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Patellar tendon adaptation in relation to load-intensity and contraction type

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ABSTRACT

Background: Loading leads to tendon adaptation but the influence of load-intensity and contraction type is unclear. Clinicians need to be aware of the type and intensity of loading required for tendon adaptation when prescribing exercise. The aim of this study was to investigate the influence of contraction type and load-intensity on patellar tendon mechanical properties.
Method: Load intensity was determined using the 1 repetition maximum (RM) on a resistance exercise device at baseline and fortnightly intervals in four randomly allocated groups of healthy, young males: (1) control (no training); (2) concentric (80% of concentric–eccentric 1RM, 4×7–8); (3) standard load eccentric only (80% of concentric-eccentric 1RM, 4×12–15 repetitions) and (4) high load eccentric (80% of eccentric 1RM, 4×7–8 repetitions). Participants exercised three times a week for 12 weeks on a leg extension machine. Knee extension maximum torque, patellar tendon CSA and length were measured with dynamometry and ultrasound imaging. Patellar tendon force, stress and strain were calculated at 25%, 50%, 75% and 100% of maximum torque during isometric knee extension contractions, and stiffness and modulus at torque intervals of 50–75% and 75–100%. Within group and between group differences in CSA, force, elongation, stress, strain, stiffness and modulus were investigated. The same day reliability of patellar tendon measures was established with a subset of eight participants.
Results: Patellar tendon modulus increased in all exercise groups compared with the control group ($p < 0.05$) at 50–75% of maximal voluntary isometric contraction (MVIC), but only in the high eccentric group compared with the control group at 75–100% of MVIC ($p < 0.05$). The only other group difference in tendon properties was a significantly greater increase in maximum force in the high eccentric compared with the control group ($p < 0.05$). Five repetition maximum increased in all groups but the increase was significantly greater in the high load eccentric compared with the other exercise groups ($p < 0.05$).
Conclusion: Load at different intensity levels and contraction types increased patellar tendon modulus whereas muscle strength seems to respond more to load-intensity. High load eccentric was, however, the only group to have significantly greater increase in force, stiffness and modulus (at the highest torque levels) compared with the control group. The effects and clinical applicability of high load interventions needs to be investigated further.

1. Introduction

Tendon is a fibrous connective tissue with a high tensile strength that functions to transfer load from muscle to bone. Some tendons have an additional function in storing and releasing mechanical load during stretch-shortening cycle activities such as running, jumping and throwing (Birch, 2007). This tendon function serves to improve performance and increase efficiency of human movement (Fukashiro et al., 2006). A paradox is that tendons that are designed for storing and releasing energy also succumb to tendon overload injury, or tendinopathy. For example, the patellar tendon stores and releases high levels of energy during jumping and this probably contributes to the high prevalence (up to 50%) of patellar tendinopathy among elite volleyball players (Lian et al., 1996; Malliaras and Cook, 2006).

The gold standard for managing Achilles and patellar tendinopathy, two of the most common lower limb tendinopathies, are

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eccentric muscle contractions applied as a regular training programme over a number of months. Recent reviews have advocated this form of muscle training based on current evidence as a first line treatment for these injuries (Gaida and Cook, 2011; Kingma et al., 2007). Little is known about the mechanisms explaining eccentric muscle training efficacy but there are reports of improved tendon structure (e.g. including reversal of pathology (Ohberg et al., 2004)) and improved muscle strength (Alfredson et al., 1998; Kongsgaard et al., 2009), although reports of improved tendon structure are not universal (de Jonge et al., 2010; Petersen et al., 2007). Pathological tendons may have reduced stiffness (Arya and Kulig, 2010; Child et al., 2010), so restoring this property may improve musculotendinous function and reduce recurrence.

Tendon is able to remodel its material and structural properties in response to increased levels of loading. Several authors have shown increased stiffness and in some cases an increase in cross sectional area (CSA) in response to chronic tendon loading (Arampatzis et al., 2007; Burgess et al., 2007; Kongsgaard et al., 2007; Kubo et al., 2007; Magnusson et al., 2008; Reeves et al., 2003). Maximizing tendon strain seems to be important in enabling tendon adaptation. Arampatzis et al. (2007) compared maximal isometric voluntary contraction (MVIC) producing either 2.5–3.0% or 4.5–5.0% strain performed four times per week over 14 weeks and found that only the 'high-strain' group had an increase in Achilles tendon stiffness. A more recent study by the same group showed that the tendon stiffness response was reduced when the strain frequency was increased (from 0.17 to 0.5 Hz) (Arampatzis et al., 2010). Taken together, tendon seems to respond to sustained contractions and greater load intensity, both producing greater strain.

Most clinical eccentric training studies use a dosage of three sets of 15 repetitions and load is progressed in order to induce pain (Alfredson et al., 1998). There is evidence that tendinopathy patients may benefit from higher load intensities such as 6RM (Konsggaard et al., 2009), but it is unknown whether the magnitude of the load or contraction type are predominant factors responsible for tendon adaptation and whether this explains some of the improved pain and function outcomes in some tendinopathy studies. The aim of this study was to investigate tendon adaptation to: (1) eccentric loading of different magnitudes, and (2) different contraction types (concentric or eccentric) at a similar magnitude, in healthy tendons.

2. Method

Thirty-eight healthy male volunteers were recruited from staff and students at Queen Mary, University of London. Men between 18 and 35 years old were recruited as load response may deteriorate with age (Reeves et al., 2004). Potential participants were excluded if they weight trained regularly or had any lower limb pain that may interfere with the interventions and tests in this study. The study was approved by the Queen Mary University of London, Research Ethics Committee.

2.1. Pre-testing

Participants' age, height, weight, weight training history (yes/no and how long ago they stopped) and activity level were recorded with a questionnaire. Knee girth (at the joint line), was measured. Weight and skinfolds were also measured at the end of the training period. Ultrasound imaging appearance (presence or absence of gray scale abnormality or Doppler signal) was assessed at baseline.

2.2. Exercise interventions

Participants were randomly allocated to one of four groups: (1) control (no exercise); (2) concentric training (80% of concentric–eccentric 1RM, 4×7–8); (3) standard load eccentric training (80% of concentric-eccentric 1RM, 4×12–15 repetitions) and (4) higher load eccentric training (80% of eccentric 1RM, 4×7–8 repetitions). In the eccentric groups, participants lifted the weight with two legs and performed the lowering phase with their left leg (thereby minimizing the influence of any concentric contraction). In the concentric group participants lifted the weight with one leg and lowered with two (thereby minimizing the role of any eccentric contraction). The training was therefore predominantly eccentric or concentric, but there was a small component of the other contraction type in each.

Participants selected a group number from an opaque envelope and were stratified based on activity ($<$ or $>$ 3 h of running and jumping activity per week). At baseline and once per fortnight the relevant 5RM was tested (eccentric for high load eccentric and concentric-eccentric for concentric and standard load eccentric group). 5RM was converted to 1RM (Brzycki, 1993) and used to set load intensity for the following fortnight. The concentric-only and standard load eccentric-only training was performed at 80% of concentric–eccentric 1RM whilst the higher load eccentric-only training was performed at 80% of eccentric 1RM. Participants exercised to fatigue which was typically 12–15 repetitions for the standard load eccentric and 7–8 repetitions for the higher load eccentric and concentric groups. Fatigue was defined as difficulty with, or an inability to complete the last 2–3 repetitions of at least the third and fourth set. The control group was asked to refrain from any weight training during the study period. Both exercise groups performed their exercise on a leg extension machine (SL-153 leg extension, Johnson Fitness, Taiwan) three times per week for 12 weeks. The duration of each eccentric lowering phase was standardized to 5 s using a metronome and knee extensions were performed in a range between 0° and 90° knee flexion.

Exercise technique and pain during training (yes/no during each session) were assessed every fortnight. Compliance was monitored closely as all participants trained in the Centre for Sports and Exercise Medicine, Queen Mary, using the same leg extension machine. Participants marked off each session they completed on a training register. At the end of the study compliance (% of sessions completed) was calculated. Participants were contacted by phone and/or email if they were falling behind in their sessions for any given week (i.e. by Tuesday if they had not performed any training during that working week) and a training time arranged. The lead researcher (PM) regularly organized to meet participants during the weekend so they could make up training they had missed.

2.3. Measurement of knee extension and flexion torque

Participants were seated comfortably in the dynamometer (Isocom, Eurokinetics, UK), with the knee in 90° flexion. The axis of the knee and dynamometer were aligned and straps were positioned at the hip and thigh. All testing and interventions were performed on the participants left leg only. Torque was measured during three maximal isometric knee flexion trials. Participants then performed a maximal isometric knee extension contraction that lasted for 5 s and were instructed to gradually increase to peak torque over the first second. Five preconditioning contractions were performed, including two maximal, and 25%, 50%, 75% of maximal. This was designed to bring tendon stiffness to a steady state for reproducibility and allowed participants practice at maintaining submaximal contractions accurately.

Following the preconditioning trials, two sets of four trials were performed at 25%, 50%, 75% and 100% of MVIC, in random order. If the torque was not stable in the final 3 s of a particular trial (visual inspection of plotted data from dynamometer) the trial was repeated. Sixty seconds rest was allowed between each trial.

2.4. Measurement of surface electromyography

Co-contraction of the antagonist was estimated so that total patellar force (that attributed to both agonist and antagonist contraction) could be calculated. Biceps femoris muscle surface electromyography (sEMG) was measured during flexion MVIC and this relationship was used to estimate antagonist (hamstring) torque based on biceps femoris sEMG during extension MVIC. To achieve this sEMG was measured from biceps femoris muscle during knee extension as well as during maximal and submaximal knee flexion contractions. EMG was recorded via wireless surface electromyography (sEMG) (Telemyo 2400T G2, Noraxon, USA). The skin was prepared and Ag/AgCl electrodes placed over the biceps femoris according to standard SENIAM guidelines (Freriks and Hermens, 2000), with an inter-electrode distance of 20 mm. Surface EMG signals were sampled at 1500 Hz, pre-amplified and band-pass filtered between 10 and 500 Hz, prior to export to excel for post-processing.

2.5. Ultrasound imaging measures of tendon elongation, CSA and length

In vivo measurement of patellar tendon elongation was performed with ultrasound imaging, using a 7.5 MHz linear array transducer (Voluson-i, GE Medical Systems, Milwaukee, USA). The lead researcher who has postgraduate training in ultrasound imaging performed all ultrasound imaging. Prior to imaging an echo-absorptive marker (a thin aluminium strip) was placed across the patellar tendon, 1 cm below the inferior patella pole (Fig. 1). The transducer was placed in the sagittal plane over the proximal part of the patellar tendon and measured patellar tendon elongation during each trial. During MVIC any proximal movement of the inferior patellar pole away from the line cast by the marker indicated patellar tendon elongation (Fig. 2) and was subsequently measured by digitizing video