Clinical Features of Patellar Tendinopathy and Their Implications for Rehabilitation

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Received 16 November 2006; accepted 12 March 2007

Published online 27 April 2007 in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/jor.20415

ABSTRACT: This study investigated the clinical features of patellar tendinopathy (PT), with focus on individuals with unilateral and bilateral PT. A cross-sectional study design was employed to compare individuals with unilateral ($n = 14$) or bilateral ($n = 13$) PT and those without PT (control, $n = 31$). Features assessed included thigh strength (normalized peak knee extensor torque) and flexibility (sit-and-reach and active knee extension), calf endurance (heel-rise test), ankle flexibility (dorsiflexion), alignment measures (arch height and leg length difference), and functional measures (hop for distance and 6 m hop test). Groups were matched for age and height; however, unilateral and bilateral PT had greater mass with a higher body mass index (BMI) than control. Also, bilateral PT performed more sport hours per week than both unilateral PT and control. Unilateral PT had less thigh strength than control and bilateral PT, whereas bilateral PT had more thigh flexibility than control and unilateral PT. Both unilateral and bilateral PT had altered alignment measures compared to control. Features that predicted symptoms in PT were lower thigh flexibility and strength, whereas those that predicted function were higher thigh strength and lower ankle flexibility. These findings indicate that unilateral and bilateral PT represent distinct entities, and that thigh strength appears particularly important in PT as it predicted both symptoms and function in PT. © 2007 Orthopaedic Research Society. Published by Wiley Periodicals, Inc. J Orthop Res 25:1164–1175, 2007

Keywords: anterior knee pain; jumper's knee; sports medicine; tendinitis; tendinosis

INTRODUCTION

Overuse conditions of the patellar tendon have historically been labeled as *jumper's knee* or *patellar tendinitis*. However, these terms are misnomers as the condition is found in many who do not participate in jumping sports,[1–3] and histopathological studies have consistently shown the underlying pathology to be degenerative (tendinosis) rather than inflammatory (tendinitis).[2,4] As tendinosis refers to a distinct histopathological finding that can only be assessed following invasive tissue biopsy, the term *patellar tendinopathy* (PT; tendino- = tendon; -pathy = disease) has been advocated clinically to describe overuse conditions of the patellar tendon.[5] PT is characterized by activity-related anterior knee pain, focal patellar tendon tenderness, and intratendinous imaging changes.[2] It is a common condition encountered in clinical practice, with a prevalence of 14% in elite athletes depending on sport.[3] However, the true clinical significance of PT lies in the morbidity that it causes. Disability associated with PT is often prolonged and in many instances causes the premature cessation of an athletic career.[6]

Despite being a significant clinical problem, little is known about the pathogenesis of PT. This has restricted treatment options, with management presently being more of an art than a science.[7] Conceptually, as with most overuse conditions, the development of PT results from the interplay of two groups of factors—extrinsic and intrinsic factors.[8] Extrinsic factors refer to factors in the environment or external to the individual that influence the likelihood of sustaining PT. These factors are most commonly indicted in the pathogenesis of PT, with the single most frequently reported

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causative factor being mechanical overload. However, the presence of PT is not consistent across individuals exposed to equivalent loading levels, suggesting that intrinsic factors also contribute.

Intrinsic factors refer to processes internal to the individual that influence their response to external mechanical loading. Intrinsic factors can range from those that can only be derived using specialized biomechanics equipment (such as three-dimensional joint kinematics and kinetics) to factors that can easily be assessed in standard clinical practice. The later are the focus of the current study given their more widespread applicability, and include features such as anthropometric characteristics, thigh muscle strength and flexibility, calf strength, ankle flexibility, foot arch height, lower limb alignment, and functional capacity. While preliminary studies have demonstrated potential roles for some of these factors in the development of PT,[9–14] the data are far from conclusive. In addition, clinical practice and preliminary research[9,10,13] suggests that individuals who develop unilateral PT may differ from those with the condition bilaterally (bilateral PT), and that males and females may also differ.

In order to confirm the preliminary research and clinical suspicions, and facilitate a more scientifically based approach to the rehabilitation of individuals with PT, this study aimed to: (1) identify clinical features of individuals with unilateral and bilateral PT which are potentially modifiable through rehabilitation; and (2) investigate the influence of sex on these clinical features. Further study aims were to: (a) establish the repeatability of the chosen clinical measures; (b) determine the symmetry in clinical features between limbs of PT participants; and (c) identify whether scores on the clinical measures predict symptoms and function in participants with PT.

METHODS

Study Design and Subjects

A cross-sectional study design was used to compare clinical features in individuals with unilateral ($n = 14$) or bilateral ($n = 13$) PT and those without PT (control group, $n = 31$). General inclusion criteria included: aged $\geq$18 years; ability to speak English; and participation in competitive basketball, netball, volleyball, soccer, or tennis at least once per week. General exclusion criteria included: previous patellar tendon surgery; injections in the knee in the past 6 months; clinical evidence of other knee pathology; and inability to walk without a limp. Further to this, controls were excluded if they had current knee pain, or knee pain or injury in the past 2 years that interfered with training or caused them to seek professional advice. To be classified as having PT, participants met the additional eligibility criteria of: knee pain on at least one of jumping/landing, running or changing directions; pain on palpation of the patellar tendon;[15] score of less than 80 points on the Victorian Institute of Sport Assessment (VISA) scale;[16] symptoms sufficient to affect exercise and activity for at least 6 months; and have a confirmed hypoechoic lesion within the patellar tendon on ultrasonography.[17] The study was approved by the Human Research Ethics Committee at the University of Melbourne and all participants provided written informed consent.

Outcome Measures

All measures were obtained by the same two examiners (KT and BRM). Test–retest reliability was assessed prior to the study in a subset of 10 healthy individuals assessed twice (7–10 days apart) by one investigator (BRM). Standard demographic [sex, age, height, mass, body mass index (BMI), leg dominance, sport hours per week] data were obtained at inclusion. Leg dominance was defined as the leg the participant predominantly jumps with. After familiarization, outcome measures were performed three times per side (with the exception of the calf endurance test which was performed once per side) and the mean value recorded (with the exception of normalized peak knee extensor torque and hop for distance for which maximal values were recorded).

Thigh Strength and Flexibility

Normalized Peak Knee Extensor Torque

Thigh strength was measured isometrically using a Kin Com dynamometer (Kin Com 5.30; Chattecx, Chattanooga Inc., TN). The setup was individualized for each participant, including aligning the lateral femoral epicondyle with the lever arm axis of rotation. Participants were stabilized and performed two submaximal and one maximal warm-up test at 60° of knee flexion, followed by three maximal isometric tests (5 s duration with 20 s rest between). Peak torque (Nm) was recorded and normalized for mass ($Nm.kg^{-1}$).

Sit-and-Reach Test

Flexibility of posterior structures (knee, hip, and lower back) was assessed by having the participant sit with their knees extended and feet flat against the vertical wall of a sit-and-reach box. They stretched forward as far as possible and held the position for 1 s, while maintaining one hand on top of the other. A measuring tape indicated where the tip of the middle finger reached (to the nearest 0.5 cm) relative to zero (aligned with the vertical wall of the sit-and-reach box; i.e., foot position). A positive measurement indicated that the fingers extended beyond the toes, while a negative measurement indicated that the individual could not get their fingers to their toes.

Active Knee Extension Flexibility

Hamstring length was assessed by having the participant maximally extended their knee while lying supine with their hip at 90° flexion (Fig. 1). A gravity inclinometer (Acuangle, Isomed, Portland, OR) on the anterior tibial border recorded tibial inclination relative to vertical. A negative value indicated inability to reach the vertical and, thus, lower posterior thigh flexibility. An individual who could reach full knee extension without restriction was instructed to maintain knee extension and slowly flex their hip as far as possible (resulting in a positive angle of the tibia with respect to the vertical).

Calf Endurance

Heel-Rise Test

Calf-muscle performance was assessed using a single-leg heel-rise test. Heel-rise height was established by having the participant maximally plantarflex their ankle and a horizontal string was placed at the height of the dorsal ankle, just inferior to the distal aspect of the anterior tibia (Fig. 2). During the test, participants maximally raised their heel off the floor, touching the string before returning to the floor at a rate of 1 heel rise every 2 s (paced by a metronome). Their knee was maintained in extension and no more than 2% of whole body mass could be placed through their contralateral arm on the wall (measured with a Nicholas Manual Muscle Tester). Five practice heel rises were performed followed by a 1 min rest prior to the actual test. The participant was asked to perform as many heel rises as possible. Repetitions were counted each time the foot contacted the string. The test was terminated if the participant leaned forward with a force greater than 2% body weight, the participant's knee flexed, or the participant failed to contact the string during three consecutive heel rises.

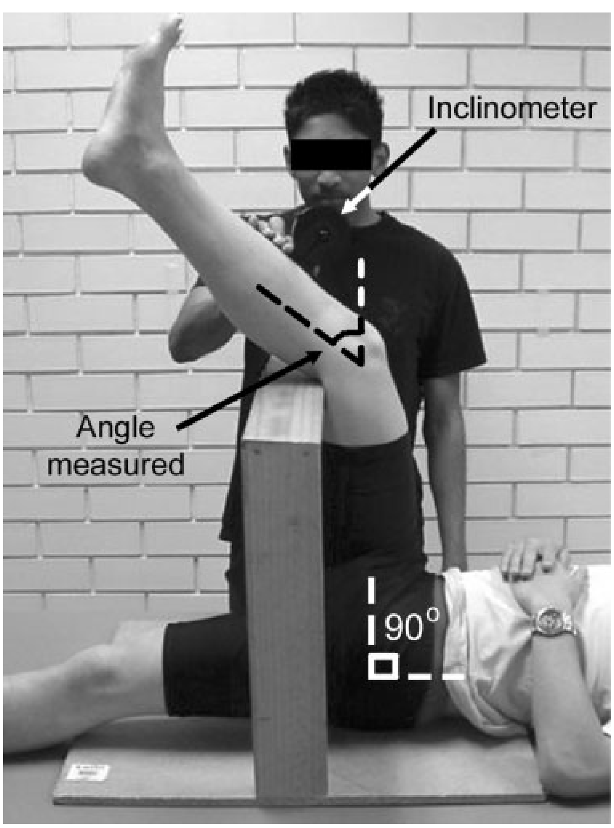

Figure 1. Assessment of active knee extension.

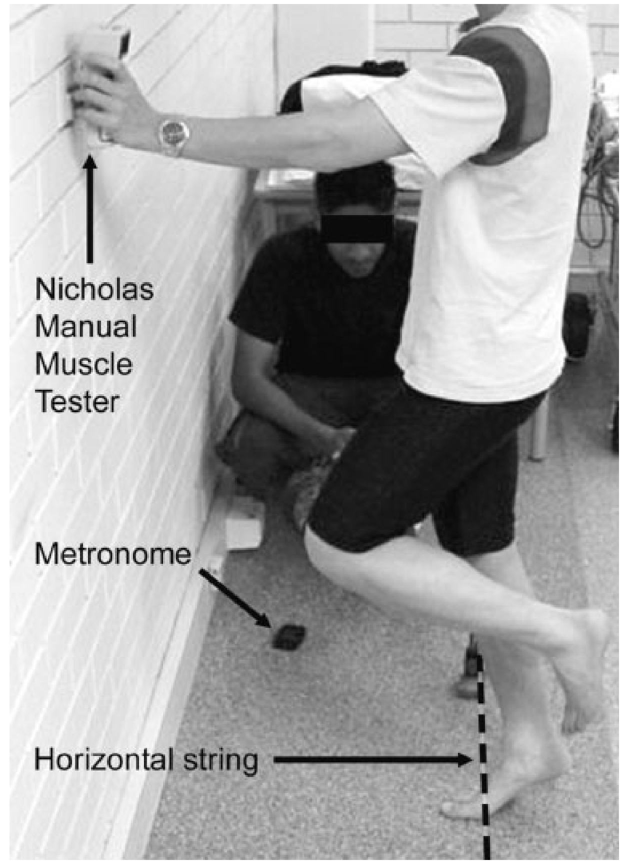

Figure 2. Assessment of calf endurance.

Ankle Flexibility

Ankle Dorsiflexion Range

A line was placed on the floor at right angle to the wall (floor line) and continued up the wall at right angle to the floor (wall line). The foot was positioned such that the bisection of the heel and second toe were aligned on the floor line (Fig. 3A). The distance of the foot to the wall was initially self-selected by the participant. The participant lunged forward to touch the center of their

DOI 10.1002/jor

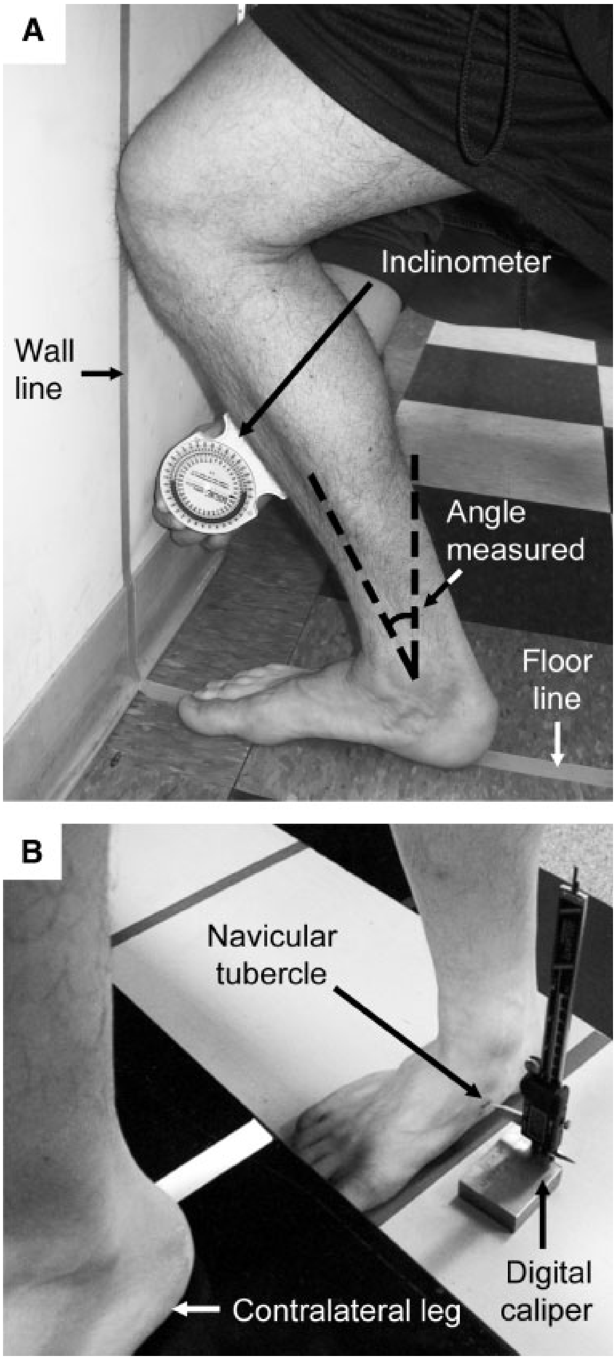

Figure 3. Assessment of (A) ankle dorsiflexion range and (B) arch height.

patella against the wall line while keeping the heel on the ground and knee in line with the second toe. If participants could or could not touch their patella on the wall line, their foot was progressively moved further from or closer to the wall, respectively. At the maximum lunge point, a gravity inclinometer was placed on the anterior border of the tibia (15 cm below the tibial tuberosity) and the angle relative to the vertical recorded.

Alignment Measures

Arch Height

Arch height was measured as the distance from the inferior aspect of the navicular tubercle to the floor. This distance was measured during maximal weight bearing using a digital vernier caliper (Fig. 3B). Individuals stood on a step, with one foot on the lower step and the other on the higher step. Both feet were aligned in the sagittal plane such that the center of the heel was aligned with the second toe. Participants were instructed to shift their weight such that the majority was placed over the lower foot. Arch height of the lower foot was measured.

Leg Length Differences

Leg length was measured in supine as: (a) anterior–superior iliac spine to the tip of the medial malleolus (medial measure); and (b) lateral prominence of the greater trochanter to the lateral malleolus (lateral measure). The length of the asymptomatic (or least symptomatic) leg was subtracted from the length of the symptomatic (or most symptomatic) leg. For the control group, differences were obtained by subtracting the length of the nondominant leg from the dominant leg.

Functional Measures

Hop for Distance

The participant hopped on one leg as far as possible from a standing start after a submaximal warm-up. The test was repeated three times for each leg and the best score was identified and recorded.

Six-Meter Hop Test

The participant hopped on one leg as fast as possible over a distance of 6 m using large forceful one-legged hopping movements. The time taken to complete this task was recorded.

Pain and Disability

Pain and disability measures assessed symptom intensity and quantified functional capacity. Symptom intensity was assessed using an 11-point numerical pain scale (NPS; with 0 = no pain and 10 = worst possible pain). The usual (NPS-U) and worst (NPS-W) pain on the subject-nominated most painful activity were recorded. These scales are valid, reliable, and responsive in the assessment of anterior knee pain.[18] Functional capacity was quantified using the VISA score, a validated measure of knee function in athletes with PT.[16] The scale ranges from 0 to 100, with 100 indicating full, pain-free function and a score below 80 being associated with symptomatic PT.[1] The VISA scale has excellent short-term test–retest and intertester reliability (both, $r > 0.95$), as well as good short-term (1 week) stability ($r = 0.87$).[16]

Data Analyses and Statistical Evaluation

All data were analyzed using SPSS version 14.0 (Norusis/SPSS Inc., Chicago, IL). Group differences (control vs. unilateral PT vs. bilateral PT) in ratio demographic data (age, height, mass, BMI, and sport hours per week) were assessed using one-way factorial analyses of variance (ANOVA), with Fisher's protected least-significant difference (PLSD) used for post hoc analyses. Mean differences and 95% confidence intervals (95% CI) were obtained for each post hoc comparison. Group differences (control vs. unilateral PT vs. bilateral PT) in nominal demographic data (dominant leg and sex) were assessed using chi-squared (χ^2) analyses. Unpaired *t*-tests were used to compare symptom duration, VISA, NPS-U, and NPS-W between unilateral and bilateral PT. Intraclass correlation coefficients (ICC) were generated for the repeatability data and standard error of measurement (SEM) calculated for each measure. Paired *t*-tests were used to establish symmetry in clinical features between the symptomatic (or most symptomatic) and asymptomatic (or least symptomatic) limbs within unilateral and bilateral PT. Group differences in clinical features were assessed using two-way factorial analyses of variance (ANOVA), with condition (control vs. unilateral PT vs. bilateral PT) and sex (male vs. female) as the independent variables. Mass was used as a covariate for the heel-rise test, arch height, hop for distance, and 6 m hop test analyses. In the event of a nonsignificant ANOVA interaction, the main effect for each variable was explored, with Fisher's protected least-significant difference (PLSD) used for post hoc analyses of significant condition main effects. Mean differences and 95% CI were obtained for each post hoc comparison.

To determine if the clinical measures were predictors of pain (NPS-W and NPS-U) and function (VISA) in the PT group, stepwise multiple linear regressions were used (criteria for entry, $p < 0.05$, and removal, $p < 0.10$). To reduce the number of potential predictors only one measure of posterior thigh flexibility (active knee extension), one measure of leg length difference (leg length difference measured medially), and one functional test (hop for distance) were included. To further lessen the number of predictor variables, bivariate correlations were performed between the measures, and symptom and function scores. Only clinical measures that were correlated with symptoms or function at a significance level of $p < 0.20$ were accepted for inclusion in the linear regression.

RESULTS

Demographic Data

Demographic data are shown in Table 1. Age, height, number of female-to-male participants, or side of leg dominance did not differ between groups (all $p = 0.16–0.98$). However, there were significant group differences for mass, BMI, and sport hours per week (all $p < 0.02$). Both unilateral and bilateral PT had greater mass than control (unilateral PT vs. control: mean differences, 9.6 kg, 95% CI, 1.1–18.2 kg; bilateral PT vs. control: mean differences, 11.2 kg, 95% CI, 2.5–20.0 kg; all $p < 0.03$). As height did not differ between groups, the greater mass in unilateral and bilateral PT resulted in these groups having higher BMIs than control (unilateral PT vs. control: mean

Table 1. Demographic Data for Each Condition

Variable	Control ($n = 31$)	Unilateral PT ($n = 14$)	Bilateral PT ($n = 13$)
Age (years)	24 ± 6	26 ± 7	28 ± 8
Height (m)	1.77 ± 0.88	1.78 ± 0.9	1.76 ± 0.9
Mass (kg)*	71 ± 11	$80 \pm 16^{\dagger}$	$82 \pm 14^{\dagger}$
BMI (kg.m^{-2})*	22.5 ± 2.4	$25.2 \pm 4.0^{\ddagger}$	$26.2 \pm 3.5^{\dagger}$
Sport (hrs.wk^{-1})*	3.3 ± 1.8	3.6 ± 2.1	$6.7 \pm 9.3^{\ddagger}$
Dominant leg (R:L)	27:4	12:2	11:2
Sex (F:M)	11:20	4:10	4:9
Symptom duration (years)	—	2.8 ± 3.0	5.0 ± 3.2
VISA	—	60 ± 15	58 ± 20
NPS-U	—	5.6 ± 2.0	5.5 ± 3.0
NPS-W	—	6.9 ± 2.5	7.0 ± 2.5

Abbreviations: PT, patellar tendinopathy; BMI, body mass index; VISA, Victorian Institute of Sport Assessment (100 represents full function); NPS-U, numerical pain scale (10 represents maximal pain) for the usual pain in the preceding week; NPS-W, numerical pain scale (10 represents maximal pain) for the worst pain in the preceding week.

Values are mean ± SD (except for dominant leg and sex, which are represented by number of cases).

*Indicates significant differences between conditions ($p < 0.02$, one-way factorial ANOVA).

†Indicates significant difference to control ($p < 0.03$, Fisher's PLSD).

‡Indicates significant difference to both control and unilateral PT ($p < 0.02$, Fisher's PLSD).

 DOI 10.1002/jor

differences, 2.7 kg.m^{-2}, 95% CI, 0.6–4.7 kg.m^{-2}; bilateral PT vs. control: mean differences, 3.7 kg.m^{-2}, 95% CI, 1.6–5.7 kg.m^{-2}; all $p \leq 0.01$). There were no differences between unilateral and bilateral PT for mass ($p = 0.75$) or BMI ($p = 0.40$); however, the bilateral PT group reported more sport hours per week than both unilateral PT (mean differences, 3.2 h.wk^{-1}, 95% CI, 0.6–5.8 h.wk^{-1}; $p = 0.02$) and control (mean differences, 3.4 h.wk^{-1}, 95% CI, 1.2–5.7 h.wk^{-1}; $p < 0.01$). Sport hours per week did not differ between unilateral PT and control ($p = 0.81$), and there no differences between unilateral and bilateral PT for symptom duration, VISA, NPS-U, or NPS-W ($p = 0.08$–0.97).

Repeatability of Clinical Measures

Clinical measures utilized in this study were repeatable as indicated by ICC values greater than 0.80, with the exception of the heel-rise test (Table 2). The heel-rise test demonstrated moderate repeatability. However, this test appears to have a strong learning effect, and because the main study was cross-sectional in nature it was still included in the testing battery.

Symmetry of Clinical Measures in Unilateral and Bilateral Patellar Tendinopathy

There were no between leg differences within unilateral or bilateral PT for any clinical measure (Fig. 4). The most symptomatic and least symptomatic legs in the bilateral PT subgroup recorded similar scores. Interestingly, in unilateral PT the symptomatic and asymptomatic legs also scored similarly.

Clinical Features of Unilateral and Bilateral Patellar Tendinopathy, and the Influence of Sex

There were no interactions between condition (control vs. unilateral PT vs. bilateral PT) and sex (male vs. female) for any clinical measure (all $p > 0.05$). However, there were significant sex (male vs. female) effects for a number of variables, regardless of condition. Females were more flexible than males in the sit-and-reach test (mean difference, 7.5 cm; 95% CI, 1.5–13.4 cm), and a similar trend towards females was noted for the active knee extension test (mean difference, 7.2°; 95% CI, −0.2°–14.6°). In contrast, females performed significantly worse on the hop for distance test, producing a shorter hop than males (mean difference, −0.32 m; 95% CI, −0.52–−0.14 m). Similarly, females took longer to complete the 6 m hop test than males (mean difference, 0.3 s; 95% CI, 0.1–0.5 s).

There were significant main effects for condition (control vs. unilateral PT vs. bilateral PT) for a number of clinical measures, irrespective of sex (Table 3). Specifically, normalized peak knee extensor torque, active knee extension, arch height, and leg length difference measured both medially and laterally all differed between

Table 2. Test–Retest Reliability of Clinical Tests

Clinical Measure	Time 1*	Time 2*	ICC	SEM
Thigh strength and flexibility				
Normalized peak knee extensor torque (Nm.kg^{-1})	2.07 ± 0.59	2.26 ± 0.06	0.85	0.16
Sit-and-reach (cm)	−2.5 ± 7.9	−3.4 ± 7.2	0.93	2.00
Active knee extension (°)	−30 ± 15	−30 ± 13	0.84	6
Calf endurance				
Heel-rise test (*n*)	31 ± 13	44 ± 9	0.57	8
Ankle flexibility				
Dorsiflexion (°)	46 ± 6	46 ± 6	0.98	1
Alignment measures				
Arch height during maximal weight bearing (mm)	40 ± 6	40 ± 7	0.95	1.5
Leg length (measured medially) (m)	0.85 ± 0.06	0.85 ± 0.06	1.00	0.3
Leg length (measured laterally) (m)	0.86 ± 0.06	0.85 ± 0.07	0.99	0.6
Functional Measures				
Hop for distance (m)	1.31 ± 0.39	1.3 ± 0.32	0.94	0.92
6 m hop test (s)	2.48 ± 0.49	2.57 ± 0.60	0.85	0.22

Abbreviations: ICC, Intraclass correlation co-efficient; SEM, standard error of measurement.
*Values are mean ± SD.

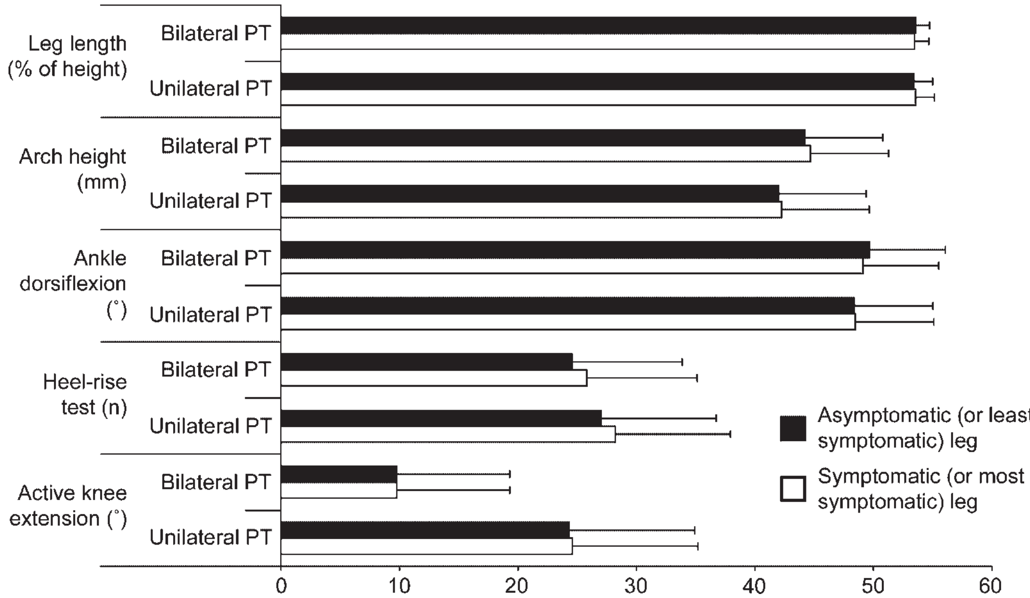

Figure 4. Symmetry in clinical measures between the symptomatic (or most symptomatic) and asymptomatic (or least symptomatic) limbs within the unilateral PT and bilateral PT subgroups. All $p > 0.05$ (paired *t*-test).

conditions (all $p < 0.05$). In addition, both of the functional measures had trends towards a main effect for condition (hop for distance, $p = 0.08$; 6 m hop test, $p = 0.07$). Post hoc analyses of condition main effects (Table 3) demonstrated unilateral PT to have less normalized peak knee extensor strength than both control and bilateral PT (all $p < 0.05$). In contrast, it was bilateral PT who were more flexible than both control and unilateral PT during the active knee extension test (all $p < 0.05$). Both unilateral and bilateral PT exhibited lower arches and greater leg length differences than controls, with the symptomatic (or most symptomatic) leg being on average longer (all $p < 0.05$). Although the main effect for neither functional measure quite reached significance, unilateral PT exhibited lower performance on the two hopping tests than both bilateral PT and control (all $p < 0.05$).

Clinical Predictors of Symptoms and Function in Patellar Tendinopathy

Bivariate correlations between the clinical measures, and the two symptom measures (NPS-W and NPS-U) and the functional measure (VISA) in PT are shown in Table 4. The clinical measures which correlated at a significance of $p < 0.20$ with both NPS-U and NPS-W were normalized peak knee extension torque, active knee extension range, leg length difference, and hop for distance (Table 4). These measures were subsequently included in the stepwise multiple linear regression. Those that remained in the significant final models as predictors of increasing both NPS-U ($p < 0.001$) and NPS-W ($p < 0.001$) were lower active knee extension flexibility and lower normalized peak knee extensor torque (Table 5). These models explained 45% and 48% of the variance in NPS-U and NPS-W, respectively.

For the measure of function (VISA scale), the clinical measures of normalized peak knee extension torque, active knee extension range, ankle dorsiflexion range, and hop for distance were entered into the stepwise linear regression as they correlated with VISA at a significance of $p < 0.20$ (Table 4). The final prediction model for increasing function included higher normalized peak knee extension torque and lower ankle dorsiflexion range, which predicted 36% of the variance in the VISA score (Table 5).

DISCUSSION

This study investigated the clinical features of PT using a battery of clinically reliable and applicable measures. Predictable sex differences were found, with males exhibiting greater functional ability and females greater flexibility. However, there

Table 3. Effect of Condition on Clinical Measures

	Condition (Mean ± SD)*			Significant Post Hoc Pairwise Comparisons†		
Clinical Measure	Control	Unilateral PT	Bilateral PT	Control–Unilateral PT	Control–Bilateral PT	Unilateral PT–Bilateral PT
Thigh strength & flexibility						
Normalized peak knee extensor torque ($Nm.kg^{-1}$)‡	2.23 ± 0.49	1.72 ± 0.61	2.29 ± 0.54	0.49 (0.13–0.86)		−0.56 (−1.00–−0.13)
Sit-and-reach test (cm)	1.8 ± 10.1	2.2 ± 10.7	9.6 ± 10.4		−7.8 (−14.2–1.4)	−9.9 (−17.4–−2.5)
Active knee extension (°)>‡	−24.6 ± 12.9	−23.4 ± 11.0	−8.1 ± 10.9		−15.9 (−23.8–−8.0)	−14.8 (−24.0–−5.6)
Calf endurance						
Heel-rise test (n)§	25 ± 12	26 ± 11	26 ± 11			
Ankle flexibility						
Dorsiflexion (°)	48.1 ± 5.7	47.9 ± 6.1	49.2 ± 7.9			
Alignment measures						
Arch height during maximal weight bearing (mm)‡,§	50.4 ± 5.9	42.1 ± 8.5	43.1 ± 7.0	8.4 (3.6–13.3)	7.3 (2.4–12.3)	
Leg length difference (measured mediatly) (mm)‡	4.5 ± 8.5	14.8 ± 8.9	11.1 ± 8.8	−9.2 (−14.4–−4.0)	−0.67 (−1.21–−0.13)	
Leg length difference (measured laterally) (mm)‡	8.1 ± 14.2	16.9 ± 14.8	23.6 ± 14.6	−8.7 (−17.5–0.1)	−1.7 (−2.6–−0.8)	
Functional measures						
Hop for distance (m)§	1.60 ± 0.31	1.37 ± 0.30	1.54 ± 0.29	0.22 (0.03–0.42)		
6 m hop test (s)§	2.1 ± 0.4	2.4 ± 0.4	2.1 ± 0.5	−0.3 (−0.5–0.0)		0.3 (0.0–0.6)

Abbreviation: PT, patellar tendinopathy.

Sit-and-reach, higher value is more flexible; active knee extension, higher value is more flexible; leg length difference, symptomatic (or most symptomatic) leg minus asymptomatic (or least symptomatic leg) leg (in UPT and BPT) or dominant minus non dominant leg (in control).

*Values indicate mean ± SD.

†Values indicate mean difference (95% confidence intervals) for significant Fisher's PLSD post hoc tests ($p < 0.05$).

‡Indicates significant main effect for condition ($p < 0.05$, two-way factorial ANOVA).

§Indicates mass included as a covariate (mass corrected means are presented).

Table 4. Bivariate Correlations between Clinical Measures, and Measures of Symptoms and Function within the PT Group as a Whole (Unilateral and Bilateral PT Combined)

	Symptoms		Function
Variable	NPS-U	NPS-W	VISA
Demographic			
Age	0.02	0.05	−0.24
Gender	0.15	0.25	−0.02
Height	−0.07	−0.07	0.22
Weight	0.10	0.08	0.09
BMI	0.18	0.15	−0.05
Sport hours per week	0.04	0.11	−0.07
Thigh strength & flexibility			
Normalized peak knee extensor torque	−0.63*	−0.63*	0.40*
Active knee extension	−0.27†	−0.31†	−0.27†
Calf endurance			
Heel-rise test	0.12	0.10	0.21
Ankle flexibility			
Dorsiflexion	0.12	0.06	−0.35†
Alignment measures			
Arch height during maximal weight bearing	0.03	−0.04	0.19
Leg length difference (measured medially)	−0.27†	−0.27†	0.20
Functional measures			
Hop for distance	−0.64*	−0.65*	0.47*

Abbreviations: PT, patellar tendinopathy; NPS-U, numerical pain scale for the usual pain in the preceding week; NPS-W, numerical pain scale for the worst pain in the preceding week; VISA, Victorian Institute of Sport Assessment; BMI, body mass index.

Values are correlation coefficients (*r*).

*Indicates significant bivariate correlation for inclusion into the stepwise linear regression ($p < 0.05$).

†Indicates significant bivariate correlation for inclusion into the stepwise linear regression ($0.05 < p < 0.20$).

were no interactions between sex and condition, indicating that the clinical features of PT were not influenced by sex. PT participants had greater mass than control, which contributed to the former having a higher BMI. Unilateral PT and control did not differ in sports hours per week; however, both groups performed less hours than bilateral PT. There were no asymmetries between legs in

Table 5. Regression Coefficients for Variables in the Final Model of the Linear Regression for Symptoms and Function within the PT Group as a Whole (Unilateral and Bilateral PT Combined)

Dependent Variable	Predictor Variables	B	SE B	β	*p*	95% CI for B
Symptoms						
NPS-U	Normalized peak knee extensor torque ($Nm.kg^{-1}$)	−2.49	0.56	−0.65	<0.001	−3.64 to −1.34
	Active knee extension (°)	−0.06	0.03	−0.31	<0.05	−0.12 to 0.00
NPS-W	Normalized peak knee extensor torque ($Nm.kg^{-1}$)	−2.33	0.51	−0.65	<0.001	−3.38 to −1.27
	Active knee extension (°)	−0.06	0.03	−0.35	<0.05	−0.12 to −0.01
Function						
VISA	Normalized peak knee extensor torque ($Nm.kg^{-1}$)	15.14	4.47	0.60	<0.01	5.91 to 24.37
	Ankle dorsiflexion (°)	−1.34	0.43	−0.52	<0.01	−2.23 to −0.46

Abbreviations: PT, patellar tendinopathy; NPS-U, numerical pain scale for the usual pain in the preceding week; NPS-W, numerical pain scale for the worst pain in the preceding week; VISA, Victorian Institute of Sport Assessment.

individuals with either unilateral or bilateral PT; however, there were group differences between conditions. Unilateral PT had reduced thigh strength compared to both bilateral PT and control. In contrast, bilateral PT had increased thigh flexibility compared to both unilateral PT and control, while both unilateral and bilateral PT had lower arch height and increased leg length difference compared to control. Clinical features that predicted symptoms in PT participants were lower thigh flexibility and strength, whereas those that predicted function were higher thigh strength and lower ankle flexibility.

The results of the current study indicate that individuals with unilateral and bilateral PT represent distinct clinical entities. Unilateral and bilateral PT differed from one another and controls in thigh strength and flexibility. These observations support previous findings.[9,10,13] For instance, Cook and colleagues[9,10,13] showed females with unilateral PT to be less flexible than both controls and bilateral PT, while males with bilateral PT had greater hip girth and a larger waist-to-hip ratio than both unilateral PT and control. However, these previous studies are limited as PT symptoms in participants were not assessed, with group allocations being based solely on ultrasonography findings. The presence of a hypoechoic lesion on ultrasonography is not predictive of current PT symptoms,[17] and does not appear to predict the likelihood that an individual will become symptomatic in the future.[19,20] Consequently, the current study provides the strongest evidence to date that unilateral and bilateral PT represent different subgroups of PT, confirming clinical suspicions and highlighting the need for these subgroups to be considered separately in both clinical and research settings.

Thigh strength measures differed across conditions, and represented a predictor of symptoms and function in PT. Unilateral PT had less thigh strength compared to bilateral PT and control, consistent with a previous report,[10] and the reduced thigh strength in unilateral PT potentially explains their reduced performance on functional testing. Supporting this, higher thigh strength was predictive of both reduced pain and improved function in PT. These findings support the belief that strength training is important in the rehabilitation of PT. Muscle strength also may be an important contributor to PT, but the current results cannot confirm this due to its cross-sectional design. While unilateral PT had reduced thigh strength that compromised function, it is not possible to establish cause or effect. Pain has well-established inhibitory influences on muscle,[21] and tendon pain during strength testing in unilateral PT may have compromised the test. In addition, it is possible that muscle atrophy associated with the long duration of symptoms in unilateral PT may have contributed to the differences. However, bilateral PT did not differ from control in thigh strength despite having equivalent pain and longer symptom duration than unilateral PT, indicating that pain and disuse atrophy may not completely explain our findings. Overall, the clinical ramification of the positive relationship between thigh muscle strength, and symptoms and function in PT is that both tendon pain and muscle function need to be addressed in the rehabilitation of individuals with PT.

Muscular tightness is considered an important factor in the development of lower limb overuse injuries, including PT.[22] Accordingly, thigh muscle flexibility was both a discriminative clinical feature of PT and predictor of symptoms. Bilateral PT had increased posterior thigh flexibility than both unilateral PT and control, suggesting that increased flexibility may contribute to the development of bilateral PT. However, posterior thigh flexibility in PT was negatively correlated with pain, indicating that increased flexibility was associated with reduced pain. This finding is in accordance with Witvrouw and colleagues,[14] who found thigh flexibility to be a prospective determining factor in PT development. Similarly, Cook and colleagues[9] demonstrated athletes with abnormal patellar tendon morphology to have reduced thigh flexibility. Grouped, these findings suggest that interventions aimed at improving thigh flexibility may facilitate reductions in PT symptoms and be an important component of PT rehabilitation. The mechanisms for this contribution are currently hypothetical, but may include changes in knee joint mechanics. For instance, posterior thigh tightness results in an increase in knee flexion during stance,[23] a predictive variable of PT.[24]

Arch height differed between groups, with both unilateral and bilateral PT having lower arch height during weight bearing compared to control. Foot morphology has long been considered an important contributor to lower limb mechanics due to the position of the feet at the ground interface, and has been implicated in the development of knee overuse injuries.[22] This suggests that arch height should be addressed in the rehabilitation of individuals with PT, possibly through the modification of extrinsic (shoes or orthoses) or other intrinsic (function of the extrinsic and intrinsic foot muscles) factors. This is simplistic for a number of reasons. Arch height neither correlated to or predicted symptoms or function in PT. Thus, arch height modification may not necessarily produce desired changes in pain or function. Also, morphology is not the sole feature of the foot that is considered responsible for knee overuse conditions. Foot morphology is typically assessed statically, as in the current study. While this provides a quantitative clinical measure, it does not represent how the foot functions dynamically.[25–27] What appears more important in terms of injury development is the amount and duration of foot motion during dynamic loading. Unfortunately, quantitative clinical measures of this motion are not widely available.

Further discriminative features of PT included sport hours per week, mass, BMI, and leg length difference. Every attempt was made to match controls to those with PT in terms of sport hours per week. However, it proved difficult to recruit controls that completed as many hours as bilateral PT. While this may represent a study limitation, it is also an important observation that is consistent with the theory that mechanical overload is a key component in PT development. Individuals with PT had greater mass and BMI than controls, consistent with previous data.[11,13] Increased mass theoretically places increased load on the patellar tendon. Whether this is causative of PT is not clear as tendon damage is a function of tendon stress, which is influenced not only by load but also tendon size. In addition, prospective data did not find a difference in mass between those who did and did not develop PT.[14] Leg length differences were also greater in individuals with PT than controls. Leg length discrepancy can generate gait deviations and may contribute to the development of lower limb musculoskeletal injuries.[28] Thus, it represents an important feature to assess in individuals presenting with PT. However, the decision of whether to intervene is not so clear as the discrepancy may represent a coincident rather than causal finding and typically a discrepancy of >20 mm is considered the intervention breakpoint. In the current study, unilateral and bilateral PT had leg length discrepancies of 14.8 ± 8.9 mm and 11.1 ± 8.8 mm, respectively. While significantly different from discrepancies observed in control (4.5 ± 8.5 mm), these values are below those considered to be functionally important.

Ankle dorsiflexion range and calf endurance were not discriminative clinical features of PT in the current study. These measures are believed to be risk factors for PT, with reductions in either potentiating the proximal transmission of impact forces to the patellar tendon–quadriceps complex.[29] Supporting this, previous studies have found ankle dorsiflexion range to differentiate between those with and without abnormal patellar tendon morphology,[12] and that individuals with PT have altered ankle joint mechanics.[30] While ankle dorsiflexion range was not found to be a discriminative clinical feature in the current study, interestingly it was found to be a significant predictor of function in PT. However, it was negatively correlated with function such that decreases in dorsiflexion range were actually coupled with increases in function. This finding requires further exploration as it directly opposes the general hypothesis that a reduction in dorsiflexion range is a risk factor for PT.

A number of limitations of the current study warrant discussion. The most obvious is its cross-sectional design which limits the ability to establish cause and effect. For instance, it is not possible to determine whether differences between conditions preexisted and contributed to the development of PT or whether they developed subsequent to symptom onset. Despite this, the study does provide useful information in terms of clinical features that deserve consideration during rehabilitation of PT and presents evidence for features that need to be studied prospectively. A further limitation was the low number of individuals recruited with unilateral and bilateral PT. As a result, it was not viable to perform separate linear regressions on the unilateral and bilateral PT groups to establish whether clinical features that predicted symptoms and function differed between subgroups. A final limitation was the assessment of a limited number of primarily static clinical features. A number of potentially important features were not assessed due to time restraints, including strength and range measures of the hip, and knee extensor endurance. These need consideration in future studies. Similarly, it is acknowledged that dynamic assessments (such as gait assessment) may provide useful information; however, these typically require specialized equipment to obtain quantitative outcomes. This equipment is not typically available in clinical practice, and we wanted to explore the features of PT using easily performed and clinical applicable tests.

In summary, the results of the current study indicate that individuals with unilateral and bilateral PT share common clinical features; however, they differ for thigh strength and flexibility. This suggests that unilateral and bilateral PT represent distinct clinical entities and should be considered separately in rehabilitation. When

 DOI 10.1002/jor

treating individuals with PT, thigh strength appears particularly important as it was reduced in individuals with unilateral PT, and predicted symptoms and function in PT.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of Dr. Zoltan S. Kiss and Ms. Elin Wee for invaluable assistance in examining participants. This study was partly supported by funding from the Australian Sports Commission.

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