In vivo human Achilles tendon deformation during the dynamic loading: preliminary results from a new approach visualising slip planes.

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Background: The Achilles tendon (AT) is composed of highly aligned, hierarchically arranged collagen fibres, connecting the triceps surae muscle to the heel. It is essential for locomotion, and AT injuries are highly debilitating, recalcitrant, and increasingly common. Recent studies have indicated that the ability to independently load different groups of collagen fibres within the AT is crucial for healthy function. Specifically, ultrasound imaging of the deformation profile across the thickness of the AT demonstrates greater non-uniformity in young than middle aged healthy participants. In vitro studies indicate that this arises from the low stiffness behavior of the matrix between the collagen units. Together, data suggests that independent loading of the sub-tendons arising from the different muscle heads of the triceps surae muscles is critical to healthy AT function and stiffening of the matrix connecting sub-tendons reduces their capacity for independent loading and leads to AT injury. Exploring this hypothesis necessitates in vivo imaging of tendon dynamics, with particular focus on the ability to demarcate sub-tendon boundaries and their associated sliding planes, not feasible with the current radio frequency (RF) based speckle tracking methods.

Aims: In this study, we develop a new approach to measure non-uniform AT deformations, which has the potential to additionally provide specific information on the location and magnitude of slippery boundaries within the tendon.

Methods: A study was carried out with 3 young healthy participants (Age: 27 ±1 Years, Weight: 67.3 ± 19.8 kg, 2 Female and 1 Male). Achilles tendon (AT) deformation was recorded during the eccentric loading exercise using an ultrasound (Ultrasonix) with linear probe (L14-5/38). The resulting RF signal was first rotated by angle ϕ (equal to that between the sound beam and tendon), to ensure the tendon data were aligned perpendicular to the direction in which tracking and strain estimation would take place prior tracking. Speckle tracking was then carried out in MATLAB (R2019a), with 2D normalized cross-correlation, with a fixed reference window of 40 x 150 pixels, and search window of 80 x 350 pixels, without any frame separation. The displacement field data for displacement along the long axis of the tendon were obtained, from which the least-square fitting technique was applied to obtain a long-axis shear strain map using a 10 pixels strain estimator.

Results: The average displacement map across the free region of the AT showed greater displacements in the deep than superficial regions of the tendon, demonstrating consistency with previously published results. However, the current approach was additionally able to map long-axis shear strains across the AT, clearly highlighting both the magnitude and location of the slippery boundary between the tendon and subcutaneous fat. Non-uniform shear strains were also observed across the tendon area, suggesting that further optimization of this approach and the ultrasound scanning parameters will enable improved identification of slippery boundaries, and thus sub-tendon sliding, within the AT during loading.

Conclusions: Data demonstrate that our newly developed approach can measure local non-uniform deformation across the AT and also visualize slippery boundaries within the field of view. The technique therefore has the potential to yield an imaging tool suitable to investigate sub-tendon sliding and reveal whether and how this is associated with Achilles tendinopathy.