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Version of Record at: https://doi.org/10.1002/jor.25563

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Challenging the Assumption of Uniformity in Patellar Tendon Structure: Regional Patellar Tendon Morphology and Mechanical Properties In Vivo

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Running Title: Patellar tendon structure is non-uniform

Word count: 2102

Author Contributions: NI contributed to funding acquisition, research design, data acquisition, analysis, interpretation, drafting the manuscript, and incorporating revisions. RSS contributed to data analysis, interpretation, drafting the manuscript, and critical review. HBS contributed to research design, data acquisition, analysis, interpretation, and critical review. DHS contributed to research design, data analysis, interpretation, and critical review. KGS contributed to funding acquisition, research design, data interpretation, supervision, and critical review. All authors read and approved the final version prior to submission.

ABSTRACT

Patellar tendons are assumed to be uniform in morphology and mechanical properties despite a higher prevalence of tendinopathies observed in the medial region. The purpose of this study was to compare the thickness, length, viscosity, and shear modulus of the medial, central, and lateral regions of healthy patellar tendons of young males and females in vivo. B-mode ultrasound and continuous shear wave elastography were performed on 35 patellar tendons (17 females, 18 males) over three regions of interest. A linear mixed-effects model ($\alpha = 0.05$) was used to determine differences between the three regions and sexes followed by pairwise comparisons for significant findings. The lateral region (mean (95% CI) = 0.34 (0.31-0.37) cm) was thinner compared to the medial (0.41 (0.39-0.44) cm, $p < 0.001$), and central (0.41 (0.39-0.44) cm, $p < 0.001$) regions regardless of sex. Viscosity was lower in the lateral (19.8 (16.9-22.7) Pa-s) versus medial region (27.4 (24.7-30.2) Pa-s, $p = 0.001$). Length had a region-by-sex interaction ($p = 0.003$) characterized by a longer lateral (4.83 (4.54-5.13) cm) versus medial (4.42 (4.12-4.72) cm) region in males ($p < 0.001$), but not females ($p = 0.992$). Shear modulus was uniform between regions and sexes. The thinner, and less viscous lateral patellar tendon may reflect the lower load the tendon experiences explaining the differences in regional prevalence of developing tendon pathology. ***Statement of Clinical Significance:*** Healthy patellar tendons are not uniform in morphology or mechanical properties. Considering regional tendon properties may help guide targeted interventions for patellar tendon pathologies.

Keywords: ultrasound, elastography, musculoskeletal modeling, tendinopathy, anterior cruciate ligament

INTRODUCTION

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The patellar tendon is a common source of pain in young active individuals.[1,2] The central third of the patellar tendon is also commonly used as an autograft for anterior cruciate ligament reconstruction (ACLR)[3] especially among athletes.[4] After this surgery there is also a high rate of pain in the region of the patellar tendon.[5] Although different regions of the patellar tendon have been shown to be more prone to developing pathology,[6,7] it remains unknown whether there are structural differences between the different tendon regions which might increase susceptibility to certain pathologies.

The patellar tendon is typically considered a uniform unit in biomechanical models[8] based on the assumption that all its regions have identical morphology and mechanical properties. This belief originates from work by Noyes et al[9] that observed in vitro maximum failure load of the medial, central, and lateral thirds of the patellar tendon to be similar. Conversely, a more recent in vitro study showed that the 3 regions of the patellar tendon have different lengths, maximum failure loads, maximum stresses, strains, and linear stiffnesses.[10] This supports the possibility that the medial, central, and lateral regions of the patellar tendon may have distinct morphology (i.e., thickness, length) and mechanical properties (i.e., viscosity, shear modulus).

In vivo measurements of tendon morphology can be obtained using B-mode ultrasound imaging, and mechanical properties of tendons can be measured using continuous shear wave elastography.[11,12] Measurements of patellar tendon shear modulus and viscosity using continuous shear wave elastography have high intra-rater reliability.[13] Tendon morphology and mechanical properties are associated with symptom severity[14] as well as with function (i.e., jump performance) in patients with tendinopathy.[12,14] Prevalence of patellar tendinopathy is also highest in the medial third of the tendon,[6,7]

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and the central third of the patellar tendon is harvested for bone-patellar tendon-bone autografts in ACLR. Assessing in vivo patellar tendon morphology and mechanical properties from the three distinct regions (medial, central, and lateral) may provide a more thorough foundation of knowledge to identify patellar tendon pathology.

A recent study suggested that young males may have different mechanical properties in the patellar tendon assessed by shear wave elastography when compared to young females.[15] To our knowledge, however, no study has evaluated the in vivo morphology and mechanical properties of the patellar tendon segmented mediolaterally into 3 regions in young males and females. The purpose of this study was to compare the thickness, length, viscosity, and shear modulus of the medial, central, and lateral regions of healthy patellar tendons of young males and females in vivo.

METHODS

Participants:

This study is a cross-sectional cohort study (Level 3). Thirty-five patellar tendons (18 right knees, 17 left knees) from healthy adults (17 female | 18 male, age: 24.3±6.3years, height: 172.7±8.9cm, body mass: 74.7±13.4kg) with no current symptoms or history of knee surgery were analyzed. Participants signed written informed consent, and the study was approved by the Institutional Review Board at the University of Delaware.

Morphology:

Participants were positioned supine with their knees supported in approximately 30 degrees of flexion by a foam roller.[16,17] Morphological measures were taken over 3 regions of interest within the patellar tendon: medial, lateral, and central regions (**Figure**

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1). The 3 regions were determined using palpation along the medial and lateral borders of the tendon on either side, and the most distal prominence of the patella, and most proximal prominence of the tibia to identify the central region. Patellar tendon thickness and length were collected over the regions of interest using B-mode ultrasound (GE Healthcare, Logiq *e*, Frequency: 10MHz, Depth: 2~3 cm).[12] Length measures were collected using extended field of view mode and established as the linear distance between the deep attachment site of the patellar tendon against the tibia (on the distal end) and the patella (on the proximal end) (**Figure 2**). Thickness measures were taken 1cm distal to the patellar attachment on a static ultrasound image as this is a common location for patellar tendinopathy.[18] All reported measures are a mean of 3 trials. In separate cohorts of participants tested in our lab, segmental morphology of thickness and length measures demonstrated excellent inter-rater [intraclass correlation coefficient (ICC)=0.959–0.996)] (**Supplemental Table 1**) and intra-rater reliability (ICC=0.872–0.991) (**Supplemental Table 2**). For the purpose of this study, all morphological measurements were taken by a single experienced rater.

Mechanical properties:

Continuous shear wave elastography (cSWE) was used to assess viscosity (Pa-s), the rate dependent measure of the tendon's ability of resist shear stress, and shear modulus (kPa), the non-rate dependent tendon's ability to resist shear stress.[11] Voigt's model for viscoelasticity was used to calculate these variables.[11] Although the Voigt model has been traditionally used for isotropic materials, a previous study demonstrated that shear modulus and viscosity from our analysis are proportional to the Young's modulus of the tendon. The measures were taken over the same 3 regions of interest

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described above. Participants were positioned seated with their knees and hips at 90 degrees of flexion, and their feet secured in a custom boot as described in our previous work.[13] The 3 regions of interest were marked with guidance of B-mode ultrasound. Shear waves were propagated from the quadriceps tendon using an external actuator, and shear wave speeds were captured at the patellar tendon using high framerate ultrasound. Given the poor inter-rater reliability (ICC=0.532–0.591) compared to intra-rater reliability (ICC=0.805–0.905) reported in our previous work,[13] a single experienced rater performed all assessments.

Statistics:

Linear mixed-effects model ($\alpha = 0.05$) with unstructured covariance matrix were used to determine the differences in tendon thickness, length, viscosity, and shear modulus over the 3 regions of interest and between sexes. Each participant was included in the model as a random effect, and the fixed effects of region (medial, lateral, central), sex, and the interaction between region and sex were assessed. For viscosity and shear modulus, the model was also adjusted for tendon thickness, as tissue thickness is known to influence shear wave propagation.[19] Pairwise comparisons were performed for significant findings. Statistics were performed in R[20] (Package: lme4).[21,22]

RESULTS

Morphology (Thickness and Length):

There was a main effect of region characterized by a smaller thickness in the lateral region compared to the medial ($p < 0.001$), and central ($p < 0.001$) regions

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regardless of sex (**Table 1**). No differences were observed between the medial and central region ($p = 0.978$). No main effect of sex or interaction effects were observed (**Table 2**).

A region-by-sex interaction effect was observed for tendon length measures. In males, tendon length was longer in the lateral region compared to both the medial ($p < 0.001$) and central ($p < 0.001$) regions. No differences were seen between the medial and central regions ($p = 0.271$). In females, there were no differences in length between the lateral and medial ($p = 0.992$) regions, but both lateral ($p = 0.003$) and medial ($p < 0.001$) regions were longer compared to the central region. Main effects of region ($p < 0.001$) were observed but there were no main effects of sex ($p = 0.232$) (**Table 1**).

Mechanical properties (Viscosity and Shear modulus):

After adjustments for thickness, a main effect of region ($p = 0.001$) was observed for viscosity. The lateral region had significantly lower viscosity compared to the medial region ($p = 0.001$), but not the central region ($p = 0.246$). The differences between the medial and central region were also not significant ($p = 0.054$). No main effect of sex or interaction effects were observed (**Table 1**). No significant main or interaction effects were observed for shear modulus (**Table 1**).

DISCUSSION

The purpose of this study was to compare the thickness, length, viscosity, and shear modulus of the medial, central, and lateral regions of healthy patellar tendons of young males and females in vivo. The lateral third of the healthy patellar tendon was found to be thinner than the other regions of the tendon, and had lower viscosity compared to the medial region, regardless of sex. These finding may in part explain underlying etiology in tendon injuries, as specific areas of the patellar tendon, such as the

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medial third in patellar tendinopathy[6,7] and the central third after bone-patellar tendon-bone autograft harvest for ACLR,[23] are common sites of pathology.

A possibly unbalanced force distribution between different regions of the patellar tendon was first suggested by Toumi et al.[24] In a cadaveric study, the authors found a significantly smaller number of trabeculae orientated superior/inferiorly in the lateral region of the distal patella in comparison to the medial and central regions.[24] This suggested that the force transmission and mechanical stress in the distal region of the patella are asymmetrically distributed, since force transmission through cancellous bone results in a modification of its architecture.[24] The authors hypothesized that these asymmetrical lines of force transmission may have an important bearing on the regional vulnerability of the medial region of the patellar tendon to tendinopathy.[24] This may also help to explain why the lateral region appears to be relatively protected from developing patellar tendinopathy.[6] Our results of smaller thickness and lower viscosity in the lateral region of the patellar tendon are consistent with the above findings, as stiffer, and thicker tendon are expected in areas of higher load. These findings provide in vivo evidence supporting the theory that asymmetrical force transmission exist among different regions of the patellar tendon.

These results may also explain why patellar tendinopathy is common after ACLR using bone-patellar tendon-bone autografts.[5] Given that our findings suggest that the two remaining thirds of the tendon (medial and lateral) are not uniform in structure, the unbalanced loads after removal of the central third may cause excessive load to be placed in the medial part of the tendon. A potential explanation for the smaller thickness and lower viscosity in the lateral region of the patellar tendon compared to the medial region may be the anatomical distal insertion of the vastii. Specifically, the oblique fibers of the vastus medialis attach to the medial border of the patella, directly pulling the bone, while the vastus lateralis is mainly inserted into the lateral retinaculum rather than directly into the patella.[24] The lack of a direct attachment of the vastus lateralis into the patella may decrease the force transmission through the lateral region of the patellar tendon.

Interestingly, regional differences were observed in viscosity (tendon's ability to resist strain at different loading rates), but shear modulus was uniform throughout the tendon. It is possible that since the patellar tendon behaves as an energy-storage tendon with special competency during high-velocity activities,[25] viscosity may be a more relevant variable than shear modulus for the patellar tendon. Supporting this assumption, a recent study found that patellar tendon viscosity was significantly associated with jumping performance, while shear modulus was not.[12]

Males had longer lengths in the lateral region of their patellar tendon compared to the medial and central regions, while females did not. This was expected, considering that females have a static knee position with larger knee abduction angle compared to males.[26] Similar results were observed by Yanke et al[10] that found that the lateral region of the patellar tendon is longer than the medial and central regions in a study with male cadavers. This finding may in part explain the differences in prevalence of patellar tendinopathy between sexes.[27] Additionally, there may be differences in the region most susceptible to developing patellar tendinopathy by sex, as load distribution may vary based on the length of the tendon. Studying the prevalence of patellar tendinopathy by sex may have to be specific to the region of the tendon. Rehabilitation and preventative interventions may also have to be tailored based on patient sex or location of symptoms within the patellar tendon.

Limitations of the present study is that only young healthy individuals were evaluated, therefore, the generalization of these results to other populations should be made with caution. We also did not have a measure of baseline activity level of this cohort. This baseline data from healthy individuals, however, provides a comparison point for future analysis in other demographics and pathological tendons. The relatively small sample size may have also prevented us from detecting regional differences in tendon shear modulus, as shear modulus has been shown to have greater minimum detectable change threshold compared to viscosity.[13] It must also be noted that while the reliability of cSWE is known,[13] the validity of the measure has yet to be described in literature. Future studies will investigate whether the non-uniform structure of the patellar tendon also exist in individuals with patellar tendon pathologies such as patellar tendinopathy and after bone-patellar tendon-bone autograft harvest for ACLR.

CONCLUSION

Our results challenge the current belief that the patellar tendon behaves as a uniform unit, as thickness and viscosity were non-uniform across the patellar tendon. The locations of high prevalence in tendon pathology may be attributed to force distributions biasing specific regions of the tendon. Considering regional tendon properties may help guide targeted interventions to address patellar tendon pathology.

Acknowledge

Funding was provided by the National Institute of Health (NIH), including the National Institute of Arthritis and Musculoskeletal and Skin Diseases, Eunice Kennedy

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Shriver National Institute of Child Health and Human Development: R37-HD037985, R01-AR072034. The project described was also supported by the American Academy of Sports Physical Therapy Legacy Fund. The content is solely the responsibility of the authors and does not represent the official views of the American Academy of Sports Physical Therapy. NI's work was supported in part by the Rheumatology Research Foundation.

Disclosures: No competing financial interests exist for any of the authors

References

1. Cassel M, Risch L, Intziegianni K, et al. Incidence of Achilles and patellar tendinopathy in adolescent elite athletes. *Int J Sports Med*. 2018;39(09):726-732. doi:10.1055/a-0633-9098
2. Chia L, Silva DDO, Whalan M, et al. Epidemiology of gradual-onset knee injuries in team ball-sports: A systematic review with meta-analysis of prevalence, incidence, and burden by sex, sport, age, and participation level. *J Sci Med Sport*. 2022;25(10):834-844. doi:10.1016/j.jsams.2022.08.016
3. Tibor L, Chan PH, Funahashi TT, Wyatt R, Maletis GB, Inacio MCS. Surgical technique trends in primary ACL reconstruction from 2007 to 2014. *J Bone Joint Surg Am*. 2016;98(13):1079-1089. doi:10.2106/JBJS.15.00881
4. Sanders TL, Maradit Kremers H, Bryan AJ, et al. Incidence of anterior cruciate ligament tears and reconstruction. *Am J Sports Med*. 2016;44(6):1502-1507. doi:10.1177/0363546516629944
5. Hardy A, Casabianca L, Andrieu K, Baverel L, Noailles T. Complications following harvesting of patellar tendon or hamstring tendon grafts for anterior cruciate ligament reconstruction: Systematic review of literature. *Orthop Traumatol Surg Res*. 2017;103(8):S245-S248. doi:10.1016/j.otsr.2017.09.002
6. McLoughlin RF, Raber EL, Vellet AD, Wiley JP, Bray RC. Patellar tendinitis: MR imaging features, with suggested pathogenesis and proposed classification. *Radiology*. 1995;197(3):843-848. doi:10.1148/radiology.197.3.7480766
7. Yu JS, Popp JE, Kaeding CC, Lucas J. Correlation of MR imaging and pathologic findings in athletes undergoing surgery for chronic patellar tendinitis. *AJR Am J Roentgenol*. 1995;165(1):115-118. doi:10.2214/ajr.165.1.7785569

8. Escriche-Escuder A, Cuesta-Vargas AI, Casaña J. Modelling and in vivo evaluation of tendon forces and strain in dynamic rehabilitation exercises: a scoping review. *BMJ Open*. 2022;12(7):e057605. doi:10.1136/bmjopen-2021-057605

9. Noyes FR, Butler DL, Grood ES, Zernicke RF, Hefzy MS. Biomechanical analysis of human ligament grafts used in knee-ligament repairs and reconstructions. *J Bone Joint Surg Am*. 1984;66(3):344-352.

10. Yanke A, Bell R, Lee A, Shewman EF, Wang V, Bach BR. Regional mechanical properties of human patellar tendon allografts. *Knee Surg Sports Traumatol Arthrosc*. 2015;23(4):961-967. doi:10.1007/s00167-013-2768-5

11. Cortes DH, Suydam SM, Silbernagel KG, Buchanan TS, Elliott DM. Continuous Shear Wave Elastography: A New Method to Measure Viscoelastic Properties of Tendons in Vivo. *Ultrasound Med Biol*. 2015;41(6):1518-1529. doi:10.1016/j.ultrasmedbio.2015.02.001

12. Sprague AL, Couppé C, Pohlig RT, Cortes DC, Silbernagel KG. Relationships between tendon structure and clinical impairments in patients with patellar tendinopathy. *J Orthop Res*. 2022;40(10):2320-2329. doi:10.1002/jor.25262

13. Ito N, Sigurðsson HB, Pohlig RT, Cortes DH, Silbernagel KG, Sprague AL. Reliability of continuous shear wave elastography in the pathological patellar tendon. *J Ultrasound Med*. 2022; in press.

14. Corrigan P, Cortes DH, Pohlig RT, Grävare Silbernagel K. Tendon morphology and mechanical properties are associated with the recovery of symptoms and function in patients with Achilles tendinopathy. *Orthop J Sports Med*. 2020;8(4):232596712091727. doi:10.1177/2325967120917271

15. Götschi T, Hanimann J, Schulz N, et al. Patellar tendon shear wave velocity is higher and has different regional patterns in elite competitive alpine skiers than in healthy controls. *Front Bioeng Biotechnol*. 2022;10:858610. doi:10.3389/fbioe.2022.858610

16. Friedman L, Finlay K, Jurriaans E. Ultrasound of the knee. *Skeletal Radiol*. 2001;30(7):361-377. doi:10.1007/s002560100380

17. Beggs I, Bianchi S, Bueno A, et al. Musculoskeletal ultrasound: Technical guidelines. *Insights Imaging*. 2010;1(3):99-141. doi:10.1007/s13244-010-0032-9

18. Hoksrud A, Ohberg L, Alfredson H, Bahr R. Color Doppler ultrasound findings in patellar tendinopathy (jumper's knee). *Am J Sports Med*. 2008;36(9):1813-1820. doi:10.1177/0363546508319897

19. DeWall RJ, Slane LC, Lee KS, Thelen DG. Spatial variations in Achilles tendon shear wave speed. *J Biomech*. 2014;47(11):2685-2692. doi:10.1016/j.jbiomech.2014.05.008

20. Teams RDC. A language and environment for statistical computing. *R Foundation for Statistical Computing*. Published online 2009.

21. Bates D, Mächler M, Bolker B, Walker S. Fitting linear mixed-effects models using lme4. Published online June 23, 2014.

22. Kuznetsova A, Brockhoff PB, Christensen RHB. lmerTest package: Tests in linear mixed effects models. *J Stat Softw*. 2017;82(13). doi:10.18637/jss.v082.i13

23. Rubinstein RA, Shelbourne KD, VanMeter CD, McCarroll JC, Rettig AC. Isolated autogenous bone-patellar tendon-bone graft site morbidity. *Am J Sports Med*. 1994;22(3):324-327. doi:10.1177/036354659402200305

24. Toumi H, Higashiyama I, Suzuki D, et al. Regional variations in human patellar trabecular architecture and the structure of the proximal patellar tendon enthesis. *J Anat*. 2006;208(1):47-57. doi:10.1111/j.1469-7580.2006.00501.x

25. Thorpe CT, Riley GP, Birch HL, Clegg PD, Screen HRC. Fascicles and the interfascicular matrix show adaptation for fatigue resistance in energy storing tendons. *Acta Biomater*. 2016;42:308-315. doi:10.1016/j.actbio.2016.06.012

26. Wu C, Yeow K, Yeow Y. Imaging approaches for accurate determination of the quadriceps angle. *Orthop Surg*. 2020;12(4):1270-1276. doi:10.1111/os.12708

27. 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(5):607-613. doi:10.1111/j.1600-0838.2011.01430.x

Figure Legends

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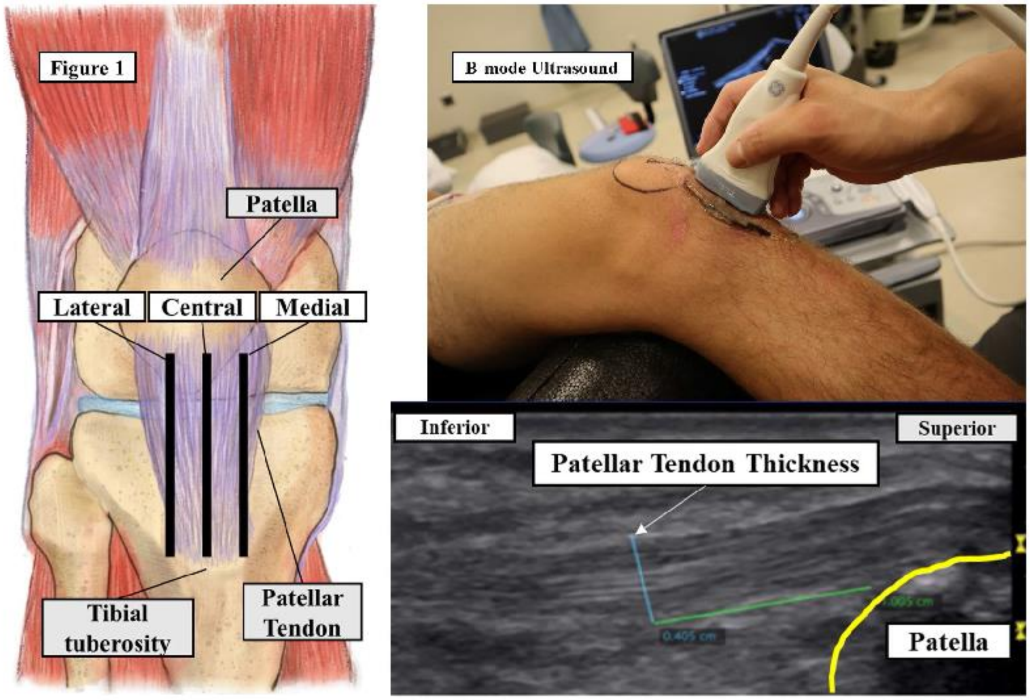

Figure 1.

Left: Depictions of the three regions of interest (medial, lateral, central). Top right: B-mode ultrasound imaging of the knee at 30degrees of knee flexion. Bottom right: Example measurement of tendon thickness 1cm distal from the patellar attachment.

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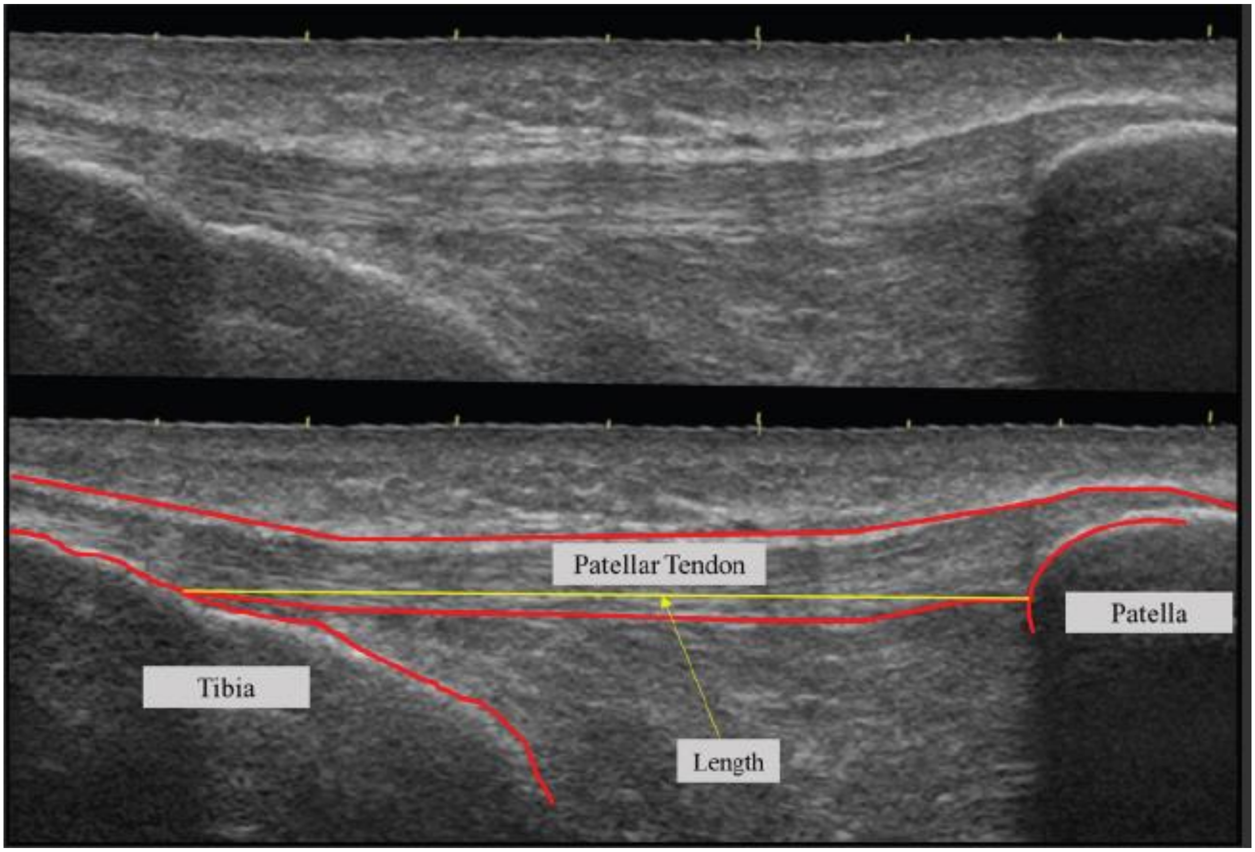

Figure 2.

Top: Extended field of view ultrasound image of the patellar tendon. Bottom: Labeled image of the patellar tendon with example length measurement from the deep bony attachment sites at the tibial tuberosity and patella.

Table 1. Patellar tendon morphology and mechanical properties by region

Variables	Medial			Central			Lateral			p-value			
	Mean	95% CI		Mean	95% CI		Mean	95% CI		Interaction effect	Main effect		
		Lower	Upper		Lower	Upper		Lower	Upper	Region × Sex	Region	Sex	Thickness
Thickness (cm)	0.414	0.388	0.439	0.411	0.386	0.437	0.340	0.314	0.365	0.181	< 0.001*	0.589	-
Lengt	4.4	4.2	4.6	4.1	3.9	4.3	4.6	4.3	4.8	0.003*	<	0.2	-

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h (cm)	2	1	3	1	0	2	0	9	1		0.001*	32	
Viscosity (Pa-s)	27.4	24.7	30.2	23.1	20.3	25.8	19.8	16.9	22.7	0.863	0.001*	0.150	0.941
Shear Modulus (kPa)	66.1	57.8	74.5	67.2	58.9	75.5	57.4	48.5	66.2	0.860	0.216	0.140	0.253

*Note: Means for viscosity and shear modulus are adjusted for thickness. CI = confidence interval, cm = centimeters, Pa-s = pascal-seconds, kPa = kilopascals, * = statistical significance*

Table 2. Patellar tendon morphology and mechanical properties by region and sex

Variables	Sex	Medial			Central			Lateral		
		Mean	95% CI		Mean	95% CI		Mean	95% CI	
			Lower	Upper		Lower	Upper		Lower	Upper
Thickness (cm)	Male	0.409	0.373	0.444	0.421	0.385	0.457	0.353	0.317	0.389
	Female	0.418	0.383	0.454	0.402	0.366	0.438	0.326	0.290	0.362
Length (cm)	Male	4.42	4.12	4.72	4.23	3.93	4.52	4.83	4.54	5.13
	Female	4.41	4.11	4.71	4.00	3.70	4.30	4.36	4.06	4.66
Viscosity (Pa-s)	Male	28.1	24.2	32.1	24.4	20.4	28.4	21.5	17.5	25.5
	Female	26.7	23.0	30.4	21.7	18.1	25.4	18.7	14.2	22.1
Shear Modulus (kPa)	Male	60.4	48.4	72.4	64.3	52.2	76.5	53.7	41.6	65.8
	Female	71.9	60.6	83.2	70.1	58.9	81.2	61.1	49.0	73.1

Note: Means for viscosity and shear modulus are adjusted for thickness. CI = confidence interval, cm = centimeters, Pa-s = pascal-seconds, kPa = kilopascals