Clinical Imaging 54 (2019) 172–177

Contents lists available at ScienceDirect

Clinical Imaging

journal homepage: www.elsevier.com/locate/clinimag

Ultrasound elastography of the patellar tendon in young, asymptomatic sedentary and moderately active individuals

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ARTICLE INFO

Keywords:
Patellar tendon
Ultrasound elastography
Active
Sedentary

ABSTRACT

Background: The recent use of ultrasound elastography to study patellar tendon softness has demonstrated increased tendon softness in high-level athletes. We hypothesized that measurable alterations in patellar tendon softness may be present in young asymptomatic subjects engaging in moderate levels of physical activity.
Methods: This was a cross-sectional study. Gray-scale ultrasound and ultrasound elastography of the right and left patellar tendons were performed in young asymptomatic sedentary subjects and moderately active subjects who engaged in at least 30 min of physical activity 4–5 times weekly. The distribution of soft, intermediate and stiff tissue within each tendon was analyzed. Tendon softness was correlated with subject age, gender and level of athletic activity.
Results: Sixty patellar tendons in 30 subjects were evaluated (18 males, 12 females, mean age 22.5 years). Seventeen subjects were defined as “active” and 13 as “sedentary.” All tendons had a normal gray-scale sonographic appearance. Tendon softness was significantly higher in active subjects ($P = 0.01$) and decreased with age ($P = 0.04$). In sedentary individuals there was no significant correlation between age and tendon softness ($P = 0.404$). Similarly, gender showed no correlation with tendon softness ($P > 0.05$).
Conclusions: Patellar tendon softness is higher in young subjects and in those engaging in moderate physical activity. This may reflect an adaptation to increased tendon load. Tendon softness in active subjects decreases with age, while it remains at a constant value in sedentary individuals.

Level of evidence: Level 3.

1. Introduction

The patellar tendon, an essential component of the extensor mechanism of the knee, is an elastic tendon which is adaptable, elongates up to 7% with knee flexion [1,2], and contracts with quadriceps loading [3]. It is subjected to rapid acceleration-deceleration forces during jumping, landing and other movements. Following a jump, the patellar tendon may be exposed to forces up to seven times the subject's weight [4]. This occurs with forward and backward movement as well as horizontal landing activities [5]. As such, repetitive jumping and landing motions may predispose to patellar tendinopathy, a common cause of anterior knee pain in athletes, particularly volleyball and basketball players [6]. Increasingly, ultrasound elastography, in conjunction with gray scale ultrasound, has been used to evaluate tendons [7–12]. Ultrasound elastography is performed by applying a compressive force to a tissue and calculating its softness based on the degree of tissue deformation. The superficial location of the patellar tendon makes it amenable to ultrasound evaluation and allows for easy application of compressive forces and measurement of tendon softness.

Recently, ultrasound elastography has been used to study patellar tendon softness in asymptomatic subjects [2,7] and in athletes with anterior knee pain [13]. Variations in tendon softness have been reported in high-level athletes performing high intensity physical activity. However, the effect of moderate physical activity on tendon softness has not been studied. It is unknown if such changes in patellar tendon softness occur at lower levels of physical activity and if they reflect subclinical injury or an adaptive change that must be differentiated from true tendon pathology. This study was performed to determine the

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https://doi.org/10.1016/j.clinimag.2018.08.017
Received 26 June 2018; Received in revised form 19 August 2018; Accepted 24 August 2018

effects, if any, of moderate physical activity on patellar tendon softness, and to determine the range of appearances of the normal patellar tendon using ultrasound elastography in young asymptomatic individuals.

2. Materials and methods

The study was approved by the institutional review board, and informed consent was obtained.

2.1. Study population

Thirty subjects were enrolled (18 males, 12 females, mean age 22.5 years). Inclusion criteria included healthy individuals with no history of systemic disease, prior significant knee injury or prior knee surgery. Subjects with knee pain (acute or chronic) or who had engaged in rigorous physical activity on the day of the ultrasound examination were excluded from the study. Participants were defined as "active" (engaged in at least 30 min of physical activity 4–5 times per week) and "sedentary." Active adult participants reported participating in jogging, running or organized sports such as basketball and soccer, and were recruited from a local gym. Active pediatric participants were recruited from a local high school and were members of the school track and wrestling teams. Sedentary adult participants were volunteers presenting for outpatient ultrasound examinations for unrelated reasons, and sedentary pediatric participants were recruited from the pediatric orthopedic clinic where they were being seen for unrelated reasons. Seventeen subjects were defined as active (10 males, 7 females, mean age 26.1 ± 8.3 years, range 11–35 years) and 13 were defined as sedentary (8 males, 5 females, mean age 17.7 ± 9.4 years, range 6–30 years). Although mean age was significantly lower in the sedentary group (P = 0.02), age range was comparable. In the active cohort, 5 participants (3 females, 2 males) were ≤21 years old and 21 participants (4 females, 12 males) were > 21 years old. In the sedentary cohort, 8 participants (4 females, 4 males) were ≤21 years old and 5 participants (1 female, 4 males) were > 21 years old. Mean age was not statistically significant different between the ≤21 year old active and sedentary cohort (active 14.8 ± 3.9 years vs. sedentary 10.9 ± 3.6 years, P = 0.089) and the > 21 year active and sedentary cohort (active 30.8 ± 3.5 years vs. sedentary 28.6 ± 1.7 years, P = 0.200). Side of hand dominance was recorded for each participant.

2.2. Ultrasound technique

Gray-scale ultrasound and ultrasound elastography of both the left and right patellar tendons was performed using a Philips iU22 ultrasound system equipped with compression strain elastography (Philips Healthcare, Bothell, WA). Subjects were scanned with a linear 12–5 MHz transducer with the knee in 30 degrees of flexion [7]. A goniometer was used to verify appropriate knee flexion. The patellar tendon was imaged along its long axis in the midline, and angulation of the transducer was performed as needed to optimally visualize the echogenic tendon fibers and eliminate hypoechogenicity related to anisotropy. Strain elastography was performed at the proximal, mid and distal thirds of the tendon by applying light pressure through the transducer, and an elastogram was obtained, with color coding of tissue elasticity superimposed on the gray-scale sonographic image (Fig. 1). A compression feedback bar on the ultrasound display monitor ensured that appropriate compression force was applied while obtaining the elastogram. Three cine clips (each 3 s long) were obtained for each portion of the tendon. All examinations were performed by one radiologist with 3 years of musculoskeletal ultrasound experience. This radiologist was blinded to the level of the participant's activity.

2.3. Image analysis

The gray-scale sonographic appearance of the tendon was reviewed by two radiologists in consensus (one of whom had performed the ultrasound examinations), and was defined as normal if it displayed an echogenic, fibrillar appearance and abnormal if areas of tendon thickening, hypoechogenicity or disorganized internal architecture were observed. At the time of image review the radiologists were blinded to the demographic information, including age, gender and level of physical activity of the subject.

ImageJ, an open source image processing software package (http://imagej.nih.gov/ij/), was used to analyze the elastogram images. Using the color threshold function in ImageJ, the distribution of soft (red and yellow), intermediate (green) and stiff (blue) areas within each tendon was determined automatically by the software, and the percentage of each tissue type recorded. The entire tendon area visible in each image was evaluated as well as the proximal, middle and distal thirds of the patellar tendon.

The image analyst was blinded to the participants age and cohort affiliation. The patellar tendon was outlined in each RGB image, and images were then cropped, so that only the patellar tendon remained. Using the 'Color Threshold' function, images were segmented based on pixel values (http://imagej.net/docs/guide/146.html). The most suitable threshold settings were selected prior to analysis based on images of three different participants. These settings were held constant for all images and applied to all images during the analysis. The area of each specific tissue type, as well as of the entire tendon was measured using the 'analyze-limit to threshold' function. The percentage of the area covered by each specific tissue type was then calculated. Details of the analysis are provided in Fig. 1.

2.4. Statistical analysis

Age, gender, right/left hand dominance and level of physical activity were recorded. At our institution individuals 21 years of age and younger are referred to pediatrics, and thus this age cutoff was employed when analyzing data by age. Tendon softness was correlated with subject variables using the Student's *t*-test and Pearson correlation using Graph Pad Prism7 software (GraphPad Software, Inc., La Jolla, CA). P-value < 0.05 was defined as statistically significant.

3. Results

3.1. Patellar tendon gray-scale appearance

All tendons demonstrated a normal gray-scale appearance, with an echogenic fibrillar pattern, no focal thickening and no areas of hypoechogenicity.

3.2. Softness of the patellar tendon in active and sedentary patients (Figs. 2–4; Table 1)

Elastogram analysis demonstrated a significantly higher amount of soft tissue in the patellar tendons of active subjects when compared to sedentary subjects (Fig. 2A). Patellar tendons of active participants contained 51% ± 13% of soft tissue (red to yellow) vs. 39% ± 12% in sedentary participants (P = 0.01). 21% ± 8% of the patellar tendon was stiff (blue) in active participants vs. 29% ± 8% stiff tissue in sedentary participants (P = 0.01). Of the three patellar tendon areas evaluated (proximal, middle, distal), observed differences were mainly due to changes in the proximal aspect of the patellar tendon (Fig. 3).

When only participants ≤ 21 years were analyzed (5 active, 8 sedentary subjects), differences in patellar tendon softness were even more pronounced (Fig. 2B). While the patellar tendon of sedentary subjects had similar amounts of soft, intermediate and stiff tissue, approximately 2/3 of the patellar tendon tissue in active subjects was soft

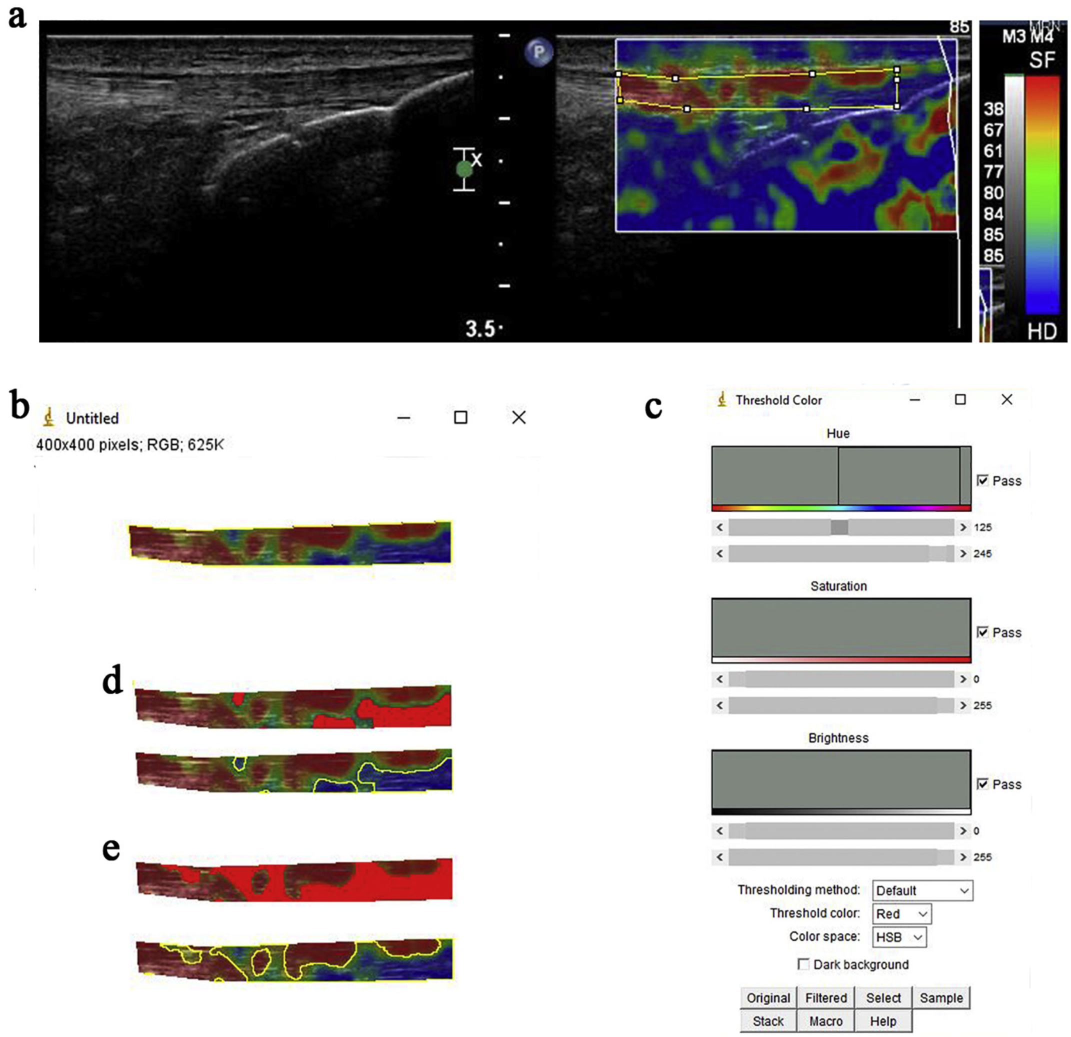

Fig. 1. Image analysis using ImageJ.
The patellar tendon was outlined in each RGB image (a), and images were then cropped, so that only the patellar tendon remained (b). Using the 'Color Threshold' function (c), images were segmented based on pixel values. No threshold was selected for 'Saturation' and 'Brightness' for all images. The threshold setting for "Hue" to detect the "blue/stiff" tissue (d) and "red/soft" tissue (e) was selected prior to analysis based on images of three different participant. For this, the sensitivity of the threshold function was manually adapted using the 'Hue' scroll bar until the red/soft or blue/stiff area were highlighted (d & e, in red) and selected (d & e, yellow outline). The same threshold settings were applied to all images during the analysis. The area covered by each tissue type was measured using the 'analyze-limit to threshold' function. In addition, the area of the entire patellar tendon (b) was measured. The percentage of area covered by each specific tissue type was then calculated. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(soft: 62% ± 10% in active vs. 36% ± 10% in sedentary, P = 0.01). Representative ultrasound elastography images of the patellar tendon of active and sedentary subjects are shown in Fig. 4.

3.3. *Age and patellar tendon softness (Fig. 5; Table 2)*

In active subjects, age significantly correlated with patellar tendon softness. A moderate negative correlation with increasing age in active individuals suggested an age-related decline in patellar tendon softness (r = −0.494, P = 0.04). In sedentary subjects, there was no correlation between age and tendon softness. When active subjects < 21-years old were compared to active subjects over 21-years old, the amount of soft and intermediate tissue was significantly higher in younger subjects (soft: 62.1% ± 10% in subjects ≤ 21-years vs. 47% ± 11% in

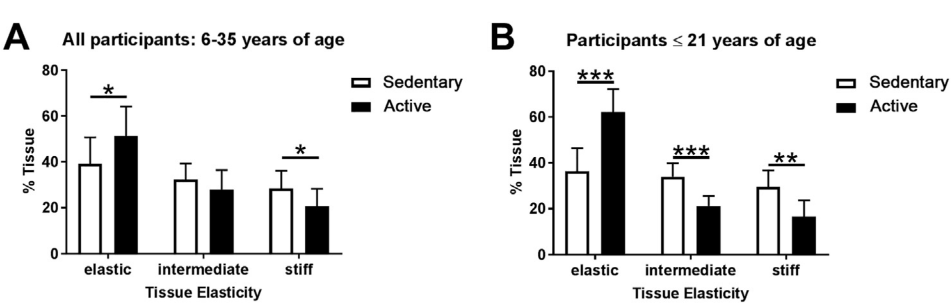

Fig. 2. Softness of the patellar tendon in active and sedentary subjects.
A. In active subjects, the amount of soft tissue was significantly higher and the amount of stiff tissue significantly lower than in sedentary individuals. B. In subjects ≤ 21 years, the amount of soft tissue in the patellar tendon was twice as high in the active group. The amount of intermediate and stiff tissue in the patellar tendon of young active subjects is significantly lower. (***P ≤ 0.01, **P ≤ 0.01, *P ≤ 0.05.)

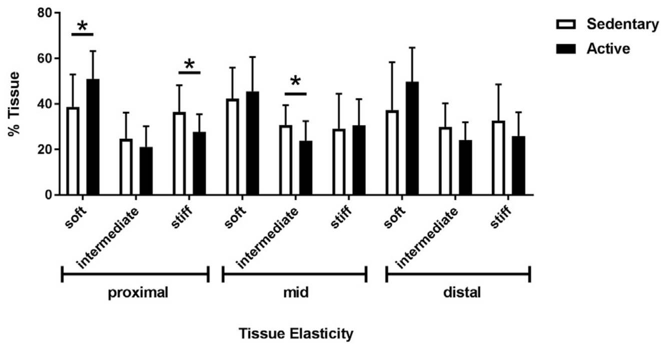

Fig. 3. Softness of patellar tendon areas in active and sedentary subjects.
In active subjects the proximal part of the patellar tendon had a significantly higher amount of soft tissue and a significantly lower amount of stiff tissue compared to sedentary individuals. In the middle part of the tendon, active subjects had a significantly lower amount of intermediate tissue compared to sedentary individuals. (*$P \leq 0.05$.)

subjects > 21-years, P = 0.02; intermediate: 21.2% ± 4.3% in subjects ≤ 21-years vs. 30.8% ± 8.3% in subjects > 21-years, P = 0.03).

3.4. Gender, right/left hand dominance and patellar tendon softness (Tables 3–4)

No significant differences in patellar tendon softness were identified based on gender or side of hand dominance.

4. Discussion

This study assessed the effect of moderate exercise on measurable patellar tendon softness. Although all subjects were asymptomatic with normal gray scale ultrasound findings, physically active subjects demonstrated significantly softer patellar tendons than sedentary subjects. The difference in tendon softness between these two groups was greatest in subjects under the age of 21 years.

Previous work has demonstrated changes in tendon size and mechanical properties as a result of exercise [14]. Heavy resistance training has been reported to result in both tendon hypertrophy and an increase in the proximal patellar tendon cross sectional area [15–17]. Histological examinations have confirmed a transient increase in

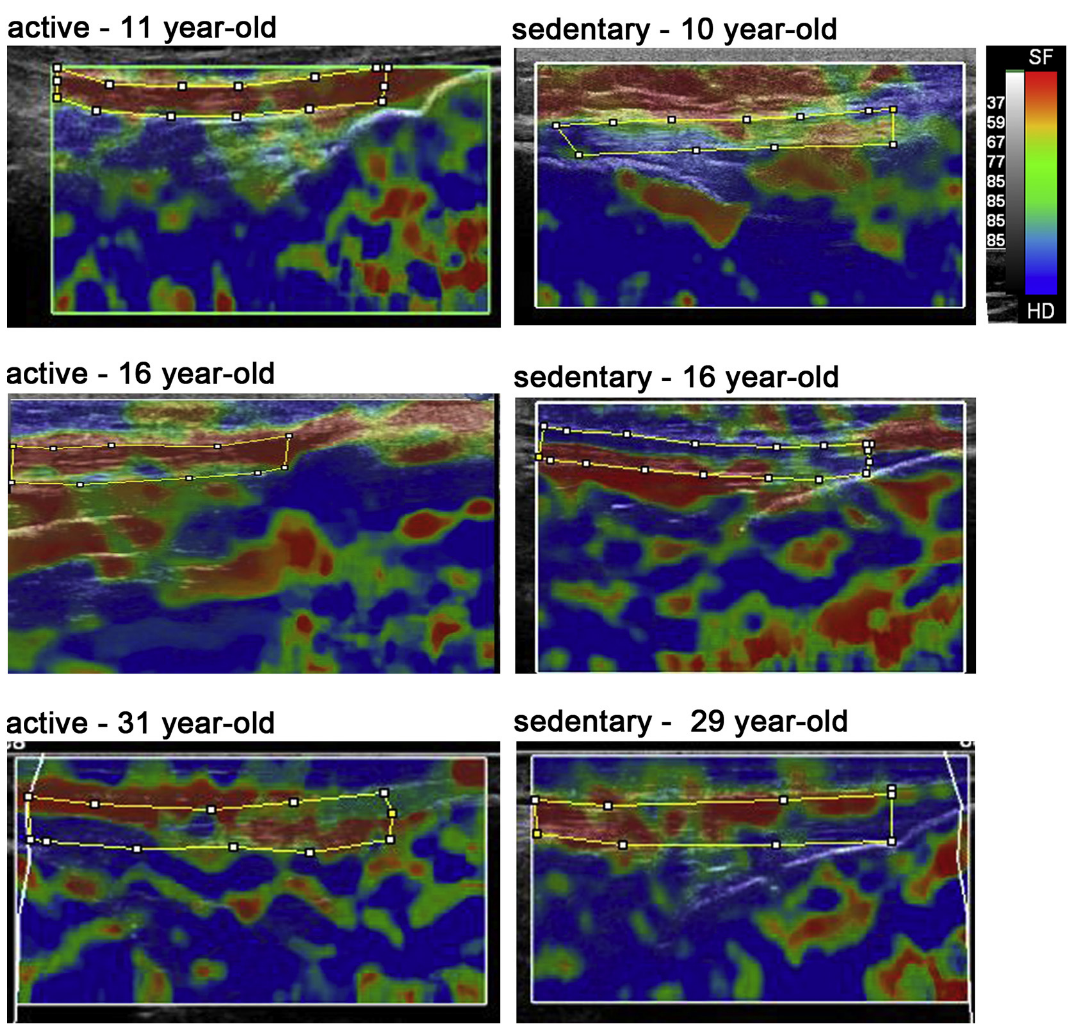

Fig. 4. Ultrasound elastography of the patellar tendon.
Representative ultrasound elastography images of active (left column) and sedentary subjects (right column). The patellar tendon is outlined (yellow line). Note, higher content of soft (red) tissue in the patellar tendon of active subjects. The amount of soft and stiff tissue for each image shown is: active 11 year-old, soft 91.8%, stiff 1.2%; sedentary 10 year-old, soft 19.4%, stiff 41.9%; active 16 year-old soft 66.4%, stiff 10%, sedentary 16 year-old soft 34.7%, stiff 37.5%; active 31 year-old soft 39.1%, stiff 30.4%; sedentary 29 year-old, soft 38.6%, stiff 33.4%, %, (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Patellar tendon softness.

% tissue area	All subjects			Subjects ≤ 21 years		
	Active	Sedentary	P-value	Active	Sedentary	P-value
Soft	51.3 ± 13%	39.2 ± 12%	0.01	62.1 ± 10%	36.4 ± 10%	0.01
Intermediate	28.0 ± 8.5%	32.3 ± 6.9%	0.15	21.2 ± 4.3%	34.0 ± 5.9%	0.01
Stiff	20.7 ± 7.5%	28.5 ± 7.7%	0.01	16.7 ± 7.0%	29.6 ± 7.2%	0.01

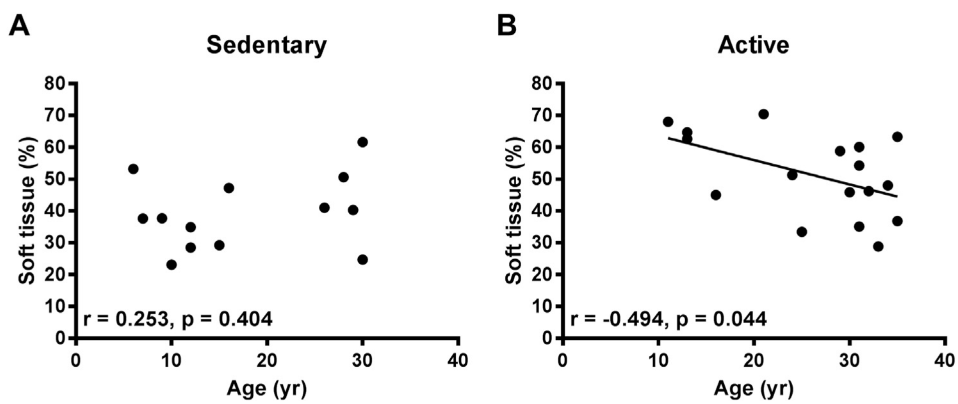

Fig. 5. Relationship between age and tendon softness.
A. Age does not correlate significantly with the amount of soft tissue in the patellar tendon in sedentary subjects. B. In active subjects, a moderate negative correlation between age and amount of soft tissue in the patellar tendon exists ($r = -0.494$, $P = 0.04$).

Table 2
Effect of age on patellar tendon softness.

% tissue area	Active			Sedentary		
	≤21 years	> 21 years	P-value	≤21 years	> 21 years	P-value
Soft	62.1 ± 10%	46.8 ± 11%	0.02	36.4 ± 10%	43.6 ± 14%	0.40
Intermediate	21.2 ± 4.3%	30.8 ± 8.3%	0.03	34.0 ± 5.9%	29.7 ± 8.3%	0.30
Stiff	16.7 ± 7.0%	22.4 ± 7.4%	0.16	29.6 ± 7.2%	26.7 ± 9.0%	0.54

Table 3
Effect of gender on patellar tendon softness.

% tissue area	Active			Sedentary		
	Female	Male	P-value	Female	Male	P-value
Soft	57.2 ± 7.6%	47.2 ± 15%	0.12	39.6 ± 15%	38.9 ± 10%	0.92
Intermediate	24.4 ± 3.9%	30.5 ± 10%	0.15	33.9 ± 8.5%	31.3 ± 6.2%	0.54
Stiff	18.5 ± 6.2%	22.2 ± 8.3%	0.33	26.5 ± 6.9%	29.7 ± 8.3%	0.49

Table 4
Effect of laterality on patellar tendon softness.

% tissue area	Active			Sedentary		
	Right leg	Left leg	P-value	Right leg	Left leg	P-value
Soft	49.1 ± 15%	54.5 ± 16%	0.32	40.3 ± 16%	38.0 ± 14%	0.70
Intermediate	27.5 ± 9.1%	28.2 ± 12%	0.83	31.5 ± 7.6%	33.5 ± 8.8%	0.54
Stiff	23.4 ± 9.6%	17.3 ± 9.7%	0.07	28.2 ± 12%	28.5 ± 9.4%	0.95

tendinous collagen deposition after exercise [18]. Our results demonstrating increased patellar tendon softness in active subjects compared to sedentary subjects may reflect a mechanical alteration in the tendon due to an adaptation to added tendon forces. This study may therefore provide further evidence that the mechanical properties of tendons may be affected by physical activity, and that these adaptive changes in the tendon are measurable and may occur even with moderate levels of physical activity. The majority of differences in tendon softness were observed in the proximal patellar tendon, likely due to increased forces in this portion of the tendon with jumping and landing activities compared to other parts of the tendon, corresponding with previously seen regional differences in the patellar tendon [18–20].

Previous publications have demonstrated age-related changes in patellar tendon softness. Our data also suggests that there is a decline in patellar tendon softness with increasing age in active but not sedentary subjects. Hsiao et al. assessed the shear-wave patellar tendon elasticity in healthy volunteers in three age groups (20–30 years, 40–50 years and 60–70 years), and reported a decrease in tendon softness with increasing age [21]. O'Brien et al. similarly found a significantly lower softness of the patellar tendon in adults compared to 8–10 year-olds using ultrasound imaging with dynamometry [22]. While these studies demonstrated changes in tendon softness over relatively large differences in age, our results indicate that such changes in elasticity may occur over much smaller age ranges, particularly in active individuals. These results must be interpreted with caution given the single time point of data acquisition. Also, it is possible that the presence of open physes in children may alter the biomechanics across the patellar tendon and thereby lead to changes in patellar tendon softness.

There are conflicting reports in the literature on the effect of gender on patellar tendon elasticity. While increased patellar tendon softness was reported in females compared to males in sedentary 18–44 year olds [23], other published reports have shown no gender differences in the patellar tendon softness regardless of age or level of physical activity [1,22,24]. This study demonstrated no gender difference in patellar tendon softness.

Limitations of this study include its small sample size, a difference in mean age between the two cohorts and a range in the type of athletic activity among the active subjects in our cohort. Since it is unclear how quickly changes in tendon softness develop, a further limitation is that tendon softness was only evaluated at a single time-point in our study group. Furthermore, information as to the length of time each of the active subjects had been engaged in their exercise regimens was not obtained; active participants engaging in moderate activity for significant time period were grouped with active participants who potentially had been engaging in moderate activity for a much shorter time period. Body mass index (BMI) was not collected for our subjects, and therefore we are unable to determine if there is a relationship between tendon softness and BMI.

5. Conclusions

In summary, patellar tendon softness is higher in adolescents and young adults engaging in moderate increased physical activity than sedentary subjects. These findings suggest that adaptive changes in the tendon may occur at a relatively young age and with moderate levels of physical activity.

Declaration of interest

None.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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