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Original research

Recovery of human Achilles tendon three-dimensional deformation following conditioning

Leila Nuri[a,*], Steven J. Obst[b], Richard Newsham-West[a], Rod S. Barrett[a]

[a] School of Allied Health Sciences, Menzies Health Institute Queensland, Griffith University, Australia
[b] School of Health, Medical and Applied Sciences, Central Queensland University, Australia

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ABSTRACT

Objectives: The tendon conditioning effect is transient, but the time course of recovery from conditioning is not known. This study examined the time-course recovery of three-dimensional (3D) Achilles tendon (AT) deformation immediately following a standardised AT conditioning protocol.
Design: Randomised crossover.
Methods: Ten healthy male adults (age: 24 ± 5 years; height: 175.8 ± 4.1 cm; body mass: 78.4 ± 6.3 kg) attended the laboratory on 6 occasions. ATs were scanned using freehand 3D ultrasound during a 50% maximal voluntary isometric contraction (MVIC) of the plantarflexors immediately prior to and following the conditioning protocol (10 × 25 s plantarflexion contractions at 50% MVIC), and then at either 15, 30, 60, 90 or 120 min post-conditioning, randomised by session.
Results: Free AT longitudinal strain was significantly increased from 3.13 ± 0.19% pre-conditioning to 7.49 ± 0.20% immediately post-conditioning and was accompanied by a corresponding reduction in free AT transverse strain from −5.35 ± 0.48% to −10.16 ± 0.49% ($p < 0.001$). There were no significant differences in free AT longitudinal or transverse strains at 60 min relative to 0 min post-conditioning, or between pre-conditioning strains and strains measured at 2 h ($p > 0.05$).
Conclusions: The free AT undergoes a creep response during conditioning which is recoverable within 2 h following conditioning. Recovery from conditioning has the potential to be a source of error during in vivo measurement of AT mechanical properties. The time window in which the free AT longitudinal and transverse strains could be achieved without a large confounding effect of creep recovery is 0–60 min post-conditioning.

1. Introduction

Following initiation of tensile loading, tendons such as the Achilles tendon (AT) experience an increase in longitudinal deformation/strain and the corresponding reduction in transverse deformation/strain with successive loading cycles until steady state mechanical behavior is reached.[1–3] At this point the tendon is said to be "conditioned".[4,5] For studies of AT mechanical behavior, it is recommended that a standardised tendon conditioning protocol be used prior to testing to ensure repeatable results,[6] as either inadequate or inconsistent tendon conditioning can alter measured tendon mechanical properties. The conditioning effect for the whole AT (i.e. gastrocnemius muscle-tendon junction (MTJ) to calcaneus) is primarily driven by a creep response from the free AT (i.e. soleus (SOL) MTJ to calcaneus) and is accompanied by a corresponding reduction in free tendon cross-sectional area (CSA) that is most pronounced within tendon mid-portion.[3] The mechanisms responsible for tendon conditioning likely reflect some combination of load-dependent changes in tendon microstructure and interstitial fluid distribution.[7,8] Tendon conditioning is believed to occur at a force intensity that is below the threshold for tendon damage (i.e. within the toe and/or elastic region of the tendon stress-strain curve), and is transient, with tendons returning to their preloaded state following a period of unloading.[5,9] Identifying the nature and time course of tendon recovery following tendon conditioning could have implications for the design of experiments that measure tendon mechanical properties and could provide information about the tendon viscoelastic properties that underpin the tendon function and adaptation.

Several in vivo studies have investigated AT recovery following training and sport activities, but the mechanical loads used in those studies were well in excess of those required for ten-

* Corresponding author.
E-mail address: leila.nuri@griffithuni.edu.au (L. Nuri).

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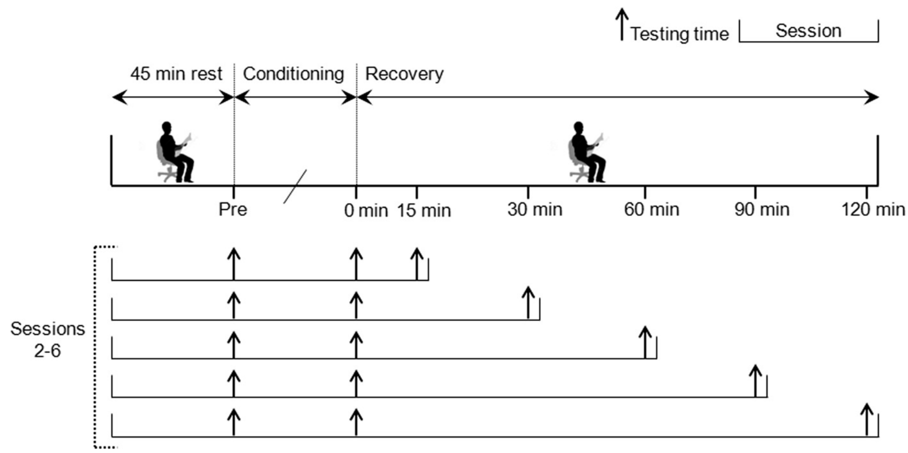

Fig. 1. Schematic representation of the whole experimental protocol. The participants ($n = 10$) reported to the laboratory for 6 different sessions. The first session was a familiarization session and the subsequent 5 sessions (sessions 2–6) were testing sessions. The AT strain measurement (testing time) was performed during a plantarflexion contraction at 50% MVIC immediately prior to conditioning (pre), immediately following conditioning (0 min), and then at either 15, 30, 60, 90 or 120 min during recovery, which was randomised by session.

don conditioning. For example, recovery of AT thickness has been shown to be complete compared to pre-exercise values after 24 h following eccentric loading (2 × 3 sets of 15 repetitions of eccentric heel drops), concentric loading (2 × 3 sets of 15 repetitions of concentric ankle loading exercise), and resistance exercise (90 repetitions of calf-raise exercise against an effective resistance of 250% body weight).[10–12] Furthermore, a duration of 4 days has been reported for full recovery of AT structural integrity following an Australian Rules Football game[13] and 3 days for recovery of AT volume and hydration after cross-country running.[14] However, a steady-state strain response in the AT can be achieved with as little as 5 × 4 s plantarflexion contractions at 80% maximum voluntary isometric contraction (MVIC),[1] 3 × 25 s plantarflexion contractions at 50% MVIC,[3] or 6 min of 0.75 Hz cyclic plantarflexion contractions at 25–35% MVIC.[2] No known studies to date have examined AT recovery from conditioning only, which would be expected to occur on a shorter time-scale (i.e. hours) compared to the recovery durations reported for the above mentioned studies of training and sport activities (i.e. 1–4 days). A further feature of the studies conducted to date on AT recovery following mechanical loading is that structural measurements were typically made at a single site using two-dimensional (2D) ultrasound.[10–14] Three-dimensional (3D) ultrasound methods are now available that can overcome some of the limitations of 2D ultrasound including the ability to: image the whole AT during a single scan, identify landmarks such at the muscle-tendon junction and calcaneal insertion in 3D space, and eliminate errors associated with controlling the 2D image plane.[15,16]

The purpose of this study was to examine the time course of the recovery of 3D AT deformation under load following tendon conditioning. The time required for recovery from conditioning effects was assessed by comparing the 3D tendon deformation during recovery with the deformation immediately prior to and immediately following conditioning. It was hypothesised that the recovery would be primarily driven by changes in the free AT and would occur on a shorter time scale (i.e. hours rather than days).

2. Methods

Ten healthy active male adults (age: 24 ± 5 years, height: 175.8 ± 4.1 cm, mass: 78.4 ± 6.3 kg) provided voluntary informed consent to participate in the study. The study was approved by the local institutional Human Research Ethics Committee and was performed in accordance with the principles of the Declaration of Helsinki.

A randomised repeated measures crossover design was used to determine the time course of recovery of AT longitudinal and transverse deformation following conditioning. Participants attended the laboratory at approximately the same time of the day on 6 separate occasions within an 18 day period. Individual sessions were separated by 2–5 days. During each session, the ankle joint torque was measured with participants positioned prone on the plinth with their hip and knee fully extended and the ankle joint in neutral position. The participant's foot was attached securely to the footplate of a fixed torque transducer (Futek TFF600, Irvine, California, USA) using a custom-built ratchet system.[16,17] Ankle joint torque was recorded at a sampling frequency of 1000 Hz and displayed in real-time on a computer monitor using a custom software program (LabVIEW 9.9, National Instruments, Austin, Texas, USA) to assist participants to produce the required torque. At the first session, the peak ankle joint torque associated with MVIC of the plantarflexor muscles was established. Participants performed 3 × 5 s maximal plantarflexor contractions with their left leg with a rest interval of 60 s between each contraction. The highest ankle torque recorded over the 3 trials was selected as the peak torque. Participants were required to refrain from any strenuous activity for at least 48 h prior to all 5 subsequent test sessions. Upon arrival at the laboratory, participants were instructed to sit for 45 min and then performed the AT conditioning protocol described by Nuri et al.[3,18] In brief, this involved performing 10 successive 25 s isometric plantarflexion contractions at 50% MVIC.[3,18] Measures of AT strain were assessed during a 50% plantarflexor MVIC using ultrasound immediately prior to conditioning, immediately following conditioning, and then at one further time point at either 15, 30, 60, 90 or 120 min during recovery, which was randomised by session using a concealed envelope procedure for each participant (Fig. 1). All participants otherwise sat comfortably on the chair with both feet flat throughout recovery. This testing design eliminates any possible confounding effects of the tendon testing trial on tendon recovery response.

Three-dimensional ultrasound (3DUS) system (a conventional 2DUS machine (SonixTouch, Ultrasonix, Richmond, BC, Canada) and a five-camera optical tracking system (OptiTrack V100:R2, Tracking Tools Version 2.5.2, NaturalPoint, Corvallis, Oregon, USA)) was used for imaging of AT during each testing trial.[16,17] A single examiner (L.N) obtained all AT images at frequency of 60 Hz, using a 58-mm linear transducer (L14-5 W/60 linear, Ultrasonix, Richmond,