Evaluation of Intrinsic Biomechanical Risk Factors in Patellar Tendinopathy

A Retrospective Radiographic Case-Control Series

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Background: Patellar tendinopathy is an overuse condition often affecting athletes. It has been postulated that patellar tendinopathy is associated with patella alta; however, this and any other anatomic risk factors have not been identified.

Purpose: To explore whether lever arm differences from radiographic measurements exist between patients with and without tendinopathy. This may provide surgeons with a simple radiographic means to identify patients at risk.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Magnetic resonance imaging scans of the knee from a sports imaging facility were screened and reviewed to identify 2 groups of patients: those with and those without imaging signs of patellar tendinopathy. The lateral radiographs were reviewed and measurements made to determine (1) lever arm ratio, (2) moment arm ratio, (3) angle between the moment and line of pull of the patellar tendon, (4) patellar tendon pivot point angle, and (5) patellar height (alta). Measurements were obtained directly from radiographs. The images and measurements were reviewed by 2 experienced orthopaedic clinicians.

Results: A total of 105 patients were included in this study: 52 with patellar tendinopathy and 53 without patellar tendinopathy (controls). The mean age was similar between groups (23 years); females accounted for 8 of 52 patients with patellar tendinopathy and 24 of 53 patients without. The lever arm ratio in the group with patellar tendinopathy versus controls was 1.71 versus 1.01 ($P = .01$), with a moment arm difference of 1.00 versus 0.80 ($P < .01$), respectively. There was no difference detected between groups for patellar tendon angle, patellar tendon pivot point angle, knee flexion angle, or incidence of patella alta. No correlation was found with our measurements and the Insall-Salvati ratio. Statistical analysis was also performed according to sex, and a statistically significant difference between groups was found for differences in lever arm ratio and moment arm.

Conclusion: The lever arm ratio and moment arm ratio from lateral radiographs were significantly different between patients with and without patellar tendinopathy. Further study is needed on the biomechanical implications of the pivot point and how altering it can affect stress within the patellar tendon, patellofemoral joint, and associated clinical outcomes.

Keywords: jumper's knee; tendinosis; biomechanics; knee; radiography

Patellar tendinopathy is an overuse condition commonly affecting jumping athletes, with a reported incidence >50% for volleyball and basketball players, as opposed to an incidence of 20% among soccer players.[14] Patellar tendinopathy is characterized by anterior knee pain, with tenderness at the distal pole of the patella.[4] The major risk factors for the condition are those that are extrinsic (ie, external to the athlete/patient). In particular, increased training volume and harder training surfaces have been associated with development of this condition.[6,18,22]

Intrinsic risk factors are those internal to the athlete/patient. Patellar tendinopathy is more common among patients with tight quadriceps and hamstring muscles,[23] abnormal leg lengths, and pes planus.[18] Previous studies have failed to show a statistical difference in the morphology of the patella between those with and those without patellar tendinopathy.[6,7,15] These studies examined the patella for differences in anatomy based on radiographic risk factors associated with patellofemoral pain and dislocation.

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Tyler et al[17] successfully demonstrated differences in sagittal patellar tilt and described a new measurement for a patellofemoral relationship, called *anteroposterior patellar tilt*—specifically, the angle formed between the patellar articular surface and the anterior diaphyseal axis of the femur on lateral knee radiograph. In that study, patients with patellar tendinopathy had a mean of 4.5° less anteroposterior tilt compared with control participants. These authors did not associate a clinical significance to this as being either diagnostic or therapeutic, nor did they provide a biomechanical explanation for why this difference existed.

As identified by Huberti et al,[9] the patella should be viewed as a lever, not a pulley, with the patellar tendon: quadriceps force ratio changing according to the degree of knee flexion. The patellar tendon experiences relatively higher degrees of stress for the first 45° of flexion, before the relationship is reversed to have a higher degree of quadriceps stress relative to the patellar tendon.[9] Van Eijden and coauthors[19-21] expanded on this, producing a series of mathematical equations to describe the position and force relationships of the patella in the sagittal plane.

The debate continues over the etiology of patellar tendinopathy as a stress-shielding/compressive phenomenon[1,2] versus a repetitive micro-overload pathogenesis. There is sufficient clinical evidence, however, to exclude compressive etiology[16] and ample biomechanical cadaveric evidence and finite element models to support repetitive micro-overload,[3,8,12] in keeping with the known overload extrinsic risk factors from clinical studies[6,18,22] to support the etiology of repetitive micro-overload.

We previously explored this topic in greater detail in an extensive review of the literature on patellar tendinopathy and the biomechanics of the extensor mechanism.[5] Considering the etiology of repetitive micro-overload, we hypothesized that the answer to identifying potential intrinsic risk factors lies in viewing the patella in the lateral plane as a lever in which, to be in equilibrium, the moments on either side must balance. The current study defines new lateral knee radiographic measurements with the aim of identifying intrinsic risk factors for patellar tendinopathy based on biomechanical principles obtained from lateral radiographs. We analyzed differences in patella-related lever measurements acquired through lateral planar radiographs of patients with and without patellar tendinopathy.

METHODS

Study Design

A retrospective case-control series study of lateral planar radiographs was performed following ethical approval. The sample size was set at 50 per group: patients with patellar tendinopathy and asymptomatic controls. We used a computer algorithm to screen the radiologist's magnetic resonance imaging (MRI) report for appropriate patients. To screen for control patients, the algorithm searched for the text "normal MRI" within the report. To screen for patients with patellar tendinopathy, the algorithm searched for the terms "patella/r tendinopathy" and synonyms "tendinosis" and "tendinitis." Patient clinical notes were not reviewed in this study, but the indication for MRI (as documented on the MRI referral) included "anterior knee pain."

The MRI report and images from patients with tendinopathy were reviewed to confirm the diagnosis. This was done by identifying thickening of the patellar tendon and increased signal intensity on both short and long echo time MRI sequences in the tendinopathy cases.[11] The next step for inclusion was to ensure that all patients (control and tendinopathy groups) had a recent lateral knee radiograph with MRI. Exclusion criteria included evidence of previous surgery, knee effusion, quadriceps tendinopathy, or other intra-articular pathology that may have affected patellar position or the indication for the original referral of investigative imaging. We also excluded patients if they were <16 years old, to ensure skeletal maturity, or >35 years old, as a quasi-restrictor intended to minimize age-related tendinopathic changes. We did not match further for sex or age to minimize selection bias.

Measurements

Radiographic measurements were performed on de-identified and scaled JPEGs of lateral knee radiographs. We used software written in Mathematica (v 10.1; Wolfram Language). The software allowed the examiners to place markings representing the points identified in Figures 1 to 3 before the program would calculate the measurements described for each image. The radiographs were independently reviewed and marked by 2 blinded examiners to calculate the described measurements.

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Ethical approval for this study was obtained from the Human Research and Ethics Committee of the University of New South Wales, Sydney, Australia (HC180197).

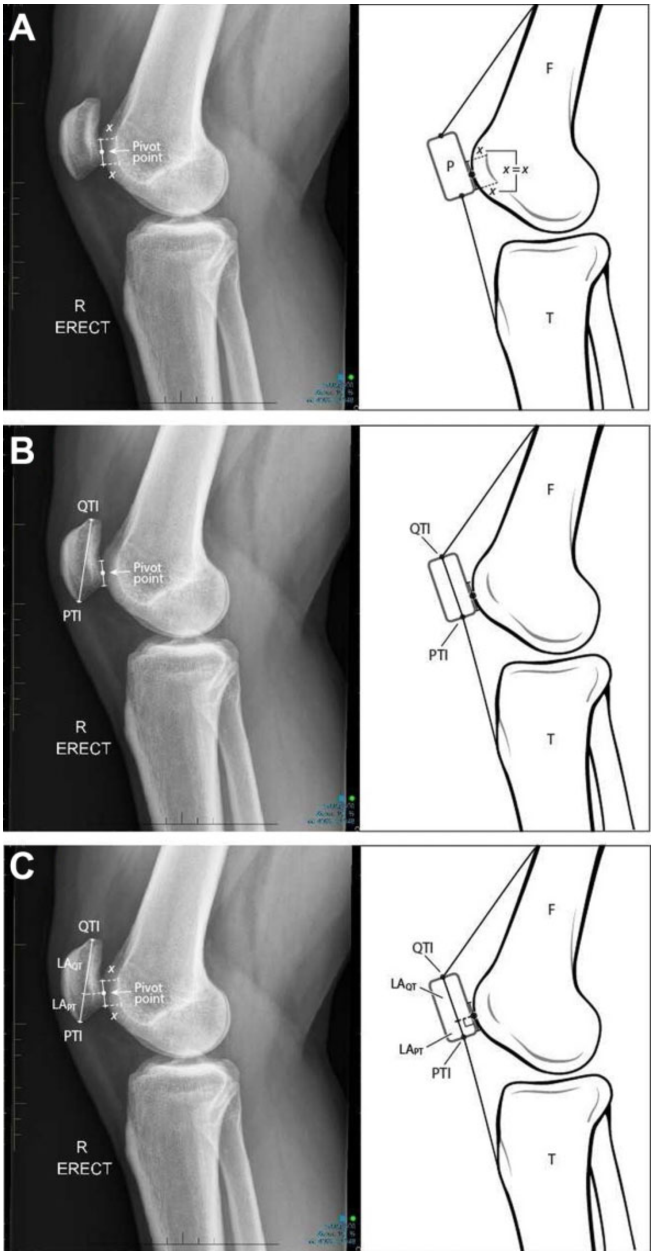

Figure 1. Lever arm ratio. (A) Locating the pivot point: this is equivalent to the midpoint of the articulation of the patella on the femur. It is found by drawing 2 lines (labeled *x*) perpendicular to the patellar articular surface equidistant from the femoral articular surface proximally and distally. The midpoint of these 2 points on the patellar articular surface is what we term the *pivot point*, equivalent to the fulcrum of the lever. (B) Lever: the lever is a line drawn from the quadriceps tendon insertion (QTI) to the patellar tendon origin/insertion (PTI). (C) Lever arm ratio: a line perpendicular to the patellar articular surface is drawn from the pivot point to the lever. This divides the lever into the lever arms of the patellar tendon (LA_{PT}) and quadriceps tendon (LA_{QT}). The lever arm ratio is LA_{QT} divided by LA_{PT}. F, femur; P, patella; T, tibia.

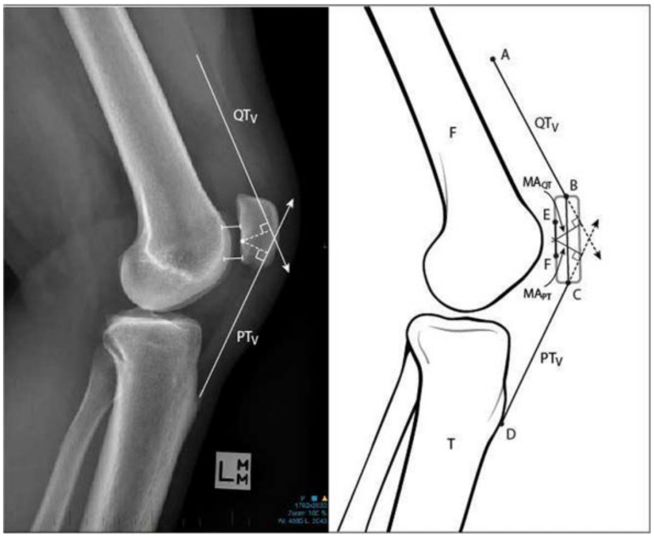

Figure 2. Moment arm ratio. Quadriceps tendon vector (QT_V) and patellar tendon vector (PT_V) are formed from a line continued with the soft tissue outline of the respective tendons. The moment arm (MA) is the perpendicular distance from the tendon vector to the pivot point (see Figure 1A for a description of the pivot point). The moment arm ratio is the MA_{QT} divided by MA_{PT}. F, femur; T, tibia.

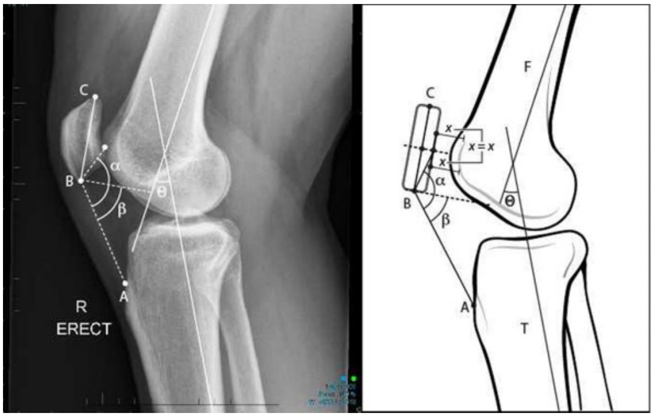

Figure 3. Angles and patellar height. Patellar height is defined by patellar tendon length (*AB*) divided by patellar length (*BC*). Knee flexion angle (Θ) is formed by the intersection of lines drawn parallel with the anterior part of the posterior diaphyseal cortex of the femur and tibia.[13] The patellar tendon angle (β) is formed by the angle between *AB* and a line drawn perpendicular to *BC* at point *B*. The patellar tendon pivot point angle (α) is formed by the patellar tendon (*AB*) and a line drawn from *B* to the pivot point. For an explanation of pivot point, see Figure 1A. F, femur; T, tibia.

TABLE 1
Inter- and Intraobserver Reliability Correlation Coefficients[a]

Measurement	Interobserver	Intraobserver
Arm ratio		
Lever	0.97	0.99
Moment	0.96	0.92
Tendon angle		
Patella	0.92	0.90
Pivot point patella	0.95	0.95
Knee flexion angle	0.99	0.99
Alta	0.97	0.92

[a]A strong correlation was seen within the same observer and between observers, reported as intraclass correlation coefficients.

Measurement Points

Our novel radiographic measurements apply lever principles to the lateral knee radiograph, viewing the patella as a lever, with the articulation point on the femur determining the fulcrum, as outlined in Figures 1 to 3. Torque is defined by the force times the perpendicular distance from the axis of rotation (lever arm) multiplied by the perpendicular component of the force vector. Figure 1 describes how to identify the pivot point/fulcrum and calculate the patellar tendon and quadriceps tendon lever arms. Figure 2 describes how to calculate the moment arms of the patellar tendon and the quadriceps tendon. The effect of the angle of pull from the vector of the patellar tendon is determined by calculating the patellar tendon angle as described in Figure 3. The pivot point patellar tendon angle investigates the combined effect of the lever arm length with the patellar tendon angle. This and the patellar tendon height (Insall-Salvati method: patella alta was defined as *AB*/*BC* >1.2)[10] are also described in Figure 3.

Statistical Analysis

Interobserver reliability was compared for all radiographic measurements described in Figures 1 to 3. Twenty radiographs were randomly selected to be remeasured by the first observer to test intraobserver reliability. Reliability was tested with the intraclass correlation coefficient (ICC) via a 2-way mixed model. A 2-tailed Student *t* test for independent samples was used to compare means between the controls and the patients with patellar tendinopathy. Statistically significant results ($P < .05$) were compared with the Insall-Salvati ratio to check for correlations among variables via ICCs. SPSS (v 25; IBM) was used to perform these statistical analyses.

RESULTS

Measurement Reliability

The ICCs for each variable as it was tested between observers are presented in Table 1, and they revealed strong intra- and interobserver reliability. The interobserver reliability of the patellar tendon angle, with an ICC of 0.92, was the lowest, whereas the knee flexion angle had the highest ICC, at 0.99. The patellar tendon angle had the lowest intraobserver reliability, with an ICC of 0.90, and the knee flexion angle and lever arm ratio had the highest, at 0.99.

Analysis

Demographic data (Table 2) revealed a significantly higher number of females in the control group versus the tendinopathy group ($P < .01$). No differences were found with respect to age between groups.

A statistically significant difference was found in the lever arm ratio ($P = .01$) and the moment arm ratio ($P < .01$) between patients with and without patellar tendinopathy. The tendinopathy group had mean lever and moment arm ratios of 1.71 and 1.00, respectively, as opposed to 1.01 and 0.80 for the control patients (Table 2). The relationship between values are further demonstrated in box plots in Figures 4 and 5 to present the spread of the data. Results presented in Table 2 include the outliers listed in Figures 4 and 5. The results of the analysis were unchanged when these 5 outliers were removed.

Patellar tendon angle, patellar tendon pivot point angle, and the prevalence of patella alta were not statistically different between controls and patients with patellar tendinopathy. Knee flexion angle was also not statistically different. Data were analyzed with respect to sex, and statistically significant between-group differences in the lever arm ratio and moment arm ratio were still of comparable magnitude (Table 2). No other statistically significant differences were found in the sex analysis.

It is known that the articulation point of the patella changes from the distal pole in extension to the proximal pole in flexion; however, the scatter plot shown in Figure 6 failed to demonstrate this linear relationship between knee flexion angle and lever arm ratio across patients in our study. There was no difference in the knee flexion angle between the control and patellar tendinopathy groups (Table 2). We performed a subanalysis of the controls and patellar tendinopathy patients using knee flexion angles of 30° to 60° and 60° to 80°. There was an even spread of patients in each group, with mean differences of 0.43 and 0.62 for the lever arm ($P = .01$) and 0.23 and 0.21 for the moment arm ($P = .04$), respectively. The remaining variables were still not statistically significant. There was no statistically significant correlation of the lever arm ratio with alta, with an ICC of 0.18 ($P = .07$).

DISCUSSION

The present study is the first to analyze the sagittal plane biomechanics of the extensor mechanism to identify morphologic intrinsic risk factors of patellar tendinopathy. Measurements were obtained from planar lateral radiographs of patients with patellar tendinopathy and were compared with controls. A statistically significant difference in the lever arm and moment arm was found for patients with patellar tendinopathy relative to control

TABLE 2
Differences Between Tendinopathy and Control Groups

	Mean (SD)			95% CI		
	Tendinopathy	Control	Difference	Lower	Upper	*P* Value[a]
Age, y	23.23 (4.71)	23.17 (5.85)	–0.04	–2.10	2.02	.97
Male[b]	85	55	30	—	—	**<.01**
Lever arm	1.71 (1.64)	1.01 (0.43)	–0.70	–1.16	–0.23	**.01**
Moment arm	1.00 (0.34)	0.80 (0.17)	–0.20	–0.31	–0.10	**<.01**
Patellar tendon angle	47.76 (7.14)	47.07 (8.24)	–1.08	–4.07	1.90	.59
Pivot point angle	107.94 (10.23)	110.65 (10.71)	2.20	–1.86	6.25	.80
Knee angle	56.13 (19.98)	59.32 (19.65)	2.57	–5.10	10.24	.96
Alta[b]	63	51	12	—	—	.52

[a]Statistically significant variables are presented in bold ($P < .05$).
[b]Nominal variables presented as percentages.

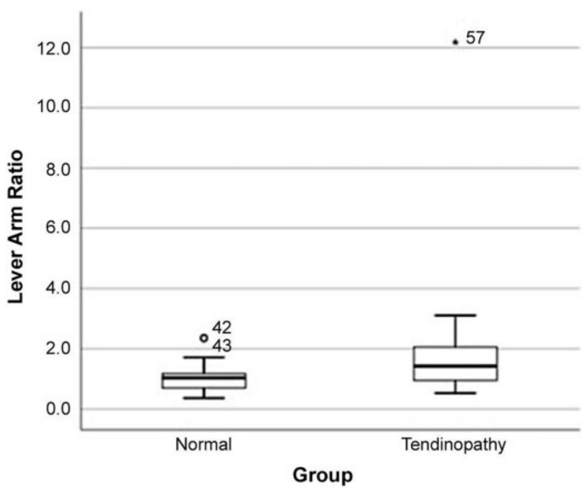

Figure 4. Box plot for lever arm ratio between those with and those without patellar tendinopathy. A statistically significant difference was identified between the lever arm of patients with tendinopathy and without. Spread of the data as demonstrated through box plot, with the upper and lower limits of the values from the horizontal lines and outliers (indicated by patient number) demonstrated outside. Upper and lower ends of the box signify the 75th and 25th percentile, respectively, and median between. All data were included in the final analysis.

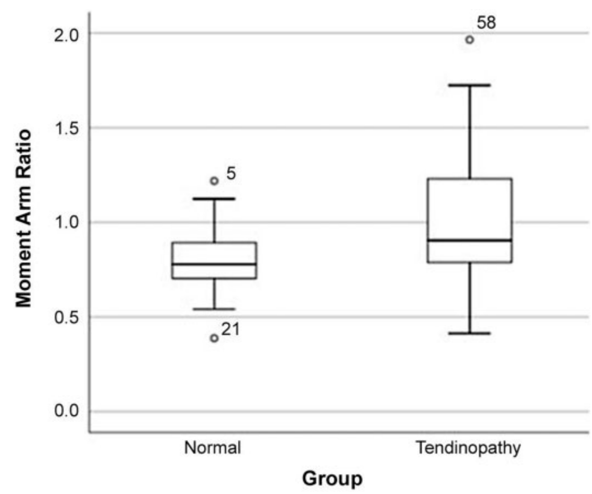

Figure 5. Box plot for moment arm ratio for those with and those without patellar tendinopathy. A statistically significant difference was identified between the moment arm of patients with tendinopathy and without. Spread of data demonstrated through box plot, with the upper and lower limits of the values from the horizontal lines and outliers (indicated by patient number) demonstrated outside. Upper and lower ends of the box signify the 75th and 25th percentile, respectively, and median between. All data were included in the final analysis.

patients. Patients with patellar tendinopathy had a patellar lever arm that was smaller relative to the quadriceps lever arm, while the patellar tendon moment arm length was smaller relative to the quadriceps moment arm. Drawing from the work of Huberti et al[9] and van Eijden et al,[19-21] we infer that those with patellar tendinopathy will experience greater force through their patellar tendon as compared with those without the condition, owing to the relationship of the patella relative to the femur.

Huberti et al[9] and van Eijden et al[19-21] also reported that the point of articulation on the patella and femur, what we termed the *pivot point* in the current study (see Figure 1A), changes with knee flexion angle. However, there was no statistically significant difference in mean ± SD knee flexion angle between the control and tendinopathy groups. The scatter plot (Figure 6) did not show a strong linear relationship between lever arm ratio and knee flexion angle. Further research to explore this relationship between the lever arm and the angle of knee flexion is warranted. We were unable to report normal and abnormal values for different ranges of knee flexion angle based on the patients reviewed in our study. Van Eijden et al[19-21] explored the relationship of patellar tendon length on patellar tendon force. The authors reported that patellar tendon length indirectly influences patellar tendon force by changing the pivot point. However, in the current study, we did not find a statistically significant difference in patella alta between patients with and those without tendinopathy (post hoc power analysis confirmed

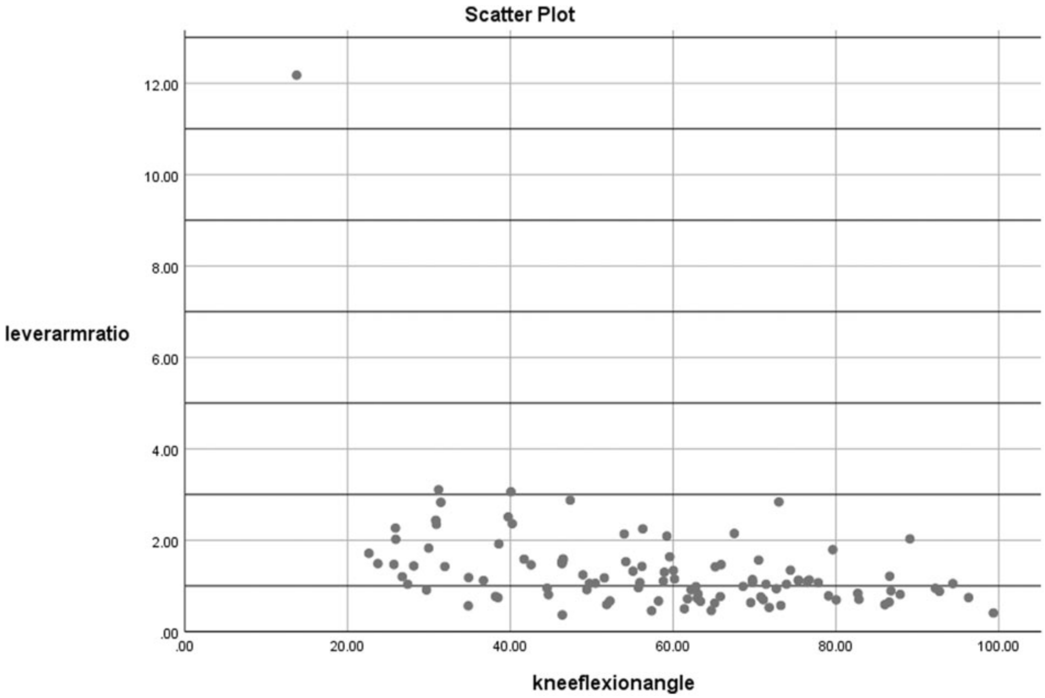

Figure 6. Scatter plot for lever arm ratio vs knee flexion angle. Visually, no clear relationship is determinable between lever arm ratio (*y* axis) and knee flexion angle (*x* axis) for patients included in the present study.

85% power to detect a mean difference of 12° for 100 patients). We also did not find a correlation between lever or moment arm with patella alta. This may explain, in part, why previous studies have failed to show a direct relationship between patella alta and patellar tendinopathy.[6,15]

In agreement with the work of Schmid et al,[16] we did not find a difference in patellar tendon angle between controls and patients with patellar tendinopathy. Our new measurement of patellar tendon pivot point angle aimed to look for a combined effect of patellar tendon angle and patellar tendon lever arm, but it did not demonstrate a difference. A post hoc power analysis showed that for a standard deviation of 5 and with 100 patients, we could have detected 2° of mean difference in patellar tendon angle. Therefore, the relative moment and lever arms were the only statistically significant biomechanical differences found.

These intrinsic differences in anatomy may explain the subset of patients who do not improve clinically despite exhausting current treatment options. The potential clinical implication of considering lever and moment arm differences is 2-fold—specifically, in terms of prevention and treatment. Radiographic screening of athletes in high-risk sports (eg, volleyball and basketball) may allow identification of those who are biomechanically predisposed to developing the condition, based on lever arm differences. Training loads and appropriate prehabilitation can be tailored to the individual athlete to try to prevent the condition.

A limitation of this study, being retrospective, is that we were not able to (1) control the degrees of flexion in which the knee radiograph was taken and (2) choose whether to accept the radiograph, which meant that we had a wide range of knee flexion angles. To account for this, we performed subanalysis by knee flexion angle, and the statistical significance of variables did not change, nor did the relative magnitude of difference. The quality of the lateral knee radiograph may also affect the measurements, as the visual relationship between the trochlea and patella changes based on projection changes with rotational differences. We did not find this to be an issue in our study. Additional further research to define normal values for lever and moment arm ratios for a range of knee flexion angles could be considered, as we did not find a strong linear relationship between lever arm ratio and knee flexion angle (see Figure 6); therefore, we are unable to report normal and abnormal values for different ranges of knee flexion angle based on single patient images.

Altering the lever arm and moment arm ratios could be a treatment option for patellar tendinopathy. A distalizing tibial tubercle osteotomy alters the point of articulation of the patella on the femur by moving it proximally on the patella earlier in the knee flexion range. This change in the articulation point, pivot point, and fulcrum of the patella can manipulate the patellar tendon:quadriceps tendon force ratio and result in a decrease in the force through the patellar tendon and a relative increase of the force through the quadriceps tendon earlier in the knee range of motion—the range that is associated with running, jumping, and landing. Further biomechanical work is needed to quantify this effect and to ensure that patellofemoral articular forces are not substantially increased before implementation of any clinical intervention.

Intra- and interobserver reliability testing in the current study showed excellent retestability across all measurements. The use of computer software to accurately and consistently perform the measurements may have aided measurement reproducibility. We identified and marked the anatomic landmarks on the lateral radiographs, as described in the figures, from which the software performed the subsequent calculations for angle and ratio measurements. This removed the user error compounded by repeated measurements.

Patient age between groups was similar (see Table 2), but there was a statistically significant between-group difference in patient sex. We chose not to match for sex but instead included appropriate patients as presented by the computer algorithm, as described in the methods of our screening process, to minimize selection bias. The sex difference was analyzed and revealed significant differences that were similar in magnitude, which suggests that this analysis was not sex specific.

This study is limited, given the retrospective and nonrandomized nature, which means that we inevitably introduced issues pertaining to selection bias. We tried to minimize this by separating patient identification and grouping from the measurement phase of the study, which was done on deidentified data. Furthermore, repeatability measurements were performed independently of each investigator.

The present study is based on MRI reports and images, with no clinical diagnosis. Johnson et al[11] showed that imaging findings correlate poorly with symptoms between asymptomatic and symptomatic individuals. However, the current study examined only patients who presented for imaging for a clinical indication of "knee pain"; we excluded patients who demonstrated other MRI pathology, which could have confounded the clinical indication for MRI. Therefore, in the absence of other imaging findings, we deduce that the reason for the referral of the included individuals with only patellar tendinopathy on MRI was because of a clinical indication for this pathology; however, it is not certain that these patients were truly symptomatic.

CONCLUSION

This study investigated differences in extensor mechanism biomechanics between patients with patellar tendinopathy and control participants, which had not previously been reported with lateral radiographs. We identified relative differences in the patellar tendon to quadriceps tendon lever and moment arms. Based on measurements from lateral radiographs, the patellar tendon had smaller lever and moment arms among patients with patellar tendinopathy versus controls. We hypothesize that these lever and moment arm differences may result in a greater force through the patellar tendon of patients with patellar tendinopathy. Further biomechanical and clinical studies are needed to test the effect of increasing the patellar tendon lever or moment arm.

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