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Lower Extremity Kinematics During a Drop Jump in Individuals With Patellar Tendinopathy

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Background: Patellar tendinopathy (PT) is a common degenerative condition in physically active populations. Knowledge regarding the biomechanics of landing in populations with symptomatic PT is limited, but altered mechanics may play a role in the development or perpetuation of PT.

Purpose: To identify whether study participants with PT exhibited different landing kinematics compared with healthy controls.

Study Design: Controlled laboratory study.

Methods: Sixty recreationally active participants took part in this study; 30 had current signs and symptoms of PT, including self-reported pain within the patellar tendon during loading activities for at least 3 months and ≤80 on the Victorian Institute of Sport Assessment Scale–Patella (VISA-P). Thirty healthy participants with no history of PT or other knee joint pathology were matched by sex, age, height, and weight. Participants completed 5 trials of a 40-cm, 2-legged drop jump followed immediately by a 50% maximum vertical jump. Dependent variables of interest included hip, knee, and ankle joint angles at initial ground contact, peak angles, and maximum angular displacements during the landing phase in 3 planes. Independent-samples *t* tests ($P \leq .05$) were utilized to compare the joint angles and angular displacements between PT and control participants.

Results: Individuals with PT displayed significantly decreased peak hip (PT, 59.2° ± 14.6°; control, 67.2° ± 13.9°; $P = .03$) and knee flexion angles (PT, 74.8° ± 13.2°; control, 82.5° ± 9.0°; $P = .01$) compared with control subjects. The PT group displayed decreased maximum angular displacement in the sagittal plane at the hip (PT, 49.3° ± 10.8°; control, 55.2° ± 11.4°; $P = .04$) and knee (PT, 71.6° ± 8.4°; control, 79.7° ± 8.3°; $P < .001$) compared with the control group.

Conclusion: Participants with PT displayed decreased maximum flexion and angular displacement in the sagittal plane, at both the knee and the hip. The altered movement patterns in those with PT may be perpetuating symptoms associated with PT and could be due to the contributions of the rectus femoris during dynamic movement.

Clinical Relevance: Based on kinematic alterations in symptomatic participants, rehabilitation efforts may benefit from focusing on both the knee and the hip to treat symptoms associated with PT.

Keywords: jumper's knee; knee pain; motion analysis; jump landing

The knee is among the most frequently injured joints, accounting for approximately 15% of all high school sports injuries and approximately 40% of all running injuries.[18,36] Specifically, injuries to the patella and patellar tendon account for almost 30% of knee structures injured in high school–aged athletes as well as some of the highest incidences of injuries in collegiate sports such as basketball, field hockey, soccer, softball, and volleyball.[17,35] Additionally, among elite athletes, patellar tendinopathy (PT) represents over 14% of all injuries, and nearly 32% and 45% of injuries in basketball and volleyball, respectively.[25]

Symptoms associated with PT have both short- and long-term consequences. The most common outcome associated with patellar tendon injuries was loss of participation, and symptom duration associated with PT can exceed 30

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months.[36] Over 50% of athletes may end their sport career due to symptoms associated with patellar tendinopathy.[20] Many athletes who continued to participate in their sport with PT demonstrated mild but persistent symptoms that remained well after their athletic career came to completion.[20]

Patellar tendonitis, tendinosis, or "jumper's knee" are the terms most commonly used to describe symptoms experienced in the patellar tendon.[22] The phrase "jumper's knee" may suggest this syndrome occurs most frequently in sports requiring repeated jumping. However, most researchers agree it should be broadened to include participants in any activity that leads to chronic overload to the quadriceps due to movements that require rapid acceleration and deceleration, quick cutting, and/or repetitive open kinetic chain knee movements.[4] Repetitive contraction of the quadriceps precipitates persistent microtrauma and inadequate healing of the patellar tendon.[28] In addition, the histopathological findings in the literature suggest that patellar tendonitis may be a misnomer because of the lack of inflammatory response and degenerative nature of the condition.[21]

Although frequent in recreationally active populations, information relating to the biomechanics of the lower extremity in those with symptomatic PT remains unclear and may contribute to injury.[2,14,26,34] Based on the lengthy symptomatic period, individuals with PT may continue participating despite pain. This paradigm creates an issue for health care practitioners attempting to manage the symptoms and condition of their patients. Detecting alterations in movement patterns in those with symptomatic PT may allow sports medicine professionals to identify better treatment and rehabilitation protocols to combat the condition.

The purpose of this study was to identify whether individuals with chronic PT (>3 months of symptom length) exhibit alterations in lower extremity kinematics during a drop-jump landing compared with healthy participants. We hypothesized that participants with PT would exhibit increased hip and knee flexion at initial contact and increased maximum hip and knee flexion as well as increased angular displacement throughout landing. This was hypothesized due to previous studies that have found increases in knee and hip flexion during landing in those with asymptomatic patellar tendon abnormality (PTA)—a condition found to predispose individuals to PT.[9,26]

METHODS

An a priori power analysis utilizing data from a previous study[2] was completed with G*Power (Version 3.0.10; Kiel University) to determine the appropriate sample size necessary to detect significant differences among the kinematic variables. Bisseling et al[2] studied those with previous history of PT, recent history of PT, and a control group during drop-jump landings. Using their results, an a priori power calculation with $\alpha = 0.05$, $1 - \beta = 0.80$ and effect sizes ranging from 0.74 to 1.00 was completed for hip, knee, and ankle flexion during landings from different heights between controls and the prior history group. Between 30 and 48 participants would be necessary to determine mean differences between groups in a number of kinematic variables of interest.[2] We calculated 60 participants would allow sufficient power to assess a number of different kinematic observations at the lower extremity between control and PT participants. While this study was not directly comparable to ours because we utilized those with current signs and symptoms of PT and the previous authors used subgroups of previous history and recent history of PT, it was the closest approximation in the existing literature and provided a starting point for necessary sample size calculations.

Participants

Sixty 18- to 35-year-old recreationally active individuals, defined as participating in greater than or equal to 90 minutes of physical activity per week at greater than or equal to 4 on the Tegner scale,[37] were recruited to participate in this study. Subjects were recruited through university-sponsored physical activity classes, club sports programs, intramural sports, flyer postings, and email. Participants were recruited into the PT group if they exhibited (1) pain only in the patellar tendon; (2) self-reported pain within the tendon during loading task activities such as jumping, squatting, and so on, during and preceding the previous 3 months; (3) continuation of practice and performing of their self-reported activity level without limitations due to their patellar tendon pain; and (4) score $\leq$80 on the Victorian Institute of Sport Assessment Scale–Patella (VISA-P), indicating decreased function.[12,34,39]

Control participants who had no self-reported history of PT or other knee joint pathology and scored greater than 90 on the VISA-P (indicating good function) were entered into the study and matched to PT participants by sex, age (±10%), height (±10%), and weight (±10%).[39] PT and control participants were excluded if they exhibited any of the following: (1) history of lower extremity surgery or fracture; (2) current enrollment in a rehabilitation or physical therapy program for knee pain; (3) use of nonsteroidal anti-inflammatory drugs or pain relievers in the previous 24 hours; (4) current injury to a lower extremity joint characterized by swelling, discoloration, heat, or pain (besides the symptomatic group criteria) or any pain due to chronic problem to either lower extremity; (5) self-reported pregnancy; or (6) history of a diagnosis of vestibular disorder, Charcot-Marie-Tooth disorder, Ehlers-Danlos disorder, or any other nerve or connective tissue disorder.

Procedures

The local human subjects institutional review board approved this research protocol, and participants provided informed consent. Participants completed the VISA-P and Tegner questionnaires and were screened for inclusion/exclusion criteria. In participants with bilateral PT, the test limb was the more symptomatic limb, as indicated by a lower VISA-P score. Participants' heights, weights, and anthropometric data were recorded.

Sixteen retroreflective markers were attached to anatomical landmarks of the pelvis and lower extremity in accordance with the biomechanical model used in the Plug-in-

Gait module of the data collection software.[8,19] Bony landmarks included the anterior superior iliac spine, posterior superior iliac spine, lateral aspect of the thighs, lateral knees, lateral aspects of the shanks, lateral malleoli, heels, and toes.

Participants completed a 5-minute warm-up on a treadmill, including walking and running. Participants walked at self-selected speeds of 1.2 to 1.4 m/s (2.7-3.1 mph) for 1 minute, and the speed was then increased until the participants were at a self-selected running pace at a range between 2.5 and 3.5 m/s (5.6-7.8 mph). Participants performed 3 maximum vertical jumps; their highest reach was recorded. The Vertec jump trainer (Sports Imports) was then set to 50% to 55% of their maximum vertical jump height. Participants then completed a 2-legged drop jump off a 40-cm box onto the force platform, followed immediately by a 50% maximum vertical jump, landing on both force plates with each leg.[1] Participants performed 3 practice drop-jump trials. Participants then performed 5 successful trials of each drop jump. A successful trial was one where participants landed with each foot completely and separately on each force platform for both the initial landing as well as the landing from the subsequent vertical jump.

Data Analysis

Marker positions were recorded via a 7-camera motion capture system (Vicon-MX40, Vicon) using Workstation software (OMG Plc) with a sampling rate of 120 Hz and mean residual error of ≤0.5 mm. Two Bertec 4060-NC force platforms (1200 Hz; Bertec Corp) were fixed to the ground, synchronized, and indicated when ground contact was achieved with >10 N.

All kinematic data were processed through the Vicon Workstation software. Spatial locations of the retroreflective markers were transformed into 3-dimensional coordinates using the Workstation method. Using the "fill gaps" routine utilizing an interpolative cubic spline, minor gaps in coordinate positions of reflective markers because of marker dropout (10 or less samples) were estimated. The kinematic model outlined by work by Davis et al[8] and Kadaba et al[19] was used to calculate segmental positions and joint angles of the lower extremity. Cardan angles were used to define the joint angles.[15,42] The rotation sequence for the segment and joint angles was *x-y-z*, following the International Society of Biomechanics recommendations.[42] For the drop-jump landing, dependent variables of interest included hip, knee, and ankle joint angles at initial ground contact (degrees), peak joint angles (degrees), and the maximum angular displacement in 3 planes during the period from landing after stepping off the box to leaving the ground for the 50% to 55% maximum vertical jump. The landing from the vertical jump was not assessed. Dependent variables of interest were averaged over the first 3 trials in which kinematic information was complete for each participant.

Statistical Analysis

All statistical analyses were performed using IBM Statistical Package for the Social Sciences software (version 21.0; IBM). Demographic data, maximum jump height, questionnaires, and biomechanical data were assessed for differences among PT participants and matched control groups utilizing independent-samples t tests ($P \leq .05$). All data were assessed to make sure all statistical assumptions for t tests were met.[11] Ninety-five percent confidence intervals and Cohen d effect sizes were also calculated for each of the dependent variables.[3]

TABLE 1
Summary of Demographic Data for the Control and Patellar Tendinopathy Groups[a]

	Control	Patellar Tendinopathy
Sex, female/male, n	15/15	15/15
Age, y (range)	21.5 ± 3.0 (18-34)	21.3 ± 3.2 (18-35)
Mass, kg	72.0 ± 14.7	72.8 ± 12.4
Height, cm	174.9 ± 10.5	174.5 ± 9.4
Maximum vertical jump, cm	43.4 ± 10.9	46.6 ± 13.7
VISA-P	**100 ± 0.0**	**64.3 ± 8.7**

[a]Values are expressed as mean ± SD unless otherwise indicated. Values in boldface indicate significant difference ($P < .05$). VISA-P, Victorian Institute of Sports Assessment–Patella.

RESULTS

Demographic data are presented in Table 1. Descriptive statistics for each of the dependent variables are presented for each group in Tables 2, 3, and 4.

The VISA-P was significantly lower in the PT group ($P < .001$) compared with the control participants. At initial ground contact, there were no statistically significant differences between PT and control participants at any joint in any plane. Participants with PT displayed significantly decreased peak hip ($P = .03$) and knee flexion ($P = .01$) angles compared with control subjects. The effect sizes of both peak hip (0.56) and knee flexion (0.68) indicated this was a moderate to large effect between the PT and control groups, respectively. The PT group displayed decreased maximum angular displacement in the sagittal plane at the hip ($P = .04$) and knee ($P < .001$) compared with the control group. The results also indicated that the hip maximum angular displacement had a moderate effect size (0.56) while the knee was a very large effect size (0.97). Effect sizes for the hip (−0.36) and knee (0.38) frontal plane angles at initial contact, as well as peak knee adduction (0.48) and ankle external rotation (0.41), were moderate for group comparisons. All other effect sizes were small. Although we were not directly interested in assessing differences between unilateral and bilateral PT individuals, 19 participants suffered from bilateral PT. There were no significant differences ($P > .05$) in landing kinematics between unilateral and bilateral participants.

TABLE 2
Distributional Statistics for Kinematic Observations at Initial Ground Contact of the Hip, Knee, and Ankle in 3 Planes Between the Control and Patellar Tendinopathy Groups[a]

			Mean, deg	SD	95% CI	t	P Value	Cohen d
Hip	Sagittal	Control	27.3	8.8	24.1 to 30.6	−0.23	.82	−0.07
		Patellar tendinopathy	27.9	8.9	24.5 to 31.2			
	Frontal	Control	−9.9	4.8	−11.6 to −8.1	−1.37	.18	−0.36
		Patellar tendinopathy	−8.0	5.8	−10.4 to −5.8			
	Transverse	Control	1.7	15.4	−4.0 to 7.5	0.45	.65	0.11
		Patellar tendinopathy	−0.18	17.5	−6.7 to 6.3			
Knee	Sagittal	Control	17.7	8.6	14.5 to 20.9	−0.75	.46	−0.19
		Patellar tendinopathy	19.5	10.0	15.8 to 23.3			
	Frontal	Control	5.2	6.3	2.8 to 7.5	1.46	.15	0.38
		Patellar tendinopathy	2.9	5.8	0.73 to 5.1			
	Transverse	Control	−1.9	12.3	−6.4 to 2.6	−0.89	.38	−0.23
		Patellar tendinopathy	1.4	16.0	−4.6 to 7.3			
Ankle	Sagittal	Control	−21.3	8.0	−24.3 to 18.2	−0.87	.39	−0.23
		Patellar tendinopathy	−19.0	11.3	−23.2 to 14.8			
	Frontal	Control	−2.6	13.1	−7.5 to 2.3	−0.21	.84	−0.06
		Patellar tendinopathy	−1.9	12.0	−6.4 to 2.6			
	Transverse	Control	0.2	2.4	−0.72 to 1.1	−0.14	.89	−0.04
		Patellar tendinopathy	0.3	2.8	−0.75 to 1.3			

[a]Sagittal plane: +, flexion/dorsiflexion; −, extension/plantar flexion. Frontal plane: +, adduction/inversion; −, abduction/eversion. Transverse plane: +, internal rotation; −, external rotation.

DISCUSSION

The results of this study did not support the original hypotheses and indicate those with PT demonstrated alterations in lower extremity joint motion during the landing phase of a drop jump. These results may have an impact on clinical practices regarding patients with PT. Participants with PT displayed decreased peak flexion and decreased maximum angular displacement in the sagittal plane at both the hip and knee compared with controls. The results contradict our hypotheses that those with PT would demonstrate an increased peak flexion angle at the knee and hip, as well as increased maximum angular displacement in the sagittal plane at the knee and hip compared with controls. These findings can be used to develop rehabilitation programs and movement retraining protocols that specifically target deficits in the PT group.

Knee

Patellar tendinopathy participants displayed reduced knee maximum angular displacement when landing from the drop jump. Results indicate that maximum angular displacement had an extremely large effect size, and PT participants demonstrated an 8° decrease in total angular displacement compared with controls. This finding contradicts our original hypothesis that PT participants would display an overall increase in angular displacement in the knee throughout the landing phase of the drop jump. This hypothesis was based on a study that suggested those with PTA, a precursor to PT, actually had increased knee flexion throughout landing compared with controls.[9] The investigators hypothesized PTA participants may be placing the tendon in an elongated position during landing, thus causing increased tensile loads on the tendon. This study was performed on asymptomatic PTA participants, not those with symptomatic PT, which could account for the differences seen between studies. The dissimilarities in findings may allow further insight into the biomechanical changes postdevelopment of PT. Factors contributing to PT may include mechanical overload, which causes a tensile failure and strain of the collagen fibers within the tendon.[6,32] The positioning combined with repetitive contraction of the quadriceps could potentially precipitate persistent microtrauma and inadequate healing of the patellar tendon, weakening portions of the tendon and rendering the effective cross-sectional area to insufficient levels that are necessary to transfer forces produced by the quadriceps.[27,41] Those with PT have also displayed higher total training volume, match exposure, and previous training volume compared with healthy participants.[40] Previous research has indicated that diminished flexibility and strength in the quadriceps and hamstrings is related to developing PT.[5,7,41] Decreased flexibility in the quadriceps and hamstrings could potentially influence the reduced angular displacement seen in the knee and hip during landing from the drop jump. Over time, those with symptomatic PT likely develop strategies to avoid these painful ranges and alternatively lessen strain on the tendon during repetitive movement, possibly explaining the decreased displacement observed. These results could indicate that, clinically, rehabilitation programs need to focus on flexibility across the knee joint extensors as well as movement retraining programs that focus on proper knee flexion during jump landings.

Another previous study found those with PT display greater knee flexion during landing from jumping maneuvers.[31] Authors performed a logistic regression on

TABLE 3
Distributional Statistics for Peak Kinematic Observations of the Hip, Knee, and Ankle in 3 Planes Between the Control and Patellar Tendinopathy Groups[a]

			Mean, deg	SD	95% CI	*t*	*P* Value	Cohen *d*
Hip	Sagittal	Control	**67.2**	**13.9**	**62.0 to 72.4**	**2.17**	**.03**	**0.56**
		Patellar tendinopathy	**59.2**	**14.6**	**53.8 to 64.7**			
		Control	11.8	8.5	8.7 to 15.0	0.86	.39	0.22
		Patellar tendinopathy	9.9	8.4	6.8 to 13.1			
	Frontal	Control	−4.1	4.5	−5.8 to −2.4	−1.43	.16	−0.36
		Patellar tendinopathy	−2.4	4.9	−4.2 to −0.6			
		Control	−12.5	4.8	−14.3 to −0.7	−1.11	.27	−0.29
		Patellar tendinopathy	−11.1	5.0	−13.0 to −9.2			
	Transverse	Control	8.9	17.1	2.6 to 15.3	0.46	.65	0.12
		Patellar tendinopathy	6.9	16.8	0.64 to 13.2			
		Control	−4.9	15.8	−10.8 to 1.0	0.45	.66	0.12
		Patellar tendinopathy	−6.8	16.1	−12.8 to −0.7			
Knee	Sagittal	Control	**82.5**	**9.0**	**79.1 to 85.8**	**2.63**	**.01**	**0.68**
		Patellar tendinopathy	**74.8**	**13.2**	**69.8 to 79.7**			
		Control	2.4	6.1	0.2 to 4.7	−0.42	.68	−0.11
		Patellar tendinopathy	3.1	5.8	0.9 to 5.2			
	Frontal	Control	11.7	12.1	7.2 to 16.2	1.81	.08	0.48
		Patellar tendinopathy	7.1	5.9	4.8 to 9.4			
		Control	−5.4	10.3	−9.2 to −1.5	0.41	.69	0.11
		Patellar tendinopathy	−6.5	10.6	−10.4 to −2.5			
	Transverse	Control	29.4	13.0	24.6 to 34.3	−0.21	.83	−0.06
		Patellar tendinopathy	30.2	13.0	24.4 to 36.0			
		Control	−13.5	15.6	−19.4 to −7.7	0.35	.73	0.09
		Patellar tendinopathy	−14.8	12.5	−19.5 to −10.1			
Ankle	Sagittal	Control	31.7	5.6	29.6 to 33.8	−0.93	.36	−0.24
		Patellar tendinopathy	33.4	8.1	30.4 to 36.4			
		Control	−33.1	−30.6	−37.2 to −29.0	−1.03	.31	−0.11
		Patellar tendinopathy	−30.6	7.4	−33.4 to −27.8			
	Frontal	Control	6.4	15.0	0.8 to 12.0	−0.79	.43	−0.20
		Patellar tendinopathy	9.2	12.6	4.6 to 13.9			
		Control	−31.1	12.1	−35.6 to −26.6	−0.04	.97	−0.01
		Patellar tendinopathy	−31.0	14.6	−36.4 to −25.5			
	Transverse	Control	7.2	4.0	5.8 to 8.7	−0.80	.43	−0.21
		Patellar tendinopathy	8.3	6.2	6.0 to 10.6			
		Control	−1.2	2.3	−2.1 to −0.3	1.48	.15	0.41
		Patellar tendinopathy	−2.3	3.0	−3.4 to −1.2			

[a]Values in boldface indicate significant differences between control and patellar tendinopathy participants ($P < .05$). Sagittal plane: +, flexion/dorsiflexion, −, extension/plantar flexion. Frontal plane: +, adduction/inversion; −, abduction/eversion. Transverse plane: +, internal rotation; −, external rotation.

10 (3 with PT) participants to predict PT using knee joint kinematics during volleyball spikes and blocks.[31] The authors found maximum knee flexion angle during the spike landing could correctly predict inclusion into the PT group; higher knee angles were more likely to exhibit PT.[31] The difference in findings seen between the current study and the former work could have several possible explanations. First, the jump landing maneuver was different. We utilized a 40-cm drop jump with a 50% maximum jump compared with a single-leg volleyball spike landing. The drop jump is likely a lower demand task compared with the volleyball spike. Second, in the previous study, 3 participants were included, and such a small sample may not have been representative of the entire PT population. Our study included 30 individuals with current signs and symptoms of PT, which is likely a more representative sample of those with PT compared with the 3 used in the previous study. Last, we may have had overall less skilled groups than in other studies, which reported increased maximum vertical jump height in those with PT compared with controls in elite volleyball athletes.[16,23,24] Because of these differences between studies, the current study is likely more applicable to recreationally active populations as opposed to elite volleyball athletes.

Hip

The PT group also displayed a significant decrease in hip maximum angular displacement, which was contradictory to our hypothesis that it would increase throughout landing. A previous study reported that hip range of motion during landing of a drop jump accounted for approximately 50% of the variability in a multiple regression to

TABLE 4
Distributional Statistics for Kinematic Observations of Maximum Angular Displacement for the Hip, Knee, and Ankle in 3 Planes Between the Control and Patellar Tendinopathy Groups[a]

			Mean, deg	SD	95% CI	*t*	*P* Value	Cohen *d*
Hip	Sagittal	Control	**55.2**	**11.4**	**50.9 to 59.5**	**2.056**	**.04**	**0.53**
		Patellar tendinopathy	**49.3**	**10.8**	**45.3 to 53.3**			
	Frontal	Control	8.3	2.9	7.2 to 9.4	−0.538	.59	−0.13
		Patellar tendinopathy	8.7	3.4	7.4 to 10.0			
	Transverse	Control	14.1	6.1	11.8 to 16.3	0.932	.36	0.25
		Patellar tendinopathy	12.8	4.3	11.2 to 14.4			
Knee	Sagittal	Control	**79.7**	**8.3**	**76.6 to 82.7**	**3.685**	**.001**	**0.97**
		Patellar tendinopathy	**71.6**	**8.4**	**68.3 to 74.8**			
	Frontal	Control	17.3	9.3	13.8 to 20.8	0.517	.61	0.13
		Patellar tendinopathy	16.1	9.0	12.7 to 19.4			
	Transverse	Control	42.8	12.2	38.2 to 47.3	−0.796	.43	−0.20
		Patellar tendinopathy	45.0	9.6	41.4 to 48.6			
Ankle	Sagittal	Control	58.3	8.2	54.9 to 61.7	−0.332	.74	−0.09
		Patellar tendinopathy	59.2	11.8	54.8 to 63.6			
	Frontal	Control	38.3	10.3	34.5 to 42.2	−1.291	.20	−0.18
		Patellar tendinopathy	40.2	11.0	36.1 to 44.3			
	Transverse	Control	9.1	3.7	7.7 to 10.5	−0.681	.50	−0.34
		Patellar tendinopathy	10.6	5.1	8.7 to 12.5			

[a]Values in boldface indicate significant differences between control and patellar tendinopathy participants ($P < .05$). Sagittal plane: +, flexion/dorsiflexion, −, extension/plantar flexion. Frontal plane: +, adduction/inversion; −, abduction/eversion. Transverse plane: +, internal rotation; −, external rotation.

predict those with PTA.[26] These authors felt the alterations in landing strategy observed in PTA participants could potentially increase both tensile and compressive loading on the tendon by changing the direction of the load on the patellar tendon, which may be contributing to the development of PT. Additionally, although muscular attachments of the patellar tendon arise from the vastus medialis, rectus femoris, vastus intermedius, and vastus lateralis, a majority of the fibers are from the rectus femoris.[38] Changes seen in the hip angular displacement may mean the rectus femoris, the only 2-joint muscle of the quadriceps, plays a greater role in the developing and perpetuating symptoms associated with PT. Similarly, altered hip landing biomechanics have been shown to be influential in the symptoms associated with other knee joint pathologies.[29] Health care providers may want to broaden their rehabilitation focus to include the rectus femoris and encourage exercises involving both the hip and the knee to address similar issues in those with PT. Rehabilitation protocols for other knee joint injuries such as patellofemoral pain syndrome have successfully incorporated hip-specific exercises and reduced associated symptoms.[10,13]

Ankle

There were no significant differences at the ankle in any plane at initial contact, peak kinematics, or maximum angular displacement. Although not statistically significant, PT participants' peak external ankle rotations were larger than control participants, with a moderate effect size but just over a 1° difference. A previous study found similar findings through performing a logistic regression on ankle joint rotational kinematics to predict presence of PT in elite volleyball athletes and did not find any relation between them.[30] Although a moderate effect size was found in the current study, no significant differences existed. Therefore this finding may not be clinically relevant during sagittal plane tasks, and kinematics at the ankle seems unlikely to contribute to PT participants' disabilities.

Limitations

There are several limitations in this study. We did not use imaging techniques such as diagnostic ultrasound to verify self-reported PT. Although this would have been ideal, previous biomechanical studies assessing PT participants versus healthy controls have used very similar inclusion and exclusion criteria, and we are confident of the presence of pathology in the PT group.[2,12,33] We also cannot make inferences regarding joint kinetics. The primary aim of this study was to assess the kinematics and movement patterns of the drop-jump landing in those with PT; without kinetic data we cannot effectively assess how much energy was absorbed during the landing. Additionally, while we can interpret data regarding the landing kinematics to participants' knee and hip ranges of motion, we did not directly measure it. Assessing participants' active and passive ranges of motion may have allowed us to have more insight into the pathological changes seen in those with PT. The power and effect size were low in comparison with some variables, which may be attributable to the uniplanar nature of the jumping task. Finally, we recruited a sample of convenience from the university community, with our sample's average age of 21 years. This sample may not be generalizable to younger or older populations.

CONCLUSION

Participants with PT displayed different movement strategies during landing compared with a healthy population during a drop-jump landing. Those with PT displayed decreased maximum hip and knee flexion. PT participants also presented with decreased hip and knee maximum angular displacement in the sagittal plane. The changes in sagittal plane movement patterns in those with PT may be due to the contributions of the rectus femoris muscle during dynamic movement. Landing in a more erect position, with less hip and knee joint displacement, may be an effort to avoid or decrease symptoms associated with tensile loading. At landing in the frontal plane, participants with PT may also land with less hip abduction and knee adduction compared with matched controls. Health care practitioners may focus their rehabilitative efforts on hip and knee landing mechanics to reduce symptoms associated with PT.

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REFERENCES

1. Beutler A, de la Motte S, Marshall S, Padua D, Boden B. Muscle strength and qualitative jump-landing differences in male and female military cadets: The jump-ACL study. *J Sports Sci Med*. 2009;8:663-671.
2. Bisseling RW, Hof AL, Bredeweg SW, Zwerver J, Mulder T. Relationship between landing strategy and patellar tendinopathy in volleyball. *Br J Sports Med*. 2007;41:e8.
3. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum; 1988.
4. Cook JL, Khan KM, Harcourt PR, Grant M, Young DA, Bonar SF. A cross-sectional study of 100 athletes with jumper's knee managed conservatively and surgically. The Victorian Institute of Sport Tendon Study Group. *Br J Sports Med*. 1997;31:332-336.
5. Cook JL, Kiss ZS, Khan KM, Purdam CR, Webster KE. Anthropometry, physical performance, and ultrasound patellar tendon abnormality in elite junior basketball players: a cross-sectional study. *Br J Sports Med*. 2004;38:206-209.
6. Couppe C, Kongsgaard M, Aagaard P, et al. Differences in tendon properties in elite badminton players with or without patellar tendinopathy. *Scand J Med Sci Sports*. 2013;23:e89-e95.
7. Crossley KM, Thancanamootoo K, Metcalf BR, Cook JL, Purdam CR, Warden SJ. Clinical features of patellar tendinopathy and their implications for rehabilitation. *J Orthop Res*. 2007;25:1164-1175.
8. Davis RB, Ounpuu S, Tyburski D, Gage JR. A gait analysis data-collection and reduction technique. *Hum Movement Sci*. 1991;10: 575-587.
9. Edwards S, Steele JR, McGhee DE, Beattie S, Purdam C, Cook JL. Landing strategies of athletes with an asymptomatic patellar tendon abnormality. *Med Sci Sports Exerc*. 2010;42:2072-2080.
10. Ferber R, Kendall KD, Farr L. Changes in knee biomechanics after a hip-abductor strengthening protocol for runners with patellofemoral pain syndrome. *J Athl Train*. 2011;46:142-149.
11. Field A. *Discovering Statistics Using SPSS*. 2nd ed. Thousand Oaks, CA: Sage; 2005.
12. Fietzer AL, Chang YJ, Kulig K. Dancers with patellar tendinopathy exhibit higher vertical and braking ground reaction forces during landing. *J Sports Sci*. 2012;30:1157-1163.
13. Fukuda TY, Melo WP, Zaffalon BM, et al. Hip posterolateral musculature strengthening in sedentary women with patellofemoral pain syndrome: a randomized controlled clinical trial with 1-year follow-up. *J Orthop Sports Phys Ther*. 2012;42:823-830.
14. Grau S, Maiwald C, Krauss I, Axmann D, Janssen P, Horstmann T. What are causes and treatment strategies for patellar-tendinopathy in female runners? *J Biomech*. 2008;41:2042-2046.
15. Grood ES, Suntay WJ. A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. *J Biomech Eng*. 1983;105:136-144.
16. Helland C, Bojsen-Møller J, Raastad T, et al. Mechanical properties of the patellar tendon in elite volleyball players with and without patellar tendinopathy. *Br J Sports Med*. 2013;47:862-868.
17. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train*. 2007;42:311-319.
18. Ingram JG, Fields SK, Yard EE, Comstock RD. Epidemiology of knee injuries among boys and girls in US high school athletics. *Am J Sports Med*. 2008;36:1116-1122.
19. Kadaba MP, Ramakrishnan HK, Wootten ME. Measurement of lower extremity kinematics during level walking. *J Orthop Res*. 1990;8:383-392.
20. Kettunen JA, Kvist M, Alanen E, Kujala UM. Long-term prognosis for jumper's knee in male athletes. A prospective follow-up study. *Am J Sports Med*. 2002;30:689-692.
21. Khan KM, Cook JL, Kannus P, Maffulli N, Bonar SF. Time to abandon the ''tendinitis'' myth. *BMJ*. 2002;324:626-627.
22. Khan KM, Maffulli N, Coleman BD, Cook JL, Taunton JE. Patellar tendinopathy: some aspects of basic science and clinical management. *Br J Sports Med*. 1998;32:346-355.
23. Lian O, Engebretsen L, Ovrebo RV, Bahr R. Characteristics of the leg extensors in male volleyball players with jumper's knee. *Am J Sports Med*. 1996;24:380-385.
24. Lian O, Refsnes PE, Engebretsen L, Bahr R. Performance characteristics of volleyball players with patellar tendinopathy. *Am J Sports Med*. 2003;31:408-413.
25. Lian OB, Engebretsen L, Bahr R. Prevalence of jumper's knee among elite athletes from different sports: a cross-sectional study. *Am J Sports Med*. 2005;33:561-567.
26. Mann KJ, Edwards S, Drinkwater EJ, Bird SP. A lower limb assessment tool for athletes at risk of developing patellar tendinopathy. *Med Sci Sports Exerc*. 2013;45:527-533.
27. Moore JS. Function, structure, and responses of components of the muscle-tendon unit. *Occup Med*. 1992;7:713-740.
28. Peace KA, Lee JC, Healy J. Imaging the infrapatellar tendon in the elite athlete. *Clin Radiol*. 2006;61:570-578.
29. Powers CM. The influence of abnormal hip mechanics on knee injury: a biomechanical perspective. *J Orthop Sports Phys Ther*. 2010;40:42-51.
30. Richards DP, Ajemian SV, Wiley JP, Brunet JA, Zernicke RF. Relation between ankle joint dynamics and patellar tendinopathy in elite volleyball players. *Clin J Sport Med*. 2002;12:266-272.
31. Richards DP, Ajemian SV, Wiley JP, Zernicke RF. Knee joint dynamics predict patellar tendinitis in elite volleyball players. *Am J Sports Med*. 1996;24:676-683.
32. Schmid MR, Hodler J, Cathrein P, Duewell S, Jacob HA, Romero J. Is impingement the cause of jumper's knee? Dynamic and static magnetic resonance imaging of patellar tendinitis in an open-configuration system. *Am J Sports Med*. 2002;30:388-395.
33. Siegmund JA, Huxel KC, Swanik CB. Compensatory mechanisms in basketball players with jumper's knee. *J Sport Rehabil*. 2008;17: 359-371.
34. Sorenson SC, Arya S, Souza RB, Pollard CD, Salem GJ, Kulig K. Knee extensor dynamics in the volleyball approach jump: the influence of patellar tendinopathy. *J Orthop Sports Phys Ther*. 2010;40:568-576.

35. Swenson DM, Collins CL, Best TM, Flanigan DC, Fields SK, Comstock RD. Epidemiology of knee injuries among U.S. high school athletes, 2005/2006-2010/2011. *Med Sci Sports Exerc*. 2013;45:462-469.
36. Taunton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD. A retrospective case-control analysis of 2002 running injuries. *Br J Sports Med*. 2002;36:95-101.
37. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res*. 1985;(198):43-49.
38. Tuong B, White J, Louis L, Cairns R, Andrews G, Forster BB. Get a kick out of this: the spectrum of knee extensor mechanism injuries. *Br J Sports Med*. 2011;45:140-146.
39. Visenti PJ, Khan KM, Cook JL, Kiss ZS, Harcourt PR, Wark JD. The VISA score: an index of severity of symptoms in patients with jumper's knee (patellar tendinosis). Victorian Institute of Sport Tendon Study Group. *J Sci Med Sport*. 1998;1:22-28.
40. Visnes H, Bahr R. Training volume and body composition as risk factors for developing jumper's knee among young elite volleyball players. *Scand J Med Sci Sports*. 2013;23:607-613.
41. Witvrouw E, Bellemans J, Lysens R, Danneels L, Cambier D. Intrinsic risk factors for the development of patellar tendinitis in an athletic population. A two-year prospective study. *Am J Sports Med*. 2001; 29:190-195.
42. Wu G, Siegler S, Allard P, et al. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion–part I: ankle, hip, and spine. International Society of Biomechanics. *J Biomech*. 2002;35:543-548.