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Short communication

Changes in tendon spatial frequency parameters with loading

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ABSTRACT

To examine and compare the loading related changes in micro-morphology of the patellar tendon.

Fifteen healthy young males (age 19 ± 3 yrs, body mass 83 ± 5 kg) were utilised in a within subjects matched pairs design. B mode ultrasound images were taken in the sagittal plane of the patellar tendon at rest with the knee at 90° flexion. Repeat images were taken whilst the subjects were carrying out maximal voluntary isometric contractions.

Spatial frequency parameters related to the tendon morphology were determined within regions of interest (ROI) from the B mode images at rest and during isometric contractions.

A number of spatial parameters were observed to be significantly different between resting and contracted images (Peak spatial frequency radius (PSFR), axis ratio, spatial Q-factor, PSFR amplitude ratio, and the sum). These spatial frequency parameters were indicative of acute alterations in the tendon micro-morphology with loading.

Acute loading modifies the micro-morphology of the tendon, as observed via spatial frequency analysis. Further research is warranted to explore its utility with regard to different loading induced micro-morphological alterations, as these could give valuable insight not only to aid strengthening of this tissue but also optimization of recovery from injury and treatment of conditions such as tendinopathies.

1. Introduction

Tendons are made up predominantly of collagen (60–85% of dry weight) (Józsa et al., 1989), with type I collagen being the predominant type. There are also elastin elements 1–2% (Kirkendall and Garrett, 1997), which are embedded with the collagen in a proteoglycan - water matrix. These elements give tendons viscoelastic properties and as such they respond acutely to loading in a load (elastic) and time (viscous) dependent way (Ker et al., 2000).

The collagen component of the tendon can be seen to be the main structural element and its structure reflects the loading deformation characteristics seen, with a nonlinear ‘toe’ (beginning of loading region) region as a consequence of the ‘crimp’ (bunching of collagen fibres) seen in resting collagen structures (Diamant et al., 1972), to a then reasonably linear elastic region reflective of the elastin structures within the tendon and sliding of the tropocollagen molecules and associated stretching of the triple collagen helices (Folkhard et al., 1987). There is also interstitial fluid flow seen with loading of tendons, possibly representing the viscous element (Hannafin and Arnoczky, 1994). The loading of tendons can result in physiologic adaptations which may be beneficial or detrimental, dependant on the loading. Tendons transfer the load via mechanotransduction from the cellular matrix to the tendon cells, resulting in biochemical responses at cellular level.

Loading protocols have previously been investigated in an attempt to identify optimal strategies for adaptation and or recovery from injury and conditions such as tendinopathies. For example, a number of studies have measured tendon cross-sectional area (CSA) and observed any increases after a period of loading. Of those that have utilized MRI to determine changes it was reported that short term loading (12 weeks and 9 weeks respectively) can result in region specific hypertrophic changes (Kongsgaard et al., 2007; Seynnes et al., 2009). However other potential possibilities of adaptation are intrinsic changes to the tendon structure as indicated by increases in Young’s Modulus (Reeves et al., 2003; Bohm et al., 2014). In the Bohm et al. study, high strain rate loading was seen to be preferential in producing tendon adaptation.

The mechanisms underlying adaptation are unclear. Studies examining acute cyclic loading have shown changes in transverse strain. Here reductions in the tendon thickness are evident when loaded (Wearing et al., 2013). The loading associated reduction in tendon thickness is suggested to be in part due to fluid transfer

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out of the tendon. However, acute changes in thickness during loading are also indicative of alterations of the tendon architecture. Here alignment and increased density of the collagen structures occurs with tensile loading (York et al., 2014). Changes in the tendon component arrangements can be indirectly described by the tendon stress/strain characteristic relationship. Below 2% strain (the toe region) represents the "stretching-out" of crimped tendon fibrils with tensile loading. This typical mechanical observation due to the 'crimped' fibril pattern can change to some degree, due to the differential crimp angle and crimp length between structures. With increased loading, a linear region in the stress strain curve appears (up to approx 4–5% strain). Here the collagen fibrils begin to alter their conformation and align themselves in the direction of tensile loading. These characteristic alterations in the tendon micro-morphology with loading may possibly be identified with ultrasound imaging (Kostyuk et al., 2004).

Visualisation of the tendon using B-mode ultrasound shows an anisotropic speckle pattern in which the pattern or image texture and brightness depends on the spatial distribution of the acoustic scatters within the tendon. This characteristic pattern and intensity is affected by the tendon structure and alignment to the ultrasound emission waves (Kannus, 2000). For healthy tendon, the speckle pattern present has a spatial frequency signature with a significant magnitude element and narrow frequency bandwidth about the peak spatial frequency (Bashford et al., 2008).

Analysis of tendon pathology had been previously performed in the frequency domain (Bashford et al., 2008). Previous work has shown peak spatial frequency radius (PSFR) in a tendon to be correlated with tendon elasticity (Kulig et al., 2016). Tendon is made up of elastic polymers. At rest, the individual polymer are more bundled, they can be stretched a finite length before breaking (Rigby et al., 1959). If ultrasound frequency analysis is able to categorise tendon mechanical properties it may be useful to examine whether this approach is sensitive enough to detect acute alterations in the tendon micro-architecture with loading.

Thus it can be seen that the acute loading and the mode of loading may influence the tendon response with acute loading. Hence this study applies the use of spatial frequency analysis of the tendon B mode images to examine indicators of acute changes within the tendon structure.

2. Materials and methods

15 male participants all gave their written informed consent and were included in this study (age 19 ± 3 yrs, body mass 83 ± 5 kg). All experimentation was approved by the local ethics committee and all procedures were in accordance with the world medical association Declaration of Helsinki (2013).

B-Mode ultrasound images (7.5 MHz 100 mm linear array B-mode ultrasound probe (Mylab 70, Esaote Biomedica, Italy) with a depth setting of 30 mm were taken of the patellar tendon in the sagittal plane, both whilst they were unloaded and during maximal voluntary isometric contractions (MVC), held for approx 5 s with the knee flexed to 90°. A familiarisation isometric contraction was performed prior to the test contraction for all subjects. Fig. 1 shows an example of an unloaded and loaded tendon. For each image pair, a region of interest (ROI) was selected corresponding to the tendon tissue seen within the image. Within the ROI, Cohens d was calculated by

$$d = \frac{\overline{X}}{\sigma_x} \quad (1)$$

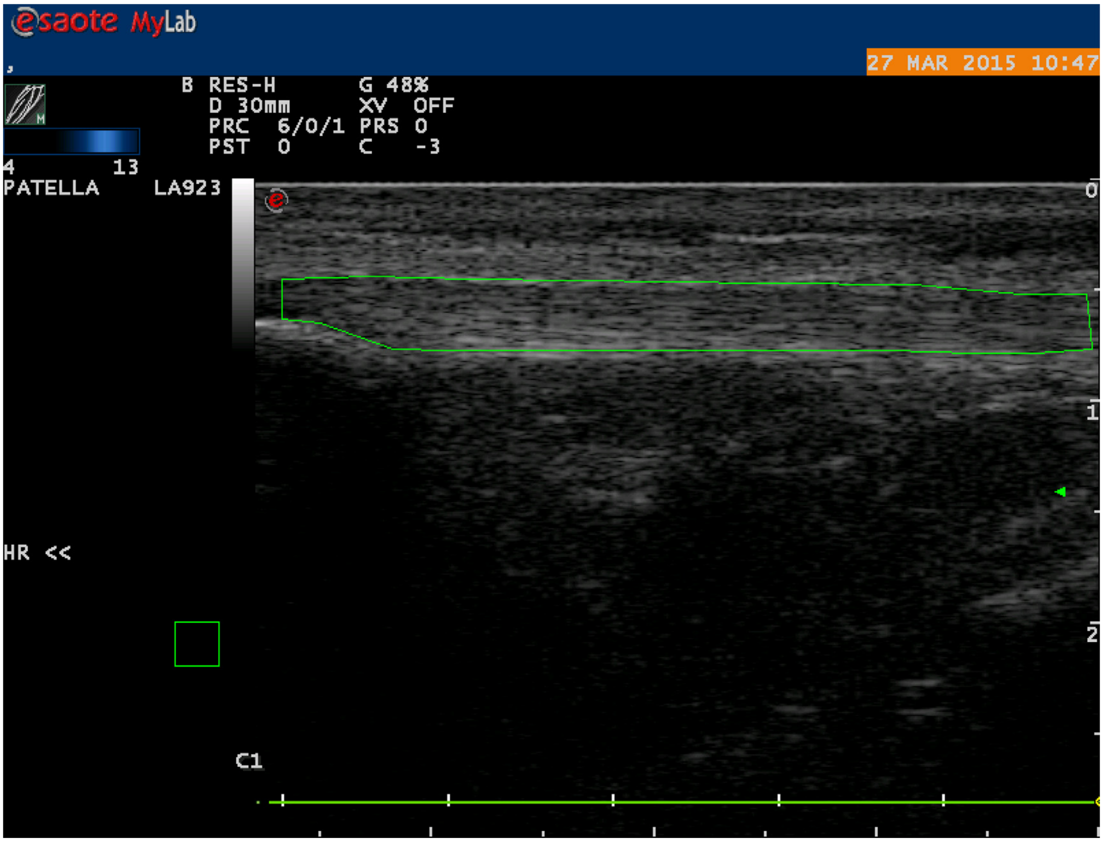

Fig. 1. Typical saggital plane ultrasound image of the patellar tendon showing the enclosed ROI rectangle box in green overlaying the patellar tendon. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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