Mechanical properties and force output of quadriceps muscle following eccentric exercise

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Purpose: Delayed Onset Muscle Soreness (DOMS) is commonly associated with intense unaccustomed exercise, particularly exercise featuring eccentric muscle contractions. When a muscle contracts eccentrically fewer fibres are recruited to manage the load. This generates excessive mechanical strain on the fibres[1] and produces so-called Exercise Induced Muscle Damage (EIMD). Previous studies have reported that EIMD causes an increase in muscle stiffness[2] and reduction in skeletal muscle force production[3]. Muscle stiffness is generally measured via torque-angle relationship but is limited by contribution of joint structures to the measurement. Magnetic Resonance Elastography (MRE) is a technique which, via the measurement of the propagation of acoustic waves, enables non-invasive, direct measurement of muscle belly stiffness. The sole MRE study to assess muscle stiffness following damage[2] reported a stiffness increase in the gastrocnemius muscle following eccentric exercise. However, a small number of subjects were recruited and physical activity was not monitored. In the present study MRE was used to investigate the relationship between muscle stiffness and muscle force production in EIMD. Additionally, Maximum Voluntary Contraction (MVC) of the knee extensors was studied using a dynamometer. The relationship between change in muscle stiffness and change in force output was investigated.

Methods: Twenty healthy male volunteer subjects were recruited (mean age 24.1± 4.3yrs). MRI scanning and functional testing were performed of the quadriceps muscle of the dominant leg at baseline, and 48 hours after completion of a standardised eccentric exercise protocol when the effects of EIMD are expected to peak. Further functional testing was performed 5, 7 and 9 days post damage. A wrist worn accelerometer monitored physical activity over the duration of the study. Subjective pain assessment to detect Delayed Onset Muscle Soreness (DOMS) was also undertaken. Prior to the muscle damage protocol a work target was calculated for each subject based on peak concentric and eccentric force. The damage protocol consisted of 12 sets of eccentric contractions targeting the quadriceps muscle and each was performed until the established work target was achieved. MRE and high resolution T2 weighted data were acquired using a 3T Siemens Verio MR system (Siemens Medical Systems, Erlangen, Germany) and a 32 channel receiver coil. A spin echo EPI sequence was used to acquire 3D MRE data with acquisition parameters, TE = 1600ms, TR = 54ms, 8 phase offsets, scan duration = 1min 6 sec. MRE data analysis was performed using a custom developed phase unwrapping and inversion software run in MATLAB[4]. MVC was studied during three 5 second maximal contractions initiated via a random audio cue. MVC testing was undertaken using a BioDex isokinetic dynamometer.

Results: T2 weighted anatomical images and elastograms obtained for the same subject before and after damage are displayed in the upper, and lower, rows of Figure 1, respectively. The T2 weighted images reveal localised hyper-intensities primarily in the Rectus Femoris (RF) (red arrow) and Vastus Intermedius (VI) muscle groups suggesting oedema in these areas. Magnitude stiffness is increased by an average of 17% over the whole quadriceps, with the RF muscle group showing a significant 22% increase ($p<0.05$) (see Figure 2). MVC was significantly reduced by an average of 27% ($p<0.001$) 48 hours following damage (Figure 3) and did not return to baseline within the period of study. Control leg MVC increased above baseline over the study duration as a result of a potential learning effect. Subjective pain assessment revealed significant ($p>0.01$) pain increases (220%) associated with EIMD confirming the presence of DOMS.

Conclusions: Following eccentric exercise, muscle stiffness is significantly increased in the quadriceps with the RF primarily affected. An accompanying significant reduction in MVC was also found. T2 hyper-intensities are generally regarded to represent oedema in the muscle[5] and this was found to be more prominent the greater the MVC reduction. Stiffness increase is found in the absence of oedema which indicates stiffness changes may not be entirely due to localised fluid accumulation. Significant pain was reported though there appears to be no relationship to stiffness increase or force reduction. MRE and T2 imaging suggest eccentric contractions of the knee extensors preferentially affect the rectus femoris muscle group, contradicting the traditional practice of solely investigating the vastus lateralis muscle group in sports science studies[6].

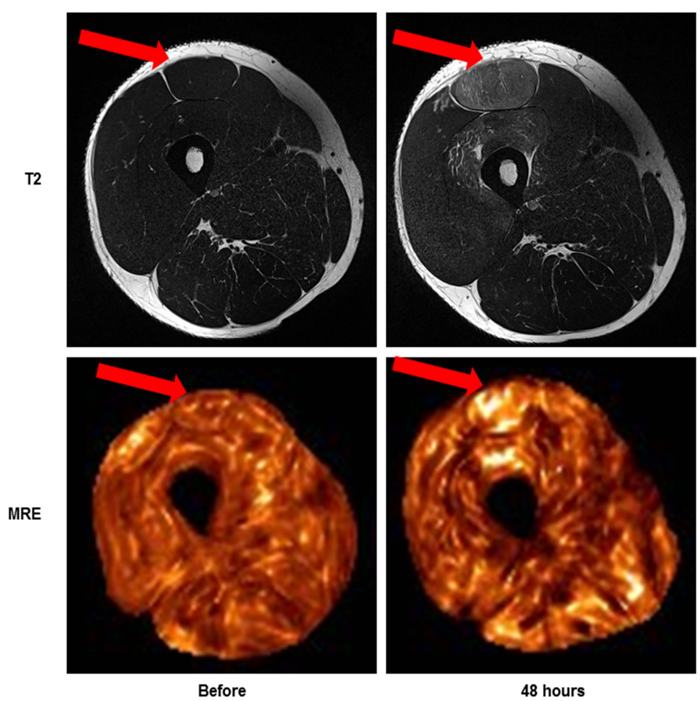

Figure 1 (above): T2 weighted (top row) and magnitude stiffness elastograms (bottom row) from a subject pre and post damage. Localised T2 hyper-intensity suggests oedema is present in the RF (red arrow) and VI muscle groups. Stiffness is also significantly increased in RF and VI groups.

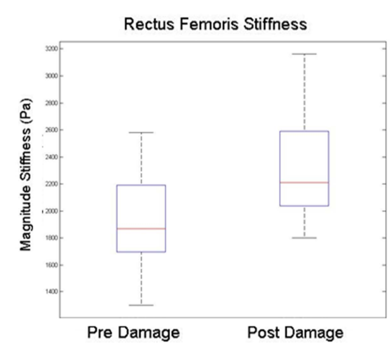

Figure 2 (above): Boxplot displaying the significant stiffness difference in the RF muscle group after damage

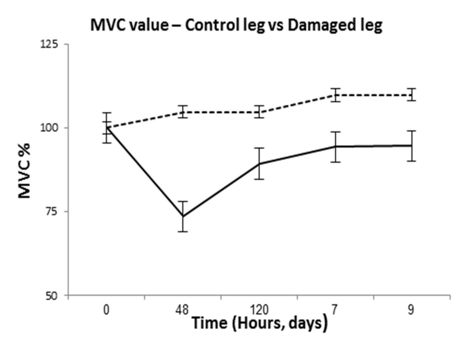

Figure 3 (above): Plot displaying the significant stiffness difference in knee extensor force output after damage

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