THE INFLUENCE OF TWISTED STRUCTURES OF THE ACHILLES TENDON ON STRAIN DISTRIBUTION – PATIENT-SPECIFIC FE STUDY

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Introduction

The Achilles tendon (AT) is a complex structure, consisting of three twisted sub-tendons [1], which influence the AT strain [2]. In Achilles tendinopathy, the tendon material properties and geometry are altered, in particular decreased Young's modulus and tendon thickening [3]. The unilateral heel drop and heel rise exercises are commonly included in the rehabilitation protocols, but it remains unknown if these exercises provide an optimal strain [4] in Achilles tendinopathy patients. Finite element (FE) models of the AT facilitate the investigation of the effects of tendinopathic changes on local tendon strain [5]. The main aim of this study was to investigate the impact of two types of rehabilitation exercises on AT strain in patients with Achilles tendinopathy, including the effect of twist of the Achilles sub-tendons.

Methods

Ten participants with mid-portion Achilles tendinopathy (7 males, 3 females; age = 46 ± 16 years; weight = 75 ± 16 kg; height = 178 ± 10 cm; VISA-A score: 76 ± 17) participated in the study. The subject-specific geometries of the free AT were developed using 3D freehand ultrasound. Free form deformation method was used to develop subject-specific FE models of the AT for each type of twist, as in our previous study [6]. As a result, each subject had three different meshes, leading to total 30 subject-specific FE models used in our study. Material properties were defined as an incompressible, transversely isotropic hyperelastic material [7]. The subject-specific Young's modulus was calculated as the slope of the line fitted to the stress-strain data between 30% and 60% of the peak force for each patient (Young's modulus: 484.9 ± 125.7 MPa). Muscles forces of each patient were obtained by a combination of 3D motion capture and musculoskeletal modelling during a unilateral heel drop and a unilateral heel rise. The average of the muscle forces among patients was used as force boundary conditions for running subject-specific FE analysis. The average strain in the mid-portion and the location of the peak of the maximum Lagrange strain were calculated to compare the strain patterns between different exercises and twist types.

Results

Average strain in the mid-portion of the AT is larger during unilateral heel drop compared to heel rise ($p < 0.05$), for all the types of twist (Type I: 0.097 ± 0.028 and 0.084 ± 0.014, Type II: 0.097 ± 0.015 and 0.088 ± 0.013, Type III: 0.1 ± 0.017 and 0.09 ± 0.014, average ± standard deviation, for heel drop and heel rise, respectively). There was no significant effect of the twist for unilateral heel drop (p=0.846) nor for the heel rise (p=0.067). The peak strain is located in the mid-portion, where the thickened area is for the majority of the patients (n=6).

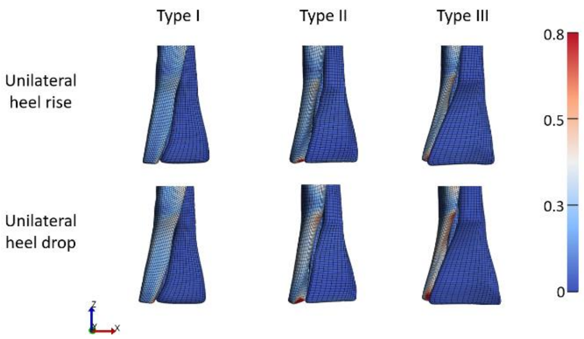

Figure 1: A representative example of the distribution of the maximum Lagrange strain for the three types of twist and the two exercises.

Discussion

The eccentric unilateral heel drop exercise resulted in significantly higher average strain compared to concentric unilateral heel rise, for all the three types of twist. The twist didn't influence the average strain. However, it influenced the location and magnitude of the peak strain. None of the exercises induce an optimal strain [4]. The location of the peak strain showed large variation across patients but it didn't change between exercises. The location of the peak strain is more related to the individual material properties and geometry rather than the muscle forces. Using these models, we will be able to further investigate the large variability in geometry and material properties amongst Achilles tendinopathy patients. This could allow to explore the potential of patient-specific rehabilitation programs, by including subject-specific material properties, geometry and muscle forces.

References

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