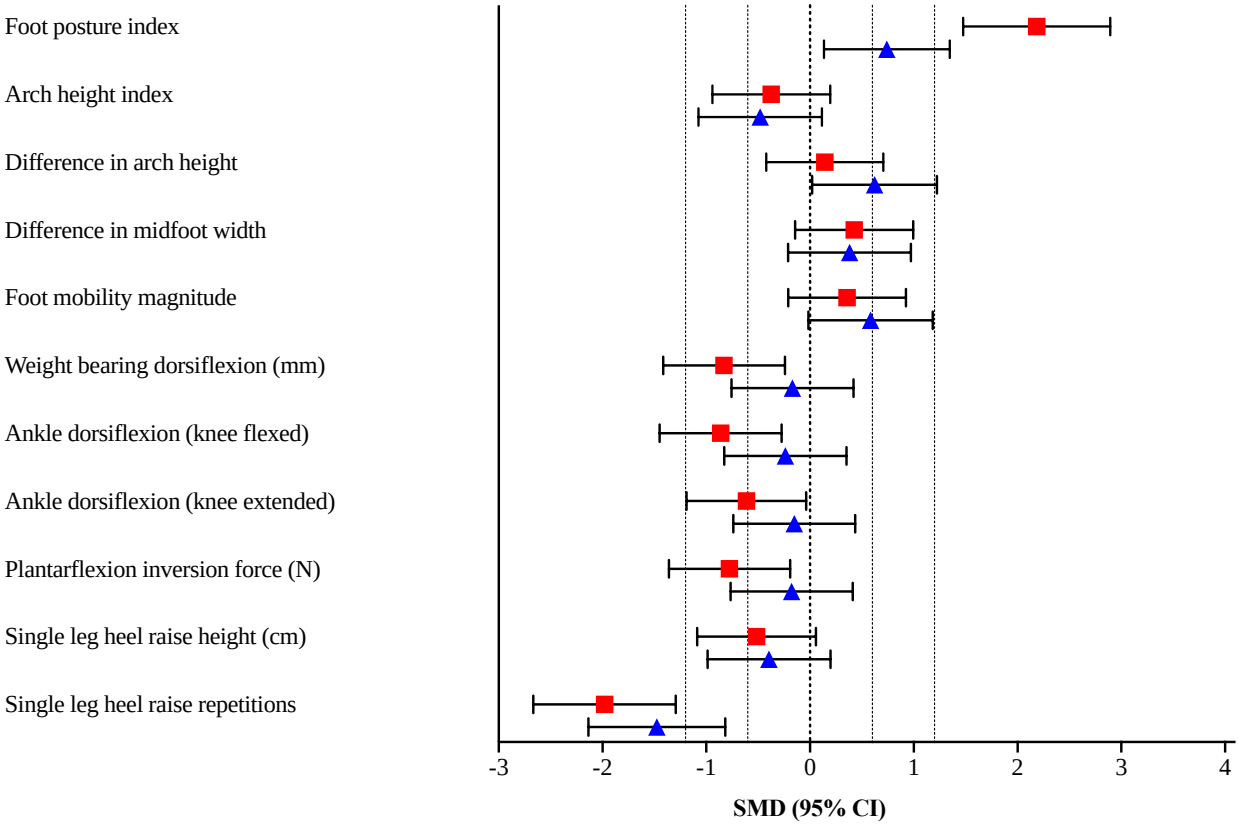


Figure 8-5 *SMD (95%) CI for body structure and function outcomes relating to the foot and ankle for the symptomatic and asymptomatic sides compared to controls. Positive SMDs indicate greater values in TPT compared to controls for the symptomatic (red square) and asymptomatic (blue triangle) sides.*

Individuals with TPT had a median (IQR) pain severity of 2 (4) out of 10 during the first SLHR (to maximal height) on the symptomatic side. During the SLHR endurance test (maximal number of repetitions) participants reported a median (IQR) pain severity of 4 (4) out of 10 and following the endurance test pain returned to pre-test severity (2 (4)). **Table 8-3** shows the reasons for stopping the maximal SLHR test for the TPT (symptomatic and asymptomatic sides) and control groups. Significantly more controls participants reached 25 repetitions, more TPT participants reported pain as the reason for stopping on the symptomatic compared to both asymptomatic side and controls, and significantly more TPT participants reported calf fatigue as the reason for stopping on the asymptomatic side compared to the symptomatic side and controls ($p < 0.05$) (**Table 8-3**).

Table 8-3 *Reasons for stopping the SLHR test, n (%)*

Reason	TPT symptomatic (n = 22)	Control (n = 27)	TPT asymptomatic (n = 19)

Completed 25 repetitions	0 (0.0)	(51.9)^	2 (10.5)
Pain tibialis posterior tendon	9 (40.9)^	0 (0.0)	0 (0.0)
Unable to reach bar	5 (22.7)	3 (11.1)	3 (15.8)
Knee flexion	3 (13.6)	2 (7.4)	1 (5.3)
Calf fatigue	4 (18.2)	8 (29.6)	12 (63.2)^
Weakness	1 (4.5)	0 (0.0)	0 (0.0)
Balance	0 (0.0)	0 (0.0)	1 (5.0)

^; denotes group proportion differs significantly from the others at the 0.05 level

Hip

Individuals with TPT generated significantly less peak normalised hip extension torque on both sides compared to controls ($p < 0.04$) (**Table 8-2**/**Figure 8-6**). There were no between group differences in torque production for any other muscle groups and there were no between side differences in the TPT group (**Table 8-2**/**Figure 8-6**). There were no differences for active or passive hip ROM between sides or between groups. The difference between active and passive ROM (lag) in ER and IR was significantly less on both sides in TPT compared to controls ($p < 0.04$) (**Table 8-2**/**Figure 8-6**).

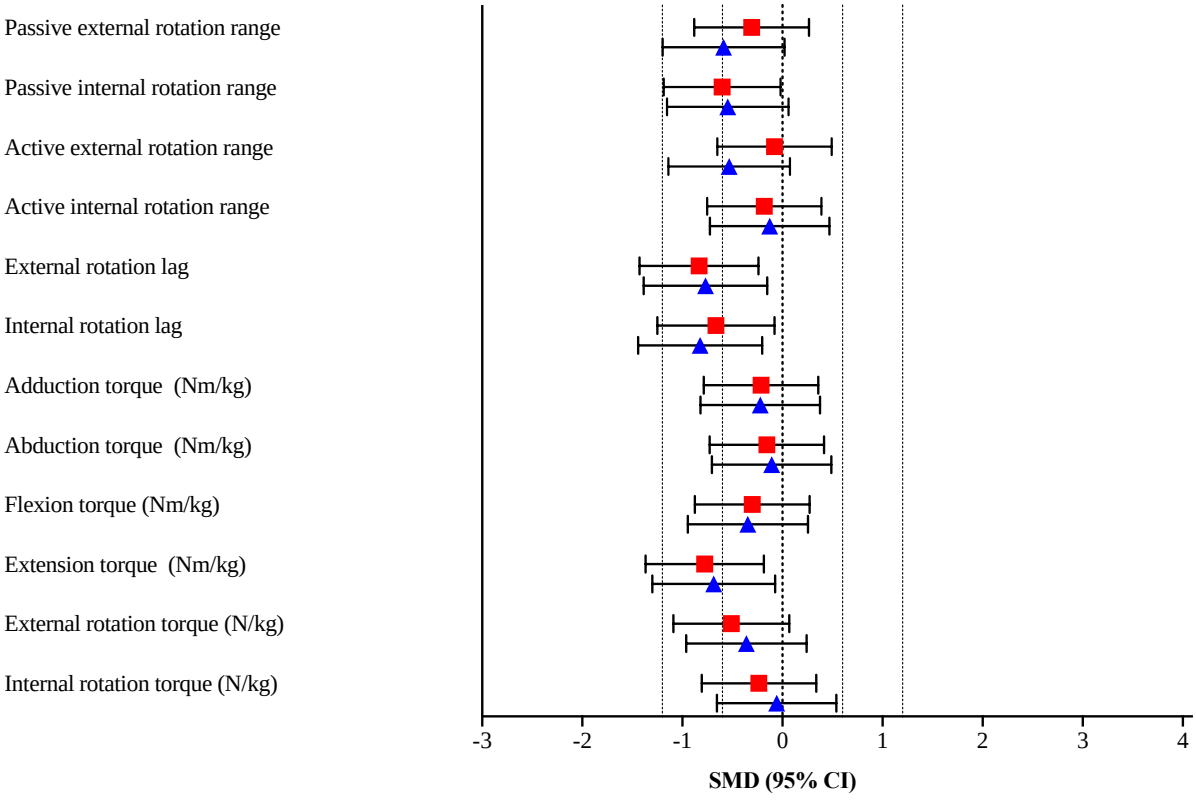


Figure 8-6 *SMD (95%) CI for body structure and function outcomes relating to the hip for the symptomatic and asymptomatic sides compared to controls. Positive SMDs indicate greater values in TPT compared to controls for the symptomatic (red square) and asymptomatic (blue triangle) sides.*

Self-report/questionnaire

Individuals with TPT had significantly greater pain scores than controls on both the FFI-R and AQoL and greater self-reported stiffness (p<0.01) (**Table 8-2**). There were no differences between groups for the senses domain of the AQoL (p = 0.83) or the PCS (p = 0.95). Eight participants (36.4%) in the TPT group exhibited a high degree of fear of movement or (re)-injury (> 37 on the TSK).

Measures of activity

Compared to controls, individuals with TPT took significantly longer to complete the stair descent/ascent task (~4.5 seconds, p<0.01) (**Table 8-4**/**Figure 8-7**). Individuals with TPT had a median (IQR) pain severity of 1 (2) out of 10 prior to performing the stairs task, 3 (2.1) during the task and 1.75 (2.3) following completion of the test.

Table 8-4 *Activity limitations and participation restriction measures*

Activity limitations	TPT (n = 22)	Control (n = 27)	Mean difference (SD)	p-value
Clinical				
Stairs - time	27.91 (4.39)	23.43 (3.23)	4.47 (2.28 to 6.67)*	<0.01
Questionnaire				
FFI-R - Difficulties	45.19 (13.54)	25 (0.00)	20.19 (14.96 to 25.42)*	<0.01
FFI-R - Activity limitations	33.68 (12.02)	25 (0.00)	8.68 (4.03 to 13.32)*	<0.01
AQoL - Independent living	6.36 (1.89)	4.15 (0.36)	2.22 (1.47 to 2.96)*	<0.01
AAS - Total time	759.36 (554.94)	744.85 (485.82)	14.51 (-284.70 to 313.72)	0.92
AAS - Rating				0.43
Inactive	0 (0)	0 (0)		
Insufficiently active	2 (9.1)	1 (3.7)		
Sufficiently active	20 (90.9)	26 (96.3)		
Participation restrictions	**TPT (n = 22)**	**Control (n = 27)**	**Mean difference (SD)**	**p-value**
Questionnaire				
FFI-R - Total	43.98 (12.05)	25.37 (1.20)	12.61 (13.93 to 23.29)*	<0.01
FFI-R - Social restrictions	39.47 (14.15)	25.96 (3.60)	13.51 (7.83 to 19.20)*	<0.01

AQoL - Total	36.55 (8.67)	27.89 (4.77)	8.66 (4.73 to 12.58)*	<0.01
AQoL - Relationships	3.95 (1.43)	3.33 (0.56)	0.62 (0.02 to 1.22)*	0.04
AQoL - Mental health	8.32 (2.75)	6.74 (2.23)	1.58 (0.15 to 3.01)*	0.03
AQoL - Coping	6.36 (1.87)	5.70 (1.61)	0.66 (-0.34 to 1.66)	0.19

**; p<0.05, Abbreviations: FFI-R; Foot function index - revised, AQoL; Assessment of Quality of Life, AAS; Active Australia Survey*

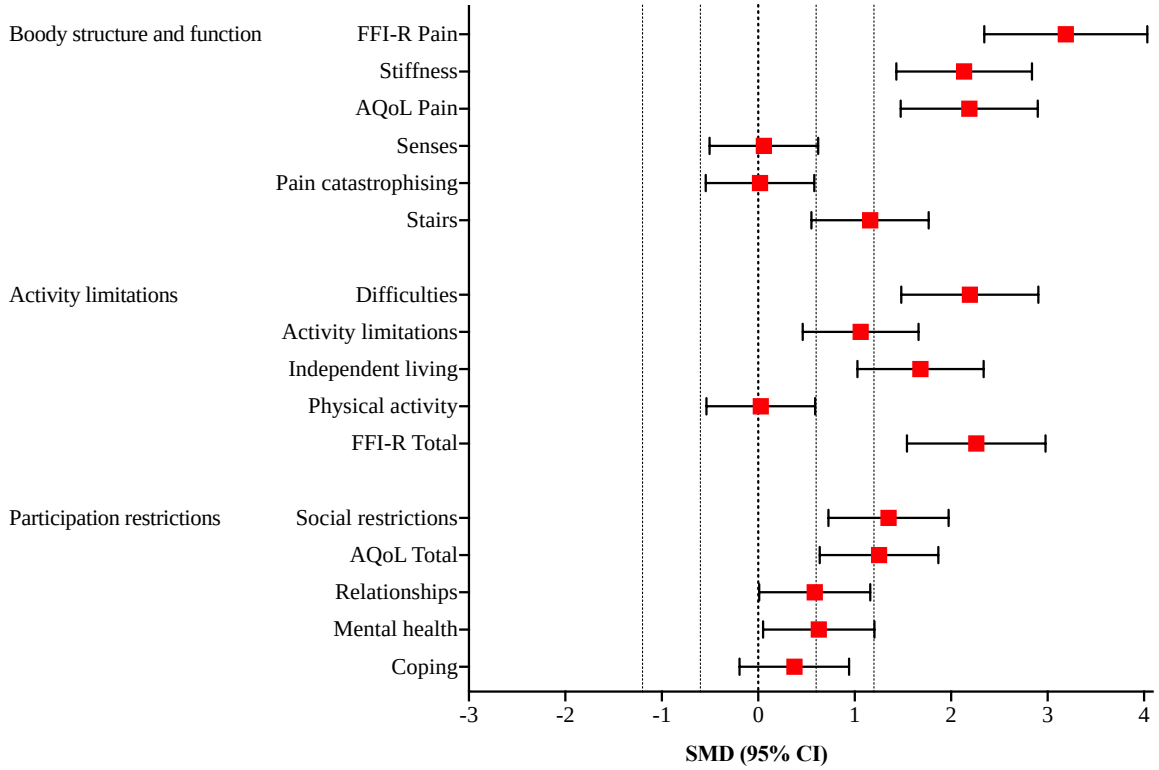


Figure 8-7 *SMD (95%) CI for body structure and function self-report outcomes and activity and participation outcomes. Positive SMDs indicate greater values in TPT compared to controls.*

There were large effects (SMD > 1.2) for greater foot-related functional difficulties (p<0.01) and difficulties with independent living (p<0.01) in TPT compared to controls (**Table 8-4**/**Figure 8-7**). There was a moderate effect (SMD 0.61-1.2) for greater activity limitations on the FFI-R in TPT (p<0.01), but there were no differences between groups in physical activity over the previous week or proportion of participants who were sufficiently active (**Table 8-4**).

Pain experienced before, during and after two functional activities (SLHR and stairs) was compared for the TPT group (Figure 8) using a repeated measures ANOVA. There were significant main effects for time (F (2, 20) = 18.93, p <0.01) and task (F (1, 21) = 8.21, p = 0.01), with no interaction (p = 0.08). Pain with the SLHR task was significantly greater than pain during the stairs task (MD (95% CI) 1.1 (0.3 to 1.9), p = 0.01) (**Figure 8-8**). For both tasks, pain during the task was significantly greater than pain before (MD (95% CI) 1.9 (1.3 to 2.6), p < 0.01) and after (MD (95%

CI) 1.5 (0.9 to 2.1), p < 0.01) and pain after the task was significantly greater than before, although to a lesser extent (MD (95% CI) 0.4 (0.1 to 0.8), p = 0.03).

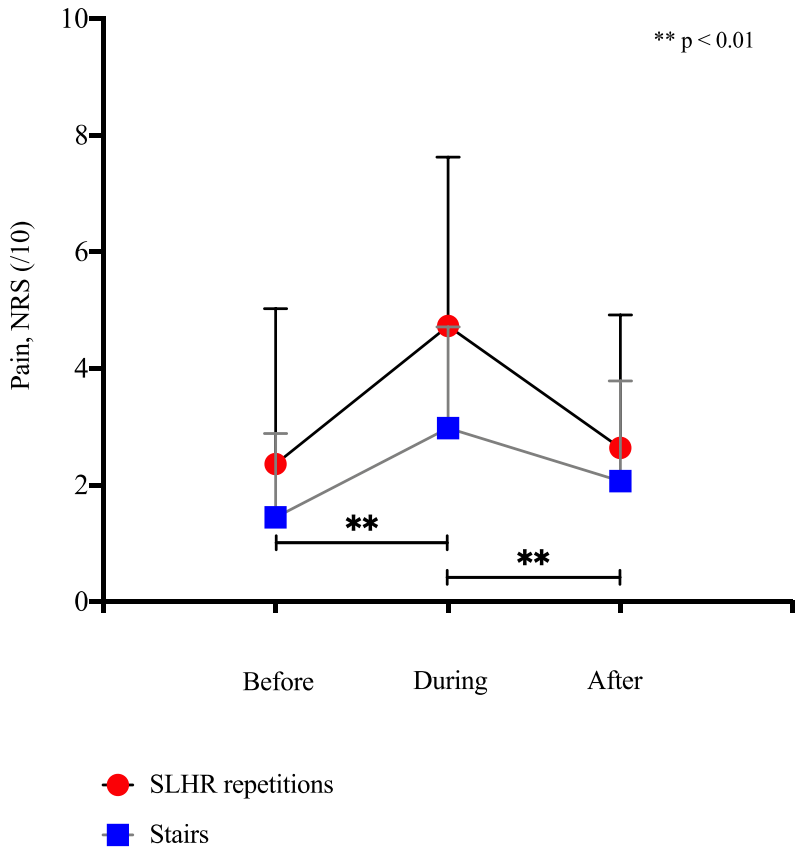


Figure 8-8 *Pain before, during and after SLHR and stairs tasks for TPT group*

Measures of participation

There were large effects for poorer self-reported foot function overall, greater social restrictions due to foot problems, and poorer quality of life overall in TPT compared to controls (p < 0.01) (**Table 8-4**/**Figure 8-7**). There were small to moderate effects (SMD 0.2-0.6) for poorer scores on the relationships (p = 0.04) and mental health (p = 0.03) domains of the AQoL (**Table 8-4**/**Figure 8-7**).

8.1.4 Discussion

Few studies have investigated impairments in body structure beyond the foot and ankle, function, activities and participation in individuals with TPT. This is the first study to report hip muscle torque in all directions and quality of life in individuals with clinically diagnosed TPT. The results of this study demonstrate significant bilateral deficits in hip extension torque production compared to healthy controls and significantly poorer quality of life, particularly in relation to independent living and pain. Individuals with TPT also took significantly longer to ascend and descend stairs and reported greater functional difficulties and activity limitations than controls. Consistent with

other studies, we also found differences in body structure and function at the foot and ankle including more pronated foot posture and local muscle deficits. [195]

Heel raise performance is a common clinical test used to assess the functional capacity of the tibialis posterior and is often reported in terms of maximal height and number of repetitions. A recent systematic review indicated large effects for poorer SLHR endurance in individuals with TPT compared to controls. [195] In addition to finding impaired endurance on the symptomatic side (~11 repetitions fewer than controls), participants with unilateral symptoms also performed fewer repetitions on the asymptomatic side compared to controls (~8 repetitions fewer). Relatively fewer individuals with TPT were able to reach the normative range for number of repetitions completed by healthy adults of the same age (n = 21 to 25 repetitions) [279] on their asymptomatic side than controls (2 v 14), which suggests that while pain and symptoms may be unilateral, there are bilateral deficits in plantar flexor endurance. Clinically, this suggests that a SLHR test should be completed on both the symptomatic and asymptomatic sides and compared to normative values rather than between sides. Interestingly, while there were bilateral impairments in overall plantar flexor endurance, only the symptomatic side demonstrated poorer isolated plantar flexion inversion force. It is possible that although overall calf muscle endurance (that has contributions from the gastrocnemius soleus complex) was poorer, the isolated tibialis posterior force production capacity on the asymptomatic side was not impaired.

Global functional impairments were identified in TPT. We found it took significantly longer for individuals with TPT to complete the stairs task (almost 5 seconds slower) which is similar to previously published work that shows women with TPT walk a significantly shorter distance in 6 minutes than controls. [66] Adequate ankle dorsiflexion ROM is required for walking and navigating stairs, and restrictions in dorsiflexion have been associated with shorter step length and slower walking speed. [287] Results from this study suggest ankle dorsiflexion ROM is significantly restricted compared to the asymptomatic side and controls. This must be interpreted with caution, as group means all fell within normative values for ankle dorsiflexion ROM. [288] However, the asymmetry between sides in the TPT group was greater than minimal detectable change, [288] and also the value at which clinically relevant impairments have been demonstrated. [289 290] Ankle plantar flexor power and hip extension torque have also been identified as predictors for walking speed, stride length and cadence in older adults. [291 292] We found bilaterally impaired hip extension torque in individuals with TPT. This is similar to findings from the only other study to investigate muscle function at the hip in women with TPT, where bilateral deficits in hip abduction and extension torque and endurance were found. [66] Clinically, assessing for ankle dorsiflexion ROM, plantar

flexor and hip extensor muscle torque may assist with identifying impairments to target in management of this population.

Impairments in muscle function, including strength, have been associated with limited participation in physical activity. [293] [294] While individuals with TPT reported significantly greater foot-related activity limitations, participation in overall physical activity was not different between groups. Considering this and the findings of bilaterally impaired plantar flexor endurance and hip extension strength, it is possible there are direction specific (sagittal plane) impairments in muscle function, rather than widespread activity-related declines. [295] It is possible that despite experiencing pain and difficulties with activities that specifically load the affected tendon, individuals with TPT are still able to participate in physical activity required to limit activity-related declines in strength. [295] Despite 91.3% of individuals with TPT participating in sufficient levels of physical activity for health, [296] over a third displayed signs of fear of movement (TSK). Considered within the biopsychosocial model of health, [297] participants with TPT also had significantly poorer overall quality of life compared to controls, particularly in regard to pain and independent living, and to a lesser extent, relationships and mental health. This suggests a there may be a psychosocial component of TPT that has not previously been considered beyond foot-related function and foot-health related quality of life.

Lower arch height is often reported as a feature of TPT. [195] In contrast to previous studies, eligibility for the TPT group in this study was based exclusively on a clinical definition of tendinopathy of the tibialis posterior tendon [64] and as such there were no criteria requiring specific foot postures for either group. This may explain the conflict between the findings for arch height in the present study and the results of a recently published systematic review and meta-analysis that found large, significant effects for lower arch height in individuals with TPT compared to controls. [195] Most studies included in the meta-analysis required control participants to have a 'normal arch' (AHI 0.33 to 0.38) which may have over-estimated the between group difference. While we found no difference in arch height, there were significant differences in the overall foot posture (FPI). Further research is required to investigate if other components of the FPI better characterise foot position in TPT than the AHI.

There are some limitations that need to be considered when interpreting the findings of this study. First, due to the cross-sectional design, it cannot be ascertained whether the impairments are a consequence or predisposing factor for the development of TPT. Second, eligibility criteria did not limit sex or age, despite TPT reportedly being more prevalent in mid-late aged females. This resulted in a large age range and a small proportion of male participants included in the study. To address this, groups were matched for age and sex. Finally, participants included in the TPT group

in this study did not have imaging-confirmed signs of tendinopathy. To address this, decisions regarding eligibility for the TPT group were based on persistent tibialis posterior tendon pain and the clinical index test with the best diagnostic utility (SLHR) and was examined and agreed upon by two physiotherapists. Despite this, it is possible that participants who met eligibility criteria for this study did not have imaging-confirmed TPT and this should be considered when interpreting the findings.

8.1.5 Conclusion

Individuals with TPT have impairments beyond the symptomatic foot and ankle. We found bilateral deficits in hip extensor torque and SLHR endurance, unilateral deficits in plantar flexion-inversion muscle force production and activity limitations with a functional stairs task. These clinical impairments were accompanied by poorer self-reported function and quality of life, particularly relating to independent living and pain. These findings suggest management of TPT should involve assessment of both sides, consideration of proximal as well as local muscle function, and addressing psychosocial aspects of the condition across all domains of the ICF.

PART C:

Overall discussion and conclusions

This section integrates the major findings of the thesis, discusses the clinical implications of these findings in relation to the ICF, limitations of the thesis, and provides directions for future research. This thesis provides a comprehensive synthesis of available literature investigating a condition that is poorly understood and poorly managed and further characterises the clinical presentation of TPT with regard to terminology, diagnosis, impairments in body structure and function, activity limitations and participation restrictions.

CHAPTER 9 Overall discussion and conclusions

The early stages of the condition referred to in the literature as PTTD or AAFD are characterised by signs and symptoms of tendinopathy of the TP tendon. [84] Debilitating and progressive, PTTD/AAFD often goes undiagnosed until substantial pain and limitations affect individuals' daily functioning. [47] Ligament failure associated with a dysfunctional TP tendon [130] results in a characteristic flatfoot deformity, for which surgical intervention is considered the only option. Surgical procedures for PTTD/AAFD are invasive and costly, with no high-level evidence to support their efficacy. With the overarching objective of informing the future development of targeted interventions for TPT, the aims of this thesis were to systematically synthesise the current evidence in relation to terminology, clinical presentation and management of TPT, to address current gaps in the literature in relation to diagnosis, and to explore the clinical presentation of TPT using the ICF framework.

9.1 Summary of main findings

9.1.1 Part A

Part A consisted of four systematic reviews of the current literature for TPT. This section began with a systematic review of RCTs of local strengthening exercises for TPT (Study 1). It highlighted the paucity of high-quality research and demonstrated significant inadequacies in current conservative management. [65] Prescription parameters were poorly reported, interventions and outcomes were exclusively related to the foot and ankle, and the treatment effects of local strengthening exercises were small.

Chapter three (Study 2) was a systematic review of selection criteria used in all primary research papers investigating PTTD and/or AAFD. The terminology PTTD and AAFD were used in this chapter to reflect what is most often reported in academic literature. We made the recommendation that PTTD is used when key signs and symptoms relate to tendon pathology, leaving AAFD to be used as an umbrella term for which there are several aetiologies. [84] This chapter found that the selection criteria for stage I and II PTTD were specific to tendon pathology (pain and/or swelling along the tendon, difficulty with foot inversion or a SLHR) and thus guided the development of the clinical tests used in Chapter six and the eligibility criteria for Chapters 7 and 8 for TPT.

Chapter four (Study 3) was a systematic review of the literature that compared clinical measures of impairment, pain and disability between individuals with TPT and control participants. Meta-analyses revealed significantly flatter foot posture and local strength deficits in individuals with TPT compared to controls. [195] These local impairments were also accompanied by deficits in foot-related function, greater pain and activity limitations compared to controls. There was preliminary

evidence for reductions in global functioning and altered hip muscle function, however, investigation of impairments beyond the foot and ankle were limited.

Chapter five (Study 4) further characterised the presentation of TPT by systematically synthesising the literature exploring foot and ankle kinematics during gait. Meta-analyses revealed greater ankle plantar flexion and hindfoot eversion across all phases of stance and greater forefoot abduction during initial contact, loading response, midstance and pre-swing. Medial longitudinal arch angle was also lower in TPT compared to controls across all phases of stance with moderate to large effects. No studies included kinematic data for proximal lower limb segments.

9.1.2 Part B

The findings from Part A identified gaps in the existing literature and current knowledge of TPT that warranted further investigation. Part B consisted of three clinical studies designed to investigate the clinical presentation of TPT with consideration of the whole ICF framework. Chapter six (Study 5) investigated the diagnostic utility of clinical tests (identified in Chapter three) in determining when there is US-identified TPT. Pain or inability to perform a SLHR was the test most likely to identify TPT. Common clinical tests such as palpation, contraction against manual resistance and observing swelling were not useful in conclusively identifying whether or not TPT was present on US.

Chapter seven (Study 6) and eight (Study 7) contribute to what is currently known about the clinical presentation of TPT. Chapter seven investigated foot and ankle impairments and self-reported function and quality of life of people with isolated TPT compared to those with TPT plus concomitant pain sites, other causes of MFP that was not attributable to TPT, and healthy controls. Differences between isolated TPT and TPT plus pain elsewhere were minimal, with only SLHR height significantly lower in those with TPT and concomitant pain. Both TPT groups had a significantly more pronated foot posture and greater deficits in SLHR capacity compared to MFP that was not attributable to TPT. Self-reported function and quality of life were not different between the three pain groups. This suggests that pronated foot posture, rather than arch height, appears to be characteristic of TPT and that individuals with TPT and concomitant lower extremity pain have the greatest deficits in local muscle function.

The final study in this thesis (Study 7) explored the global impact of TPT on the individual by considering outcomes under each domain of the ICF compared to pain-free controls. In addition to impairments in local body structure and function (e.g. pronated foot posture and SLHR endurance), individuals with TPT demonstrated bilaterally impaired hip extension torque. Large effects were found for activity limitations including greater time to complete stairs descent/ascent and

difficulties with independent living. Considering participation, overall foot-related function and quality of life is poorer in individuals with TPT compared to controls, particularly in relation to social restrictions, relationships and mental health.

9.2 Integration of main findings in relation to the ICF framework; looking beyond body structure and function

Effective management of chronic musculoskeletal conditions requires consideration of factors beyond the biomedical model of health care, that is, beyond impairments in body structure and function. [298 299] The ICF framework is based on a biopsychosocial approach to overall functioning and disability, [16] by describing impairments in body structure and function, activity limitations and participation restrictions with consideration of personal and environmental factors. [7] The following section will discuss the integration of the findings of impairments in body structure and function, and the associated implications for activity and participation.

9.2.1 Foot posture and TPT

A review of the literature in Study 3 found large effects for altered foot posture in TPT compared to controls, but this must be interpreted with caution as most studies had requirements for certain foot posture in the control or TPT groups (i.e. within 1 SD of normative values). Without such requirements, Studies 6 and 7 also demonstrated large effects for more pronated foot posture in TPT compared to medial foot/ankle pain that was not attributable to the TP tendon, and controls. Pronated foot posture has been implicated as a risk factor for the development of lower limb overuse injuries and pain. [300-302] Considering the development of TPT specifically, a pre-existing flat- or pronated-foot posture is the most commonly proposed aetiologic risk factor, [132 276 277 303] but there is a lack of rigorous, prospective studies to support this notion. Notwithstanding, the association between pronated foot posture and TPT could potentially be bi-directional, particularly when considered from an anatomical and tendon loading perspective, and each will be discussed briefly below.

9.2.1.1 Foot posture as a potential contributor to the development of TPT

Abnormal kinematics have been implicated as a risk factor for developing lower limb tendinopathies. A recent systematic review of observational studies found that peak rearfoot eversion is a significant factor in development of lower limb tendinopathies in runners. [304] Repetitive microtrauma associated with subtalar and mid-tarsal joint pronation may contribute to the development of tendinopathy, due to the role the TP muscle and tendon play in stabilising and supporting the medial longitudinal arch. [256] Literature suggests that excessive or repeated pronation at the subtalar joint associated with flat foot posture may increase the eccentric load on the TP

tendon, [277] [305] which may result in mechanical overload and subsequent development of tendinopathy.

A recent study found that despite significant relationships between TP tendon strain, energy absorption at the subtalar joint and subtalar joint pronation, there were no associations between tendon strain and TP muscle force. [306] This suggests that the TP tendon may be predisposed to strain-related injury due to its role in absorption of energy at the subtalar joint. Greater subtalar joint moments during increased walking velocities drive increases in tendon stress, [307] which may further contribute to micro-damage and tendon degeneration due to resultant increases in tendon strain, [306] which is the biggest predictor of tendon failure during cyclic loading. [308]

9.2.1.2 Foot posture as a potential consequence of TPT

A flat foot deformity that develops as a consequence of TP tendon failure is often reported in the literature. [46] [130] [258] Increased loading through the soft tissue structures of the posteromedial foot and ankle, due to progressive loss of TP function, [309] has been implicated in the development of AAFD. The association between the loss of TP tendon function and concomitant ligament failure has been discussed in several publications with *in vivo* studies demonstrating the most frequently and severely involved capsuloligamentous structure is the spring ligament. [130] [204] [278] [310-314] One cross-sectional study also found that while the spring ligament complex (superomedial and inferomedial calcaneonavicular ligaments) was the most severely and frequently involved, there were high frequencies of talocalcaneal interosseous ligament, anterior component of superficial deltoid ligament, plantar metatarsal ligament and plantar naviculocuneiform ligament involvement. [130] While significant associations have been demonstrated, causation (i.e. the direction of the relationship between insufficiency of the TP and ligament failure) cannot be determined without prospective study designs, which to date are lacking.

9.2.2 Foot posture and potential relationships with pain and disability

Findings of flat- or pronated-foot posture, with or without ligament involvement, in the presentation of TPT need to be considered in terms of the global impact of altered foot posture on the individual, specifically in relation to activity limitations and participation restrictions. While findings from this thesis demonstrate altered foot posture and activity limitations and participation restrictions in TPT, relationships between foot posture and measures of disability and quality of life were not calculated as sample size was not large enough to properly or validly explore relationships.

Relationships between foot posture and measures of activity and participation have not been specifically investigated in TPT elsewhere. Some insight can be gained from examining literature investigating foot posture in the general population. Although limited, there are two studies

exploring the impact of foot posture on functional outcomes and quality of life. For example, in a random population sample, one study has demonstrated that foot health-related quality of life and foot function were lower in participants with asymptomatic flat foot posture than those with normal foot posture (on the Foot Health Status Questionnaire and the FFI), but found no difference between groups on the generic quality of life outcome (Short Form Health Survey (SF-36)). [315] Another cross-sectional study also found no differences in general, nor specific foot health-related quality of life, between participants with low, normal or high arches. [316] While this does not provide conclusive evidence that foot posture is not associated with quality of life, it highlights that further research is required to explore the impact of foot posture on disability, including quality of life, particularly in those with TPT.

9.2.3 Tendon structure and the associations with pain and disability

In Study 5 of this thesis, the frequency of greyscale changes within the TP tendon on US in those presenting with medial foot/ankle pain was 42.3% (22 of 52 participants). This was lower than the frequency of those who were given a clinical diagnosis of TPT based on tests commonly used by clinicians to diagnose tendinopathy (i.e. pain on palpation and pain or inability to load the tendon). This suggests some disconnect between the clinical presentation of TPT (i.e. reporting of persistent tendon pain in the area of the TP tendon and pain or inability to perform a SLHR) and structural changes within the tendon and imaging. This relationship, or lack of relationship, between imaging findings and the clinical presentation of tendinopathy (i.e. pain) is often debated in the tendinopathy literature. [255] It is accepted that imaging in tendinopathy is able to identify the presence and extent of intra-tendinous structural changes, when changes are substantially advanced. Imaging may miss substructural changes (i.e. histopathological changes). Notwithstanding, interpretation of structural changes within a tendon needs to occur in conjunction with the clinical features of tendinopathy (i.e. presence of persistent tendon pain, aggravated by mechanical loading). [64 246]

Tendinosis is the term used for histological or imaging signs of degeneration within the tendon, independent of clinical features of tendinopathy. [247] As in other tendinopathies, [317] there is evidence of degenerative tendinosis within the TP tendon, [318 319] and several histopathological studies have demonstrated increased mucin content, fibroblast hypercellularity, neovascularisation and disruption of the linear orientation of collagen fibres. [318 320 321] Some participants in Study 5 whose presentation did not fit the clinical picture for TPT (i.e. pain in the medial foot/ankle area but did not have pain on tendon loading) were found to have greyscale changes (i.e. *tendinosis*) on US imaging. Abnormal structure on imaging can be present in up to 50% of asymptomatic tendons, [250-253] and is frequently found in other tendons such as the patellar tendon, [252] Achilles tendon, [322 323] rotator cuff tendons [324] and lateral epicondylalgia. [325] Conversely, some participants who did fit the

clinical picture for TPT (i.e. localised tendon pain and pain with loading) did not demonstrate degenerative changes in the TP tendon on US. Current literature indicates that a tendon can still be a source of pain and dysfunction, despite relatively normal structure on imaging. [246] It may be useful to consider TPT using the model proposed by Coombes et al [326] which integrates local tendon pathology with motor and pain system changes. Investigating potential interactions between the peripheral and central nervous systems and local tendon changes, as in other tendinopathies, [327] may provide a greater understanding of TPT. [238]

9.2.4 Potential for changes in pain processing in TPT

Pain system changes have been implicated in the persistence of tendon pain and may be useful to consider when interpreting the findings of this thesis. A significant proportion of participants with medial foot/ankle pain (with and without meeting selection criteria for TPT) had concomitant pain sites (bilateral pain and pain in sites remote to the medial foot/ankle). The concepts of physiological and pathophysiological pain may underpin these findings. 'Nociceptive' (physiological) pain is pain that occurs in the presence of actual or anticipated tissue damage or inflammation, whereas pathophysiological pain occurs when there is altered processing and/or output from the central and/or peripheral nervous systems. [238 328 329] The persistence of localised, and widespread pain, in chronic musculoskeletal conditions has been proposed to be a result of peripheral or central sensitisation. [329 330]

The International Association for the Study of Pain (IASP) defines sensitisation as an "*increased receptiveness of nociceptive neurons to their normal input, and/or recruitment of a response to normally subthreshold inputs.*" [331] Peripheral sensitisation involves increased receptiveness and decreased thresholds of peripheral nociceptive neurons, whereas central sensitisation involves increased receptiveness of nociceptive neurons in the central nervous system. [331] Allodynia ("*pain due to a stimulus that does not normally provoke pain"*) and hyperalgesia ("*increased pain from a stimulus that normally provokes pain"*) are the clinical manifestations of peripheral or central sensitisation, or both. [331]

Assessment of these clinical manifestations has allowed the relationship between persistent tendinopathies and altered pain processing to be explored. Quantitative sensory testing (QST) enables objective assessment of the response to noxious and non-noxious stimuli and is a means by which the presence and extent of hyperalgesia and allodynia can be inferred. [332] Systematic reviews and QST studies suggest that peripheral and/or central sensitisation may play a role in persistent tendinopathies, [333 334] and in the lower limb, the presence of local hyperalgesia appears to predominate. [335 336] To date, the presence (or absence) of peripheral and/or central sensitisation has not been investigated in TPT.

Bilateral pain and pain in sites remote to the medial foot/ankle were observed in this thesis. While developing bilateral symptoms in lower limb tendinopathy is common, [337] and the development of concomitant lower limb pain in remote sites is often attributed to altered biomechanics and loading (i.e. during ambulation), central sensitisation may provide an alternative explanation for the development of bilateral pain, [338] and warrants investigation in TPT. Evaluating pain associated with TPT with consideration of potentially altered central and peripheral pain processing and modulated neural output, may help to better understand the clinical manifestation of the condition and assist with developing management strategies that address potential pathophysiological pain presentations.

9.2.5 Potential for motor system changes in TPT

Just as the integration of local tendon pathology and pain system changes may underpin the findings of this thesis, it is also important to consider potential motor system changes in the presentation of TPT. Systematic synthesis of existing literature (Studies 3 and 4) revealed that consideration of impairments beyond the affected foot and ankle in TPT was largely omitted. To address this gap in the literature, not only were foot and ankle outcomes evaluated for both the symptomatic and asymptomatic sides in Study 6 and 7, impairments in hip muscle function and activities were evaluated in individuals with TPT in Study 7 and compared to pain-free controls. Results indicated that individuals with TPT (with and without concomitant pain sites) have bilateral impairments in muscle function both locally and proximally, with Study 7 identifying that, compared to controls, participants with TPT have unilaterally impaired plantar flexion/inversion force production and bilateral deficits in plantar flexor endurance and hip extensor torque production.

Impaired muscle function (i.e. force production, endurance) can result from changes within the contractile components of the muscles themselves (i.e. sarcopenia, atrophy) or nervous system changes (i.e. motor control) and are influenced by lifestyle (i.e. physical activity), biological (i.e. hormones) and psychosocial factors (i.e. fear of movement). [339] It stands to reason then, that just as the development of bilateral symptoms is common, so too is the presentation of bilateral impairments in unilateral musculoskeletal conditions. [333]

Aberrant motor control has been demonstrated in tendinopathy. The direction of the relationship between altered motor control and tendinopathy is still unclear, with the majority of research in the area consisting of case-control or cross-sectional studies. Some evidence suggests that altered motor control may contribute to the development of tendinopathy, [340] while other studies suggest changes in motor system function occur after symptom development. While it was not possible to establish whether impairments in hip extension torque preceded or were an adaptation to the onset of TPT,

considering these impairments from a biomechanical perspective may help develop hypotheses that can be tested in future research.

Systematic synthesis of the literature investigating kinematic characteristics during gait (Study 4) highlighted that individuals with TPT have significantly greater hindfoot plantar flexion and eversion, forefoot abduction and lowering of the medial longitudinal arch during the stance phase (i.e. dynamic pronation). Greater subtalar joint pronation (a combination of rearfoot eversion, forefoot abduction and ankle dorsiflexion) has been associated with hip internal rotation and pelvic alignment in individuals with asymptomatic flatfoot postures. [341] This alteration in biomechanics and positioning has been proposed to contribute to overload of lower limb structures resulting in overuse injuries due to micro-trauma. [342] When applied to TPT, increased loading through the medial portion of the foot due to altered proximal movement patterns is a potential mechanism for mechanical overload of the TP tendon.

The 'mechanical overload' theory implicates the hip external rotators and abductors as potential contributors to the development of TPT (i.e., due to altered biomechanics and/or posture), yet Studies 3 and 7 of this thesis demonstrated no differences in hip abductor or external rotator torque in individuals with TPT compared to controls. Further research is required to establish whether, despite normal hip abduction and external rotation torque, hip muscle activity or adduction and/or internal rotation moments are altered in those with TPT. It is possible that hip muscle activity is not a contributing factor to the development and persistence of TPT, but rather a consequence.

Considering the sagittal plane findings of Study 4 and 7 together may provide an explanation for hip extension deficits in TPT. Individuals with TPT demonstrated shorter stride length, restricted DF range of motion, greater ankle PF throughout stance, impaired plantar flexor force production and impaired hip extension torque. As DF increases compression of the TP tendon posteriorly to the medial malleolus, [343] individuals with TPT may instinctively avoid end range DF, and with poorer PF power [214] may be required to shorten their stride, initiating hip flexion before the hip extensors activate. While further research is required to investigate proximal muscle activity and kinematics during gait (particularly in the sagittal plane), it is possible that proximal impairments may be an adaptation to reduce medial foot/ankle symptoms.

9.2.6 The implications of psychological factors in TPT

The perception of pain is influenced by behavioural, social, emotional and cognitive factors. [344 345] A number of psychological features have been implicated in the development and persistence of chronic musculoskeletal pain and disability including fear, anxiety, depression and catastrophisation. [346-349] In Study 6, individuals with TPT and concomitant pain, but not those with

isolated TPT or medial foot/ankle pain that was not attributed to TPT, had significantly poorer quality of life in regard to relationships, mental health and coping compared to controls, and fewer participants with TPT and concomitant pain were participating in sufficient physical activity for health. A large, prospective cohort study found a bidirectional influence of pain on mental health, and mental health on pain. [350] Participation in physical activity has positive effects across a range of psychological symptoms, including depression, anxiety and self reported health status. [351] While relationships between pain, physical activity and psychological factors were not able to be investigated in this thesis due to small sample size, being aware of psychological factors that may be associated with TPT may assist in optimising management. [349 352] Previous research in females with metabolic syndrome has demonstrated strong relationships between physical activity and mental health. [353] This relationship might be important to consider when interpreting the findings of this thesis, as individuals with medial foot/ankle pain (TPT or other) were predominantly female and had significantly higher BMI than control participants. While similar proportions of control and TPTplus participants were post-menopausal, the proportion of TPTplus participants meeting physical activity guidelines [286 296] was significantly less than controls (71% in TPTplus compared to 96% of controls) and BMI was significantly higher. There is some evidence for higher prevalence of tendon conditions in post-menopausal women, which appears to be associated with metabolic factors including BMI. [354]

9.3 Limitations

There are limitations that need to be considered when interpreting the findings of this thesis. First, the sample of participants recruited for Chapters 6 to 8 (Studies 5-7) were predominantly female, with a broad age range (18 to 70 years). While this reflects what has previously been reported in the literature in terms of a predominance of females with 'PTTD/AAFD', age range was not limited to mid-late (40+) as it was unclear from the previous literature whether the demographic is the same for those with a clinical diagnosis of tendinopathy. It is possible that there may be differences in the clinical presentation of younger individuals with TPT compared to older adults (i.e., duration of symptoms, severity). Future research should consider exploring potential subgroups within the TPT population.

Second, limitations of cross-sectional study design should be considered when interpreting the findings of Studies 6 and 7. All variables were measured on participants presenting with pain in the medial foot/ankle region for at least three months duration, and as such it is not able to be determined whether observed findings were a cause or result of TPT. That is, causality cannot be inferred. Despite this, cross-sectional study designs are useful as a first step in describing population characteristics and are well suited to exploring the presentation of a condition such as TPT where

there are significant gaps in the current evidence base. As the aim of this thesis was to explore the clinical presentation of TPT and informing future research and development of targeted interventions, cross-sectional design (Studies 6 and 7) was appropriate as it allowed for a vast array of clinically relevant outcome measures spanning each domain of the ICF to be assessed in participants presenting with medial foot/ankle pain and enabled comparisons to be made with controls.

Third, the recruitment rate from the general population was unknown prior to conducting this body of research. This thesis significantly contributes to a currently under-researched condition and provides preliminary findings not only in relation to the clinical presentation and impact of TPT but on the prevalence of TPT. Between July 2017 and March 2019, >1600 potential participants were screened online, >500 by phone and >150 underwent physical screening. Of those, 42 received a clinical diagnosis of TPT (with and without other pain locations). A main finding from this thesis is the relatively infrequent presentation of isolated cases of TPT (15 in this body of work), compared to those with TPT and other areas of lower limb pain (n=27), and those with medial foot/ankle pain that does not present clinically as TPT (n=29). As such, the participants included in Studies 5-7 were not unique samples and there was considerable overlap across studies (see **Appendix 7**). As well as overlap of participants between studies, some outcomes were presented in both Study 6 and 7. This was because in Study 7, outcomes were chosen under each domain of the ICF to represent those that may be impaired based on previous studies, and the sample was a group of participants likely to present clinically (i.e. meeting selection criteria for TPT but permitted to have pain elsewhere, provided TPT was their predominant complaint).

Fourth, findings from this thesis are based on small sample sizes and this should be taken into account when interpreting results. As this thesis was primarily exploratory (i.e. the aim was to explore the presentation of TPT under each of the ICF domains), we were unable to conduct power analyses for Studies 5-7. This is because we were not confident in estimating effect sizes used in power analyses. Results are presented as SMDs, that is, we have provided point estimates of effect in this thesis so that readers are able to interpret whether effects are real or not. The limitations of relatively small sample sizes and the power to detect significant differences should be considered when interpreting results. Furthermore, small sample size may contribute to type II errors (i.e., incorrectly accepting the null hypothesis, or finding no difference when a difference is actually present).

Finally, there is current debate around whether imaging is required for the diagnosis of tendinopathy. In this study, participants were allocated to the TPT or non-TPTMFP based on the findings of the diagnostic utility study presented in the fifth chapter of this thesis. TPT participants

included in Chapters 6 to 8 met the selection criteria for TPT based on persistent tendon pain and pain with mechanical loading. [64] The mechanical loading test chosen was the SLHR, as this had the highest positive and negative likelihood ratios in the diagnostic utility study (Study 5). Overall the ability of the clinical index tests to accurately detect when there is US-identified TPT (i.e. greyscale changes on the reference standard) was low. Despite having the highest likelihood ratios (positive and negative), post-test shifts in probability for the SLHR test were small (18% if positive and 19% if negative). As such, it is possible that participants included in the TPT groups across all studies, may not have had greyscale changes on US, despite meeting the selection criteria for TPT. Conversely, it is also possible that participants included in the non-TPTMFP group in Chapter seven did in fact have imaging signs of TPT.

9.4 Clinical implications of thesis findings

This thesis has several important clinical implications. Data suggest that just over half (53%) of patients presenting with medial foot/ankle pain would receive a clinical diagnosis of TPT based on the criteria of persistent pain in the area of the TP tendon, and pain on or inability to perform a SLHR, and if US was used to diagnose the presence of greyscale changes within the tendon, this would decrease to 2 in 5 (40%). This suggests that symptomatic TPT may present without signs of tendinopathy on US imaging, and that clinicians should consider results from index tests together with presenting impairments when diagnosing TPT. When patients presenting with medial foot/ankle pain have pain with or inability to perform a SLHR, impaired heel raise capacity and bilateral pronated foot posture (quantified using the FPI, a quick and easy clinical assessment tool), clinicians should consider TPT.

When a clinician is managing a patient presenting with medial foot/ankle pain, findings from this thesis suggest the importance of considering the relatively infrequent presentation of isolated TPT (21% of those presenting with medial foot/ankle pain). TPT often presents with concomitant knee and/or hip pain, or other foot pain, indicating that clinicians should be assessing for concomitant pain areas and managing accordingly. Furthermore, participants with TPT demonstrated impairments in hip muscle function, which indicates that assessment and management should include evaluation of the proximal lower limb.

Mental health, relationships and coping strategies may be important to consider in the management of TPT. This suggests that clinically, a biopsychosocial approach should be taken in the management of all individuals presenting with medial foot/ankle pain, but particularly those with TPT and pain elsewhere who may present with greater psychosocial concerns compared to the normal population.

As clinical recommendations about the most efficacious local strengthening exercise for TPT could not be made in Study 1 of this thesis, clinicians should be encouraged to use their assessment of presenting impairments to guide management. Assessment and management should not only include local body structure and function impairments, but proximal muscle function in addition to taking a biopsychosocial approach by evaluating limitations in activity and restrictions in participation, including quality of life.

9.5 Implications and directions for future research

This thesis provides a comprehensive summary of the clinical presentation of TPT, a condition which is poorly understood and often poorly managed. Findings of the thesis highlight several different, but related implications for future research. The first is the difficulty in recruiting individuals with the condition. Considering this limitation, future research may need to involve multi-site collaborations and consider the expansion of selection criteria to include those who have concomitant pain sites, as this is commonly how individuals with TPT present.

All future research should include clear reporting of the selection criteria used to include participants in TPT groups, the presence (or not) of concomitant pain sites and use the terminology recommended in this thesis. That is, that TPT is the preferred terminology when medial foot/ankle pain symptoms can be attributed to the TP tendon (i.e. persistent tendon pain that is worse with loading activities), and that AAFD should be reserved as an umbrella term for the condition of an adult-acquired flat foot, with the aetiology specified. This will ensure that future research is consistent, allowing for both clinical application of research findings and synthesis and/or comparison of findings between studies.

The diagnostic utility of evidence-informed clinical tests for the condition, as evaluated in Study 5, is relatively poor. While it may be useful to conduct a larger diagnostic utility study to establish the ideal clinical diagnostic criteria, issues with recruitment (as discussed in relation to this thesis) may impede this line of future research. An alternative direction for future research takes into consideration the findings of Study 6, which demonstrated that those presenting with medial foot/ankle pain, with or without a clinical diagnosis of TPT, exhibit similar functional (both clinical and self-reported) impairments and psychosocial features. As the population characteristics of the participants included in this thesis are known to influence somatosensory profiles (i.e. primarily female, overweight, middle aged), [355] [356] future research investigating whether pain processing (central or peripheral) is altered in individuals with TPT, and if so, to what extent, is warranted.

Second is the need for research that explores potential correlations between significant impairments in TPT and pain, function and quality of life. For example, exploring the relationships between

pronated foot posture and SLHR capacity and measures of activity and participation, and considering the impact of these impairments on overall global functioning for those with TPT will help to guide future management of the condition. Of particular importance is identifying features of the condition affecting activity and participation that are modifiable and can be targeted with non-surgical management. Future research may also benefit from recruitment of participants with isolated and concomitant pain sites, and those who present with medial foot/ankle pain that is not attributed to TPT (as was done in Study 6 in this thesis), to explore any differences in relationships between these presentations, and to inform whether these presentations can be considered together in terms of the impact of impairments on pain and disability.

Third is the investigation of kinematic characteristics and muscle activity of the proximal lower limb. Considering the findings of hip extension torque deficits (Study 7), the presence of altered foot and ankle kinematic characteristics during gait (Study 4) and the lack of research investigating kinematics more proximally than the foot and ankle, this is an area that warrants future research.

There is still a significant gap in the literature regarding the efficacy of exercise management for TPT using rigorous, high-quality methodologies with thoroughly described exercise prescriptions targeted for tendinopathy. Further research is warranted to investigate the effects of non-surgical intervention on pain and functional outcomes demonstrated in this thesis in individuals presenting with TPT. The findings of this thesis lend themselves to proposing a novel approach to conservative management of TPT and/or medial foot/ankle pain, by targeting the impairments identified in previous chapters and considering the current state of research in lower limb tendinopathy. Interventions should be targeted towards not only specific impairments but take into consideration a biopsychosocial approach to the management of the condition. A feasibility study, to inform a larger clinical trial, should be the first step of future research into the management of medial foot/ankle pain. The feasibility study would ideally take into consideration the eligibility criteria proposed within this thesis, the findings of this thesis, the development of an intervention addressing all impairments (i.e. global impairments as demonstrated in Study 7) and evaluate outcomes across all domains of the ICF (i.e. quality of life, as per Study 7).

9.6 Conclusions

This thesis has improved our understanding of the clinical presentation of TPT by systematically synthesising the existing literature and evaluating the diagnostic utility of clinical tests for TPT, investigating gaps in the literature identified by the systematic reviews and providing directions for future research. The results of this thesis indicate that the overall diagnostic utility of clinical tests to identify US defined TPT is poor, but that pain or inability to perform a SLHR is the best predictor of greyscale changes within the TP tendon on US. TPT is characterised by not only local

impairments in foot posture and SLHR capacity but also hip extension weakness, difficulties with stairs and has an impact on global functioning and quality of life. In order to develop targeted and effective management approaches for TPT that consider the biopsychosocial aspects of the condition, further research should investigate relationships between modifiable impairments and pain and disability.

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Appendices

Appendix 1 *Ethics Approval*

THE UNIVERSITY OF QUEENSLAND

Institutional Human Research Ethics Approval

Project Title:	The Hip in Posterior Tibialis Tendinopathy (HiPT) Study of Impairments and Associated Characteristics, Prognostic Factors and an Intervention: a Prospective Longitudinal Parallel Group trial - 17/10/2017 - AMENDMENT
Chief Investigator:	Prof Bill Vicenzino, Dr Michelle Smith
Supervisor:	Prof Bill Vicenzino, Dr Michelle Smith, Dr Rebecca Mellor
Co-Investigator(s):	Dr Rebecca Mellor, Ms Megan Ross, Prof Paul Hodges
School(s):	School of Health and Rehabilitation Sciences
Approval Number:	2016001728
Granting Agency/Degree:	None
Duration:	31st December 2021

Comments/Conditions:

Amendment 17/10/2017:
Addition of measures:
(a) Diagnostic utility study
(b) Physical impairment measures
(c) Laboratory measures, addition of:
(c -i) Kinetic data analysis
(c-ii) Tasks
(c-iii) Surface/fine wire EMG
(c-iv) Foot devices

- Amendment form, 17/10/2017
- Project description v3, 17/10/2017 (Tracked & Clean)
- Participant Consent Form v3 17/10/2017 (Tracked & Clean)
- Participant Information Sheet v3 17/10/2017 (Tracked & Clean)

Note: if this approval is for amendments to an already approved protocol for which a UQ Clinical Trials Protection/Insurance Form was originally submitted, then the researchers must directly notify the UQ Insurance Office of any changes to that Form and Participant Information Sheets & Consent Forms as a result of the amendments, before action.

Name of responsible Committee:
University of Queensland Human Research Ethics Committee A
This project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research* and complies with the regulations governing experimentation on humans.

Name of Ethics Committee representative:
Professor Emerita Gina Geffen
Chairperson
University of Queensland Human Research Ethics Committee A
Registration: EC00456

Signature G. Geffen Date **20/11/2017**

Appendix 2 *Published manuscript incorporated in Chapter two*

Ross MH, Smith MD, Mellor R, Vicenzino B. Exercise for posterior tibial tendon dysfunction: a systematic review of randomised clinical trials and clinical guidelines. *BMJ open sport & exercise medicine.* 2018;4(1):e000430. doi:10.1136/bmjsem-2018-000430

Appendix 3 *Published manuscript incorporated in Chapter three*

Ross MH, Smith MD, Vicenzino B. Reported selection criteria for adult acquired flatfoot deformity and posterior tibial tendon dysfunction: Are they one and the same? A systematic review. *PLoS One*. 2017;12(12):e0187201. doi: 10.1371/journal.pone.0187201

Appendix 4 *Published manuscript incorporated in Chapter four*

Ross MH, Smith MD, Vicenzino B. Self-reported social and activity restrictions accompany local postural and strength impairments in posterior tibial tendon dysfunction: a systematic review. Journal of Foot and Ankle Research. 2018;11(1):49. doi: 0.1186/s13047-018-0292-z

Appendix 5 *Studies reporting kinematic data by segment, plane and phase of gait cycle*

Segment	Plane	Gait cycle	Houck* [124]	Ness* [128]	Neville [125]	Rabbito [126]	Ringleb [214]	Tome [127]	Van de Velde^ [215]	Total
Hindfoot (Ankle)(Shank-Cal)	Coronal (INV/EV)	2. LR	1	1	1	0	1	1	1	6
Hindfoot (Ankle)(Shank-Cal)	Coronal (INV/EV)	5. PreSw	1	1	1	0	1	1	1	6
Hindfoot (Ankle)(Shank-Cal)	Coronal (INV/EV)	3. MS	0	1	1	0	1	1	1	5
Forefoot (Cal-Met)	Transverse (IR/ER)(ABD/ADD)	2. LR	0	1	1	0	1	1	1	5
Forefoot (Cal-Met)	Transverse (IR/ER)(ABD/ADD)	3. MS	0	1	1	0	1	1	1	5
Forefoot (Cal-Met)	Transverse (IR/ER)(ABD/ADD)	5. PreSw	0	1	1	0	1	1	1	5
Hindfoot (Ankle)(Shank-Cal)	Sagittal (PF/DF)	2. LR	1	1	0	0	1	0	1	4
Hindfoot (Ankle)(Shank-Cal)	Sagittal (PF/DF)	5. PreSw	1	1	0	0	1	0	1	4
Hindfoot (Ankle)(Shank-Cal)	Coronal (INV/EV)	4. TS	1	1	1	0	0	1	0	4
Forefoot (Cal-Met)	Sagittal (PF/DF)	2. LR	1	1	0	0	1	0	1	4
Forefoot (Cal-Met)	Sagittal (PF/DF)	5. PreSw	1	1	0	0	1	0	1	4
Hindfoot (Ankle)(Shank-Cal)	Sagittal (PF/DF)	3. MS	0	1	0	0	1	0	1	3
Hindfoot (Ankle)(Shank-Cal)	Transverse (IR/ER)(ABD/ADD)	2. LR	0	1	0	0	1	0	1	3
Hindfoot (Ankle)(Shank-Cal)	Transverse (IR/ER)(ABD/ADD)	3. MS	0	1	0	0	1	0	1	3
Hindfoot (Ankle)(Shank-Cal)	Transverse (IR/ER)(ABD/ADD)	5. PreSw	0	1	0	0	1	0	1	3
Forefoot (Cal-Met)	Sagittal (PF/DF)	3. MS	0	1	0	0	1	0	1	3
Forefoot (Cal-Met)	Coronal (INV/EV)(VAL/VAR)	2. LR	0	1	0	0	1	0	1	3
Forefoot (Cal-Met)	Coronal (INV/EV)(VAL/VAR)	3. MS	0	1	0	0	1	0	1	3

Forefoot (Cal-Met)	Coronal (INV/EV)(VAL/VAR)	5. PreSw	0	1	0	0	1	0	1	3
Forefoot (Cal-Met)	Transverse (IR/ER)(ABD/ADD)	4. TS	0	1	1	0	0	1	0	3
Medial longitudinal arch	Medial longitudinal arch	2. LR	0	0	1	0	0	1	1	3
Medial longitudinal arch	Medial longitudinal arch	3. MS	0	0	1	0	0	1	1	3
Medial longitudinal arch	Medial longitudinal arch	5. PreSw	0	0	1	0	0	1	1	3
Hindfoot (Ankle)(Shank-Cal)	Sagittal (PF/DF)	1. IC	1	1	0	0	0	0	0	2
Hindfoot (Ankle)(Shank-Cal)	Sagittal (PF/DF)	4. TS	1	1	0	0	0	0	0	2
Hindfoot (Ankle)(Shank-Cal)	Coronal (INV/EV)	1. IC	1	1	0	0	0	0	0	2
Forefoot (Cal-Met)	Sagittal (PF/DF)	1. IC	1	1	0	0	0	0	0	2
Forefoot (Cal-Met)	Sagittal (PF/DF)	4. TS	1	1	0	0	0	0	0	2
Hallux	Sagittal (PF/DF)	2. LR	0	1	0	0	0	0	1	2
Hallux	Sagittal (PF/DF)	3. MS	0	1	0	0	0	0	1	2
Hallux	Sagittal (PF/DF)	5. PreSw	0	1	0	0	0	0	1	2
Medial longitudinal arch	Medial longitudinal arch	4. TS	0	0	1	0	0	1	0	2
Tibia	Sagittal (Fwd/Bwd)	1. IC	0	1	0	0	0	0	0	1
Tibia	Sagittal (Fwd/Bwd)	2. LR	0	1	0	0	0	0	0	1
Tibia	Sagittal (Fwd/Bwd)	3. MS	0	1	0	0	0	0	0	1
Tibia	Sagittal (Fwd/Bwd)	4. TS	0	1	0	0	0	0	0	1
Tibia	Sagittal (Fwd/Bwd)	5. PreSw	0	1	0	0	0	0	0	1
Tibia	Coronal (ABD/ADD)	1. IC	0	1	0	0	0	0	0	1
Tibia	Coronal (ABD/ADD)	2. LR	0	1	0	0	0	0	0	1
Tibia	Coronal (ABD/ADD)	3. MS	0	1	0	0	0	0	0	1
Tibia	Coronal (ABD/ADD)	4. TS	0	1	0	0	0	0	0	1
Tibia	Coronal (ABD/ADD)	5. PreSw	0	1	0	0	0	0	0	1
Tibia	Transverse (IR/ER)	1. IC	0	1	0	0	0	0	0	1
Tibia	Transverse (IR/ER)	2. LR	0	1	0	0	0	0	0	1

Tibia	Transverse (IR/ER)	3. MS	0	1	0	0	0	0	0	1
Tibia	Transverse (IR/ER)	4. TS	0	1	0	0	0	0	0	1
Tibia	Transverse (IR/ER)	5. PreSw	0	1	0	0	0	0	0	1
Hindfoot (Ankle)(Shank-Cal)	Transverse (IR/ER)(ABD/ADD)	1. IC	0	1	0	0	0	0	0	1
Hindfoot (Ankle)(Shank-Cal)	Transverse (IR/ER)(ABD/ADD)	4. TS	0	1	0	0	0	0	0	1
Midfoot (Cal-Mid, Mid-Met)	Sagittal (PF/DF)	2. LR	0	0	0	0	0	0	1	1
Midfoot (Cal-Mid, Mid-Met)	Sagittal (PF/DF)	3. MS	0	0	0	0	0	0	1	1
Midfoot (Cal-Mid, Mid-Met)	Sagittal (PF/DF)	5. PreSw	0	0	0	0	0	0	1	1
Midfoot (Cal-Mid, Mid-Met)	Coronal (INV/EV)	2. LR	0	0	0	0	0	0	1	1
Midfoot (Cal-Mid, Mid-Met)	Coronal (INV/EV)	3. MS	0	0	0	0	0	0	1	1
Midfoot (Cal-Mid, Mid-Met)	Coronal (INV/EV)	5. PreSw	0	0	0	0	0	0	1	1
Midfoot (Cal-Mid, Mid-Met)	Transverse (IR/ER)(ABD/ADD)	2. LR	0	0	0	0	0	0	1	1
Midfoot (Cal-Mid, Mid-Met)	Transverse (IR/ER)(ABD/ADD)	3. MS	0	0	0	0	0	0	1	1
Midfoot (Cal-Mid, Mid-Met)	Transverse (IR/ER)(ABD/ADD)	5. PreSw	0	0	0	0	0	0	1	1
Forefoot (Cal-Met)	Coronal (INV/EV)(VAL/VAR)	1. IC	0	1	0	0	0	0	0	1
Forefoot (Cal-Met)	Coronal (INV/EV)(VAL/VAR)	4. TS	0	1	0	0	0	0	0	1
Forefoot (Cal-Met)	Transverse (IR/ER)(ABD/ADD)	1. IC	0	1	0	0	0	0	0	1
Hallux	Sagittal (PF/DF)	1. IC	0	1	0	0	0	0	0	1
Hallux	Sagittal (PF/DF)	4. TS	0	1	0	0	0	0	0	1
Hallux	Coronal (INV/EV)(PRON/SUP)	1. IC	0	1	0	0	0	0	0	1

Hallux	Coronal (INV/EV)(PRON/SUP)	2. LR	0	1	0	0	0	0	0	1
Hallux	Coronal (INV/EV)(PRON/SUP)	3. MS	0	1	0	0	0	0	0	1
Hallux	Coronal (INV/EV)(PRON/SUP)	4. TS	0	1	0	0	0	0	0	1
Hallux	Coronal (INV/EV)(PRON/SUP)	5. PreSw	0	1	0	0	0	0	0	1
Hallux	Transverse (IR/ER)(VAL/VAR)	1. IC	0	1	0	0	0	0	0	1
Hallux	Transverse (IR/ER)(VAL/VAR)	2. LR	0	1	0	0	0	0	0	1
Hallux	Transverse (IR/ER)(VAL/VAR)	3. MS	0	1	0	0	0	0	0	1
Hallux	Transverse (IR/ER)(VAL/VAR)	4. TS	0	1	0	0	0	0	0	1
Hallux	Transverse (IR/ER)(VAL/VAR)	5. PreSw	0	1	0	0	0	0	0	1
Midfoot (Cal-Mid, Mid-Met)	Sagittal (PF/DF)	1. IC	0	0	0	0	0	0	0	0
Midfoot (Cal-Mid, Mid-Met)	Sagittal (PF/DF)	4. TS	0	0	0	0	0	0	0	0
Midfoot (Cal-Mid, Mid-Met)	Coronal (INV/EV)	1. IC	0	0	0	0	0	0	0	0
Midfoot (Cal-Mid, Mid-Met)	Coronal (INV/EV)	4. TS	0	0	0	0	0	0	0	0
Midfoot (Cal-Mid, Mid-Met)	Transverse (IR/ER)(ABD/ADD)	1. IC	0	0	0	0	0	0	0	0
Midfoot (Cal-Mid, Mid-Met)	Transverse (IR/ER)(ABD/ADD)	4. TS	0	0	0	0	0	0	0	0
Medial longitudinal arch	Medial longitudinal arch	1. IC	0	0	0	0	0	0	0	0

** reported peak and excursion, ^ reported excursion only, Abbreviations:*

Appendix 6 *Online survey of clinicians regarding the use of ultrasound in the diagnosis of tibialis posterior tendinopathy*

The following survey was circulated on social media between the 18th and 25th of February, 2019.

				Elements of US important for reference standard for TPT in order of importance (1 most important, 4 least important)			
ID#	Profession	Number of TPT patients per month	Frequency of US for diagnosis	Greyscale changes in tendon	Greyscale changes in peritendon	Fluid in peritendon	Doppler
1	Podiatrist	11-15	Always	4	3	1	2
2	Surgeon	11-15	Rarely	1	3	2	4
3	Sports physician	6-10	Usually	2	4	1	3
4	Radiologist	6-10	Always	1	4	3	2
5	Radiologist	6-10	Always	1	4	2	3
6	Podiatrist	6-10	Always	1	4	2	3
7	Podiatrist	6-10	Rarely	1	3	2	4
8	Podiatrist	6-10	Rarely	3	4	1	2
9	Podiatrist	6-10	Sometimes	4	3	1	2
10	Podiatrist	6-10	Rarely	1	4	3	2
11	Sports physician	6-10	Never	4	1	3	2
12	Podiatrist	6-10	Sometimes	1	2	3	4
13	Physiotherapist	6-10	Never	1	4	2	3
14	Podiatrist	6-10	Rarely	3	4	1	2
15	Sonographer	<5	Usually	1	2	4	3
16	Sports physician	<5	Usually	2	4	1	3
17	Podiatrist	<5	Rarely	3	2	1	4
18	Sports physician	<5	Always	1	3	2	4
19	Physiotherapist	<5	Always	2	4	3	1
20	Physiotherapist	<5	Never	3	4	2	1
21	Physiotherapist	<5	Never	1	3	2	4
22	Physiotherapist	<5	Sometimes	1	4	3	2
23	Sports physician	<5	Usually	1	3	2	4
24	Physiotherapist	<5	Usually	1	3	2	4
25	Physiotherapist	<5	Usually	1	4	2	3
26	Physiotherapist	<5	Rarely	3	2	1	4
27	Physiotherapist	<5	Never	1	3	4	2
28	Physiotherapist	<5	Never	3	1	2	4
29	Podiatrist	<5	Usually	2	4	3	1
30	Podiatrist	<5	Rarely	3	4	2	1
31	Sports physician	<5	Usually	1	3	2	4
32	Physiotherapist	<5	Never	3	2	1	4
33	Physiotherapist	<5	Rarely	2	1	3	4
34	Physiotherapist	<5	Sometimes	1	2	3	4
35	Physiotherapist	<5	Rarely	4	3	2	1
36	Physiotherapist	<5	Rarely	1	4	3	2
37	Sonographer	>15	Always	1	3	2	4

38	Podiatrist	None	Sometimes	1	4	3	2
Total		38	Most important	21	3	9	5
Physiotherapist		15	Second most	5	6	16	11
Podiatrist		12	Second least	8	12	11	7
Sports Physician		6	Least important	4	17	2	15
Radiologist		2					
Sonographer		2	Most important	55.3%	7.9%	23.7%	13.2%
Surgeon		1	Second most	13.2%	15.8%	42.1%	28.9%
			Second least	21.1%	31.6%	28.9%	18.4%
			Least important	10.5%	44.7%	5.3%	39.5%

Appendix 7 *Results for index tests, clinical diagnoses and break down of participants included in each study*

ID	Clinical index test findings						Studies included in thesis						
							All			Study 5	Study 6		Study 7
	Group	Medial foot/ankle pain present	Tender on palpation	Swelling	Pain or weakness with resisted plantarflexion inversion contraction	Pain or inability to single leg heel raise	Consent	Phone screening	Physical screening	Rater 2 physical screening	Ultrasound	Foot measures	Questionnaire	Hip measures
1	TPT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
2	TPT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
3	TPT	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
4	TPT	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
5	TPT	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
6	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
7	TPT	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
8	TPT	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
9	TPT	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10	TPTplus	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No
11	TPTplus	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
12	TPTplus	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
13	TPT	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
14	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
15	TPT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
16	non-TPTMFP	No	No	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No
17	TPTplus	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
18	TPT	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
19	TPT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
20	TPTplus	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No
21	non-TPTMFP	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No

22	TPT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
23	non-TPTMFP	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
24	TPTplus	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No
25	non-TPTMFP	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
26	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
27	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
28	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
29	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
30	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
31	non-TPTMFP	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
32	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
33	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
34	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
35	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
36	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
37	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
38	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
39	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
40	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
41	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
42	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
43	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
44	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
45	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
46	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
47	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
48	non-TPTMFP	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
49	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
50	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
51	TPT	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
52	non-TPTMFP	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
53	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No

54	TPT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
55	TPTplus	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
56	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
57	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
58	TPTplus	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
59	non-TPTMFP	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
60	non-TPTMFP	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
61	TPTplus	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
62	TPTplus	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
63	TPTplus	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No
64	TPT	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
65	TPT	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
66	TPTplus	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
67	TPTplus	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
68	non-TPTMFP	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No
69	TPTplus	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No
70	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
71	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
72	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
73	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No
74	TPTplus	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
75	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
76	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
77	TPT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
78	non-TPTMFP	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
79	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	No	No	Yes	Yes	No
80	TPTplus	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No
81	TPTplus	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
82	TPT	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
83	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No
84	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
85	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No

86	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
87	TPTplus	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
88	non-TPTMFP	Yes	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No
89	non-TPTMFP	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
90	non-TPTMFP	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No
91	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
92	TPTplus	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
93	TPT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
94	TPT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
95	TPT	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
96	TPTplus	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
97	non-TPTMFP	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
98	Control	No	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes
Control	27	0	0	0	0	0	27	0	27	0	0	27	27	27
TPT	22	22	20	12	16	22	22	22	22	16	15	22	22	22
non-TPTMFP	29	23	8	2	4	3	29	29	29	24	26	29	25	0
TPTplus	20	20	18	14	12	20	20	20	20	19	11	20	11	0
TOTAL	98	65	46	28	32	45	98	71	98	59	52	98	85	49