Medical Engineering and Physics 000 (2018) 1–6

Contents lists available at ScienceDirect

Medical Engineering and Physics

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

Patellar tendon buckling is altered with age

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ARTICLE INFO

Article history:
Received 22 January 2018
Revised 22 March 2018
Accepted 30 April 2018
Available online xxx

Keywords:
Crimp
Rupture
Tendinopathy
Sex-based differences

ABSTRACT

Recent evidence has revealed that the patellar tendon exhibits buckling during passive knee extension, wherein the tendon folds back onto itself. The clinical relevance of such buckling is unclear, but it has been suggested that it serves to protect the patellar tendon from rupture when subjected to a sudden extreme contraction. Although prior evidence suggests buckling occurs universally, it is poorly understood, and may be influenced by age and sex. Healthy adults ($n = 41$, aged 21–80 years) were recruited to assess age- and sex-based differences in patellar tendon buckling during passive knee extension. 93% of subjects exhibited buckling in extension, with buckling more prominent in the distal tendon. No age- or sex-based differences in buckling magnitude were observed, but a significant age-based difference in buckling angle was found, with the tendon unbuckling later in flexion in younger adults compared with middle-aged ($p = 0.025$) and older ($p = 0.014$) adults. Intrinsic factors were also linked with buckling; for example, smaller maximum knee extension (i.e. less flexibility) correlated with smaller buckling magnitude ($p = 0.037$, $R^2 = 0.116$), suggesting a link between patellar tendon buckling and joint-level mechanics. These results suggest that buckling is an inherent component of normal knee function that older adults may be failing to take advantage of, predisposing them to injury. Further study will be critical to elucidate the clinical implications of patellar tendon buckling.

Introduction

Tendon injuries remain poorly understood, making them difficult to both prevent and treat. Some risk factors, like age and sex, have been identified, but these factors seem to affect different tendons disparately. For example, although the Achilles and patellar tendons have similar functional behavior, the influence of age and sex on injury incidence varies; whereas Achilles tendon rupture and tendinopathy occur most commonly in middle-age [1,2], ruptures in the patellar tendon occur much later in life [1], and no clear link has been found between age and patellar tendinopathy [3–6]. Likewise, though males are at higher risk for Achilles and patellar ruptures [1,7,8], as well as patellar tendinopathy [5,9,10], Achilles tendinopathy is equally common in males and females [2]. It could be postulated that the differences arise due to their different anatomy; notably the subtendons of the Achilles [11], and the presence of the patella bone embedded within the patellar tendon, but histological data support the categorization of the patellar tendon as more similar in composition to tendon rather than ligament [12]. Alternatively, the various hypotheses that have been proposed to explain the links between tendon injuries, age and sex, often focus on age- or sex-based changes in tendon tissue, which thus fail to explain why the Achilles and patellar tendons would be affected differently by these factors, thereby suggesting that factors other than broad tissue-based changes must play a role in injury development.

Joint-level mechanics may be key to understanding the difference in Achilles and patellar tendon injury incidence. One factor that has yet to be fully considered is the buckling of the patellar tendon that occurs when the knee is relaxed and in an extended posture [13]. This tendon buckling, in which the tendon folds back on itself, has rarely been described in the literature and is not widely recognized as a characteristic of normal knee function. In fact, the few studies that described buckling previously have theorized that it is a sign of tendon damage [14–16], a theory called into question by our previous observation of universal buckling in the patellar tendons of healthy young adults ($n = 20$ [17]). Although the clinical relevance of buckling has yet to be elucidated, observations of region-specific differences may provide a clue. Specifically, it was found that buckling occurred during a greater portion of the flexion cycle in the less-frequently injured distal tendon [18–20], suggesting that buckling may serve to protect this region of the

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https://doi.org/10.1016/j.medengphy.2018.04.024
1350-4533/© 2018 Published by Elsevier Ltd on behalf of IPEM.

Table 1
Subject information by group. All data are presented mean ± standard deviation. Statistically significant ($p < 0.05$) differences are shown in the last column, described as either between young and middle-aged adults (*YM*), young and older adults (*YO*), middle-aged and older adults (*MO*), or no significant differences between groups (*n.s.*).

	Young (21–40)	Middle-aged (41–60)	Older (61+)	
Sex	10 M, 10 F	5 M, 5 F	6 M, 5 F	
Age (yrs)	28 ± 4	51 ± 4	71 ± 6	*YM, YO, MO*
Height (cm)	174 ± 7	175 ± 13	166 ± 8	*n.s.*
Weight (kg)	70 ± 11	75 ± 14	71 ± 12	*n.s.*
BMI	23 ± 3	24 ± 3	26 ± 2	*YO*
Max. extension (deg flexion)	6 ± 7	4 ± 3	5 ± 4	*n.s.*
VISA-P score	98 ± 3	99 ± 2	92 ± 6	*YO, MO*

tendon from injury. A link between buckling, age and sex, could help to explain why the injury rate of the Achilles and patellar tendons are seemingly affected differently by age and sex differences. In addition, prior observations found that the magnitude of buckling was increased in subjects who were less active and older, suggesting that excessive buckling could be a sign of tissue degeneration, though all subjects in the prior study were relatively healthy and from a narrow age range (23–37). Thus, we undertook this follow-up study to evaluate whether there are any age- or sex- based differences in patellar tendon buckling. We hypothesized that (1) buckling magnitude would increase with age, (2) buckling magnitude would be greater in males, and (3) buckling angles would be smaller in older adults who are more predisposed to injury.

Methods

In compliance with the Commission for Medical Ethics UZ KU Leuven (protocol #s59014), healthy subjects (aged 40+) were recruited and provided written consent. Subjects were included only if they had no self-reported history of knee injury, surgery or musculoskeletal disorder ($n = 21$). Upon arrival, all subjects were asked to report their height and weight, and to complete the VISA-P questionnaire [21] to assess their patellar tendon health (Table 1).

Subjects were seated in an isokinetic testing device (Biodex Medical Systems, Shirley, NY, USA) and a twin-axis electric goniometer (Biometrics Ltd, Newport, UK) was used to record knee flexion angle. The session began with a six-minute warm-up period through the subjects' range of motion (ROM) from maximum extension to 90° of flexion, to precondition the muscle-tendon tissues [22]. Next, an ultrasound transducer (10 MHz, L14-5/38, Ultrasonix Corporation, Richmond, BC) was positioned over the patellar tendon to collect dynamic (70 fps) radiofrequency (RF) data. Because the transducer's width (38 mm) was insufficient to capture the full length of the patellar tendon, data were collected in a random order from either the proximal or distal tendon. For both locations, anatomical landmarks were identified (either the distal edge of the patella or the notch of the tibial tuberosity) and kept in view. Five repeat trials of passive flexion/extension through the ROM were collected for each transducer position. Next, a hypoechoic wire was secured over the midportion of the tendon, and flexion/extension cycles were repeated, with three trials collected from each transducer position. In post-hoc analyses, the shadow created by the wire was used to compute the full tendon length. LabVIEW (National Instruments Corporation, Austin, TX, USA) was used during all trials to synchronize ultrasound data with the electric goniometer.

Ultrasound B-mode images were reconstructed and evaluated in MATLAB (R2015B, Mathworks, Natick, MA, USA). Images were viewed sequentially, from knee extension to flexion, and the frame at which the tendon borders became continuous (i.e. the tendon is fully unbuckled) was identified visually, with the corresponding knee angle extracted and termed the buckling angle (Fig. 1). This analysis was repeated three times per trial, with the results averaged to determine a mean distal and mean proximal buckling angle for each subject, if present. Poor quality trials were removed, such that on average 9 ± 1 trials (of 10 total) were included in the analysis per subject. The distance between tendon insertion points was estimated in MATLAB from the images collected with the hypoechoic wire in place and was computed as the sum of the distance between the distal edge of the patella and the wire, and the wire and the tibial tuberosity. Because the tendon buckles in extension, this metric is not equivalent to the tendon length. Distance measures were repeated three times for each image, with the average taken for each subject. From this measurement, buckling magnitude could be computed. Buckling magnitude is a measure of how much of the tendon's length is buckled in maximum extension, and is computed mathematically as the difference in the distance between insertion points at the maximum buckling angle (i.e. proximal or distal) and maximum extension, normalized to the tendon length at 90° [17].

To enable broader assessments of any potential age-related changes, previously reported data [17] from healthy young adults (aged <40, $n = 20$) collected using the same setup were also included in the analysis. Thus, in total, data from 41 adults were assessed. For group-wise comparisons, subjects were divided by age: young (aged 21–40, $n = 20$), middle-aged (41–60, $n = 10$) and older (61+, $n = 11$) adults. ANOVAs were used to assess group-wise differences in intrinsic characteristics (age, BMI, maximum extension, maximum tendon length, VISA-P Score) and buckling results (distal and proximal buckling angle, buckling magnitude). Significant interactions were followed up with Tukey post-hoc tests ($p < 0.05$). *t*-Tests were used to assess sex-based differences in terms of the intrinsic characteristics and buckling results described above. Linear regressions were then used to test for correlations between BMI, maximum extension, maximum tendon length, and VISA-P score and buckling results. Linear regressions also tested for a link between age and maximum extension. Finally, the intrinsic characteristics of subjects with and without evidence of distal and proximal buckling were compared using *t*-tests. All statistics were performed in SPSS (IBM Corp., Armonk, NY, USA), with $p < 0.05$ taken as significant.

Results

Buckling was observed in 38 of the 41 subjects (Figure 1). Of these 38, all exhibited buckling in the distal tendon, and 26 also exhibited proximal buckling. No statistical differences were found between subjects with and without buckling in terms of age, BMI, maximum extension, maximum tendon length or VISA-P score.

In terms of group-wise comparisons, an aging effect was observed (Fig. 2), with young adults exhibiting a significantly larger buckling angle (i.e. unbuckling occurred at a more flexed posture) compared with middle-aged ($p = 0.025$) and older adults ($p = 0.014$). No group-wise differences in terms of proximal buckling or buckling magnitude were found. There were some intrinsic differences between age groups; young subjects had significantly lower BMIs than older subjects ($p = 0.04$), and older subjects

Please cite this article as: L.C. Slane et al., Patellar tendon buckling is altered with age, Medical Engineering and Physics (2018), https://doi.org/10.1016/j.medengphy.2018.04.024