Eccentric exercise induces delayed onset muscle soreness without signs of exercise induced muscle damage in a single human subject

By Jonathan Luke

250477824

University of Western Ontario

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Abstract

Delayed onset muscle soreness (DOMS) is a commonly researched phenomenon following eccentric exercise. Even so, the underlying physiological causes of DOMS remain unclear. One hypothesis suggests that lengthening contractions cause microscopic muscle damage that in turn causes DOMS. This hypothesis has been the basis of a new term for the set of symptoms following intense unaccustomed eccentric exercise: exercise induced muscle damage (EIMD). However, the association between muscle damage and DOMS has been doubted by some, and correlations between DOMS and other measures of damage have been weak. The present study employed an exercise protocol that compared eccentric and concentric contractions of the quadriceps of separate legs in the same participant. Perceived pain, isometric maximal voluntary contraction (MVC) torque, and T2 relaxation times for the quadriceps were measured before, following, 24 hours after, and 48 hours after exercise. A 60% increase in perceived pain 24 hours following exercise was observed in the eccentric leg only, indicating unilateral DOMS. MVC torque decreased ~15% in both legs, and T2 relaxation times increased ~8% in both legs; these changes may indicate that damage was not present or that minor muscle damage was present bilaterally. Because DOMS was only experienced unilaterally, while any evidence of possible damage was observed bilaterally, it is concluded that muscle damage was not the physiological cause of DOMS in the participant. Because the present study is a single case, future research is necessary to confirm these findings and extend the conclusions to DOMS in general.

Introduction

The phenomenon of delayed onset muscle soreness (DOMS) was first reported by Hough (1902);
he noticed a condition of muscle soreness beginning eight to ten hours following exercise in untrained
muscles. Since then, DOMS has been the subject of a large body of research. Though it has been shown
that DOMS is most prevalent following exercise involving eccentric contractions (Cheung, Hume, &
Maxwell, 2003; Asmussen, 1956; Smith, 1992; Connolly, Sayers, & McHugh, 2003; Howatson & van
Someren, 2008), the underlying cause of DOMS remains unclear (Cheung, et al. 2003; Howatson & van
Someren, 2008; nosaka 2002). A common hypothesis is that intense eccentric contractions cause
structural damage to muscle fibers (Cheung, et al. 2003; Smith, 1992; Connolly, et al. 2003; Howatson &
van Someren, 2008). Because some studies have found histological changes in muscle fiber structure and
chemical markers of tissue damage (such as increases in plasma creatine kinase (CK) activity occurring
coincidentally with DOMS) (Yu, Carlsson, & Thornell, 2004; Warren, Lowe, & Armstrong, 1999; Smith,
Brunetz, Chenier, McCammon, Houmard, Franklin, & Israel, 1993; Nosaka & Clarkson, 1997; Foley,
Jayaraman, Prior, Pivarnik, & Mayer, 1999), this hypothesis has led some researchers to treat DOMS as a
symptom of a larger condition of muscle damage or to use the term exercise induced muscle damage
(EIMD) in the place of DOMS (Nosaka & Clarkson, 1997; Sayers, Clarkson, & Lee, 2000; Kraemer,
Bush, Wickham, Denegar, Gomez, Gotshalk, Duncan, Volek, Newton, Putukian, & Sebastianelli, 2001;
Al-Nakhli, Petrofsky, Laymon, & Berk, 2012; Yu, et al. 2004; Nosaka & Newton, 2002; Nosaka,
Newton, & Sacco, 2002; Clarkson & Hubal, 2002; Tiwst & Eston, 2005). This umbrella term, EIMD,
constitutes DOMS and several changes that often accompany DOMS after eccentric exercise: decreased
voluntary torque production, increased muscle circumference (edema), persistent increases in T2
relaxation times as measured by magnetic resonance imaging (MRI), and the aforementioned histological
changes and increases in circulating chemical markers of damage (Warren, et al. 1999; Sayers, et al.,
2000; Jayaraman, Reid, Foley, Prior, Dudley, Weingand, & Meyer, 2004; Nosaka & Newton, 2002;

Nosaka, Newton, & Sacco, 2002; Yu et al. 2004; Kraemer, et al., 2001; Twist & Eston, 2005; Clarkson & Hubal, 2002).

However, the relationship between DOMS and these other symptoms may be weak. A study by Nosaka, Newton, and Sacco (2002) sought to evaluate the relationship between soreness and signs of muscular damage. To do so, they had two groups of male participants perform eccentric exercise protocols that differed in number of repetitions. They found significant differences between groups for changes in strength and plasma CK activity, but no difference between groups for soreness on palpation of the affected muscle; furthermore, they found no correlation between soreness on palpation and strength or plasma CK activity. They concluded that "DOMS may not be directly related to muscle damage and subsequent inflammation", and suggested that future research should continue to investigate the underlying cause of DOMS.

Other studies have also provided reason to doubt the assumption that DOMS is tied directly to muscle damage. An earlier study by Rodenburg, Bär, and De Boer (1993) found increases in soreness did not correlate significantly with decreases in strength following eccentric exercise; a study by Nurenberg, Giddings, Stray-Gundersen, Fleckenstein, Gonyea, and Peshock (1992) found that linear regression analysis demonstrated a poor correlation between the extent of DOMS and muscle fiber structural disruption; and, a review of measurement tools by Warren, et al. (1999) found soreness to be the most commonly used measure of injury following eccentric exercise in a sample of 51 studies, but concluded that "soreness has correlated poorly with changes in muscle function, both in terms of magnitude and time course." Because the muscle damage hypothesis is so prevalent in research involving DOMS, yet remains unproven, the purpose of the present study is to describe an observed case as evidence against this hypothesis in which a single individual exhibited DOMS without accompanying signs of muscle damage.

The present case compares the results of eccentric and concentric exercise in the quadriceps muscle group of separate legs in one subject. Following data collection, similarities were noticed between the present study and a prior study by Jayaraman, et al. (2004); both studies employed eccentric knee

extension exercise, recruited young healthy adult male participants, and measured isometric maximal voluntary contraction (MVC) torque and T2 relaxation times over time. Jayaraman, et al. (2004) investigated the effects of topical heat and static stretching as possible treatments for the symptoms of EIMD. They found the treatment ineffective, but observed large decreases in MVC torque and large increases in T2 relaxation times following eccentric exercise, indicating that participants experienced muscle damage. Due to the similarities in methodology, some comparisons have been drawn between the magnitude of changes observed by Jayaraman, et al. (2004) and the present study. Because the present study is not able to implement statistical assessments of significance, these comparisons are intended to provide some context as to the magnitude of changes expected with muscle damage.

Methods

Experimental Design

Four participants were recruited to participate in this study. An exercise protocol intended to temporarily damage the quadriceps muscle group of each participant was created involving exclusively eccentric contractions for one leg and exclusively concentric contractions for the opposite leg. Three subjects underwent a moderate protocol that did not produce DOMS (EXmod). When perceived soreness was not present 24 hours following EXmod, the fourth subject (Subject P) underwent a more intense exercise protocol (EXhvy). MRI images, strength measures, and perceived pain measures of the quadriceps were recorded at baseline before exercise (PRE), the same day after exercise (POST), 24 hours post-exercise (24HR), and 48 hours post-exercise (48HR). POST was 30 min after exercise for all measurements except the MRI images, which were taken 2-4 hours after exercise.

Subjects

Four males (aged 21-24 years old) from The University of Western Ontario were recruited to participate in this study. Participants were asked if they had performed strenuous leg exercise, such as

weightlifting or running, in the three months prior to the study and excluded if they had. The study protocol was approved by The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects and conformed to the Declaration of Helsinki. Informed oral and written consent was obtained prior to testing.

Exercise protocol

Exercise protocols were conducted at The University of Western Ontario Recreation Center and were supervised by a certified personal trainer. One-leg one repetition maximum (1RM) was found for knee extension on a selectorized knee extension machine by performing two repetitions at increasing loads with 5 mins of rest between loads to allow for recovery from fatigue. The load reached when only one repetition could be performed was considered the participant's 1RM. This protocol was derived from the protocol for establishing a 1RM recommended by the National Strength and Conditioning Association (Cramer & Coburn, 2004). This was done without isolating eccentric and concentric contractions; participants lifted and lowered the weight with the same leg for each repetition. Estimation of 1RM was followed by an additional 5 mins of rest. An exercise protocol intended to induce DOMS was then conducted dynamically with one leg performing concentric contractions only and the other performing eccentric contractions. The participant concentrically lifted the weight with one leg to full extension. The weight was then supported while the participant lowered the concentric leg and raised the opposite leg. The opposite leg then lowered the weight eccentrically in a controlled manner over a 3 s count. One full range of motion through full extension back to the starting position constituted one repetition.

The EXmod protocol consisted of 5 sets of 10 repetitions using 80% of the 1RM with 2 mins of rest between sets. For the purpose of this study, failure was considered inability to maintain proper form including an inability to concentrically lift the weight or an inability to eccentrically lower the weight in a controlled manner. None of the three subjects reached failure in either leg in any of the sets.

The EXhvy protocol consisted of 5 sets to failure using 80% of the 1RM with 2 mins rest between sets. When failure was reached in 10 repetitions or less, the weight was lowered 10% for the next set.

Table 1 lists the exact weights lifted and repetitions performed in each set for Subject P, the only participant to perform the EXhvy protocol. Weight was lowered for Subject P twice: between the 3rd and 4th sets and between the 4th and 5th sets. Failure was achieved in the concentric leg in all 5 sets. Because each set was finished when the concentric leg reached failure, failure was not reached in the eccentric leg in any set.

Table 1. *Exercise protocol: weights lifted and repetitions performed by Subject P.*

Estimated 1RM (lb)	80% 1RM (lb)	Set	Load (lb)	Repetitions
185	150	1	150	18
		2	150	12
		3	150	10
		4	135	9
		5	120	12

Perceived pain measures

Perceived pain was measured using a 100mm visual analog scale (VAS). The scale used is presented in Figure 1. To ensure the greatest validity and intra-rater reliability, the findings of the Wewers and Lowe (1990) review of visual analog scales were used in constructing the scale; the scale was made unipolar and horizontal, with vertical end lines and labels beyond the end lines, without descriptors or number demarcations, and an attempt was made to ground the non-zero label in the more relatable term "unbearable pain". Participants were first instructed to rate the weather outside to familiarize them with the VAS and its function before testing began; all participants demonstrated and verbally confirmed their understanding. When measuring pain, participants were instructed to place a vertical line along the scale that best represented their physical pain within their quadriceps, excluding affectual or psychological pain. Pain was evaluated in each leg with light palpation of the anterior aspect of the thigh before each strength testing protocol. All measurements were taken to the nearest mm, rounding down to allow for a rating of 0 (pen marks were ~.5 mm in width).

How severe is your pain? Place a vertical mark on the line below to indicate how bad you feel your pain is:

No Pain ⎣_____⎦ Unbearable Pain

Figure 1. 100 mm VAS perceived pain scale. Subjects place a mark along the spectrum indicating the extent of their pain (not drawn to scale).

MRI measures of damage

Prior to the MRI, participants were given an MRI screening questionnaire to ensure safety. Magnetic resonance images were acquired via serial axial plane in a 3.0 Telsa full-body MAGNETOM Verio (Siemens, Munich, Germany) magnet; a Siemens 6-channel body coil was placed over the subject's thigh. Participants were inserted into the magnet bore feet first, in the supine position. Twenty-six 5mm thick multi-echo T2-weighted images separated by 2mm and centered on a mark half way between the patella and the anterior superior iliac spine were acquired using the following parameters: 3300 ms repetition time; 13.2, 26.4, 39.6, 52.8, 66, 79.2, 92.4, 105.6, 118.8, 132, 145.2, 158.4, 171.6, 184.8, 198, 211.2 ms echo times; 195x115 matrix; 399x399 mm field of view.

The T2 weighted images were analyzed in OsiriX (version 4.1.1, Geneva, Switzerland), an open-source image processing software package. The slice containing the greatest leg cross-sectional area was chosen for analysis. The quadriceps muscle was isolated within the image as the region of interest, via manual tracing. To ensure consistency, the region of interest was isolated in all images by the same researcher and over only two days. The built-in T2 fit map plug-in for OsiriX was used to generate a fitted curve of T2 relaxation times and a mean T2 relaxation time using the set of echo-times for the region of interest. In an attempt to more closely replicate the methods used by Foley, et al. (1999) and Jayaraman, et al. (2004), who used only 30 ms and 60 ms echo times, this analysis was conducted a second time using only the 26.4 ms and 66 ms echo-times with the same results as the initial analysis.

Strength measures

A Cybex NORM dynamometer (CSMi Medical Solutions, Stoughton, MA) was used to evaluate maximum isometric strength via isometric maximal voluntary contractions (MVC). Voluntary activation of the quadriceps was estimated during each MVC using an interpolated twitch technique (ITT), as described by Behm, St-Pierre, and Perez (1996). Electrodes were constructed for electrical stimulation from strips of aluminum foil approximately 20 cm long and 5 cm wide wrapped in paper towel. Each electrode was soaked in water and the applied side coated in ultrasound gel before application, then secured to the anterior aspect of the thigh with athletic tape. Both electrodes were oriented transversely with one placed ~5 cm distal to the groin and the other placed ~10 cm proximal to the patella. Participants were then secured in the dynamometer chair—using a harness and straps at the ankle, thigh, and waist— with the hip flexed to approximately 90° and with the joint axis of the knee aligned with the dynamometer axis. Stimulation was conducted using a stimulator (DS7AH; Digitimer, Ltd., Welwyn Garden City, Hertfordshire, UK), and Spike2 software (v. 6, CED, Cambridge, UK) was used to control stimulation as well as record torque outputs. All torque data was obtained at a 100 Hz sampling rate and converted by a 12-bit A/D converter (Model 1401 Plus; CED, Cambridge, UK).

At the beginning of each session, maximum twitch torque was determined by applying single twitches with increasing stimulation frequencies. After a plateau in evoked torque was reached, the accompanying frequency was recorded and used in subsequent twitches. After a 3 min rest period, the subject conducted a 3-second isometric MVC knee extension with the knee flexed at a 90° angle and with verbal encouragement. A single evoked twitch was given preceding the MVC, during the MVC, and following the MVC.

In the baseline session only, the subject conducted two MVCs separated by 3 minutes of rest, and a third if estimated voluntary activation did not exceed ~70%. This provided a minimal familiarization with maximal voluntary efforts.

Analysis was performed offline using Spike2 by a single researcher for consistency. MVC torque (Nm) was determined as the highest attained plateau. Peak potentiated twitch torque and the increase in

torque following the mid-MVC evoked twitch were determined, and the ratio between them used as an estimate of voluntary activation. All torque values were determined to the nearest tenth of a Nm.

Results

Perceived pain

Figure 2 shows Subject P's VAS scores (mm) for perceived pain in each leg over the course of the experiment; a dotted line represents the peak group mean increase reported by Jayaraman, et al. (2004). In the concentric leg, the subject experienced only a minor increase in soreness at 24HR and 48HR. In the eccentric leg, the subject experienced a minor increase in soreness at POST and large increases in soreness at 24HR and 48HR. The following qualitative observations were also made: during the testing sessions for the 24HR and 48HR time periods, Subject P complained of substantial pain in the eccentric leg, both ambient and during activity, and was observed with a slight alteration in gait characterized by labored movements.
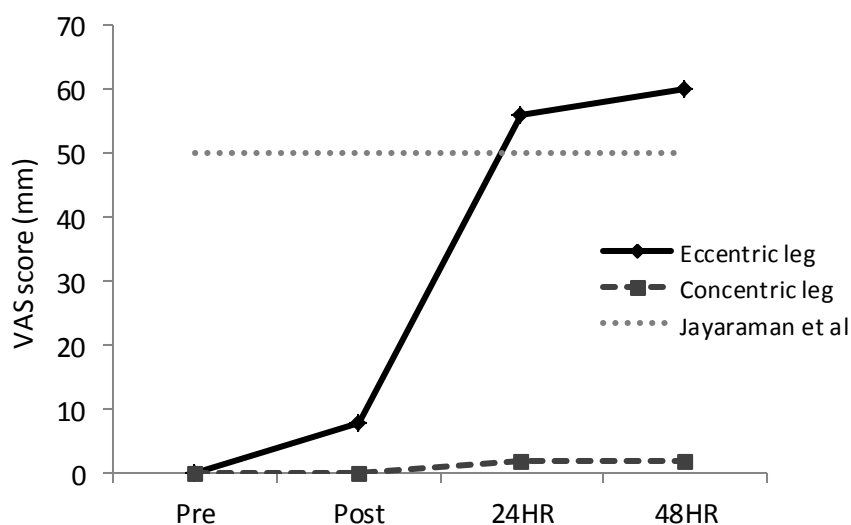

Figure 2. VAS scores (mm) for both legs of Subject P. Dotted line represents the peak group mean change in Jayaraman, et al. (2004).

T2 relaxation times

Figure 3 presents the series of T2 weighted magnetic resonance images for the eccentric leg in Subject P (darker colors correspond to greater signal strength). Both legs demonstrated a small increase in T2 relaxation times for the knee extensor compartment. Figure 4 demonstrates the relative increases from baseline in T2 times for both legs over time. A dotted line representing the peak change found by Jayaraman, et al. (2004) (who employed a similar methodology measuring damage in the quadriceps group) has been added to Figure 4 for comparison purposes. The peak increase for Subject P came at the 24HR time point for both legs: 8.3% for the eccentric leg and 4.8% for the concentric leg. The difference between both legs was minimal at all time points. Mean T2 relaxation times for the knee extensor compartment are presented in Table 4 and ranged from 51.95 ms to 56.25 ms in the eccentric leg and 54.15 ms to 56.74 ms in the concentric leg.
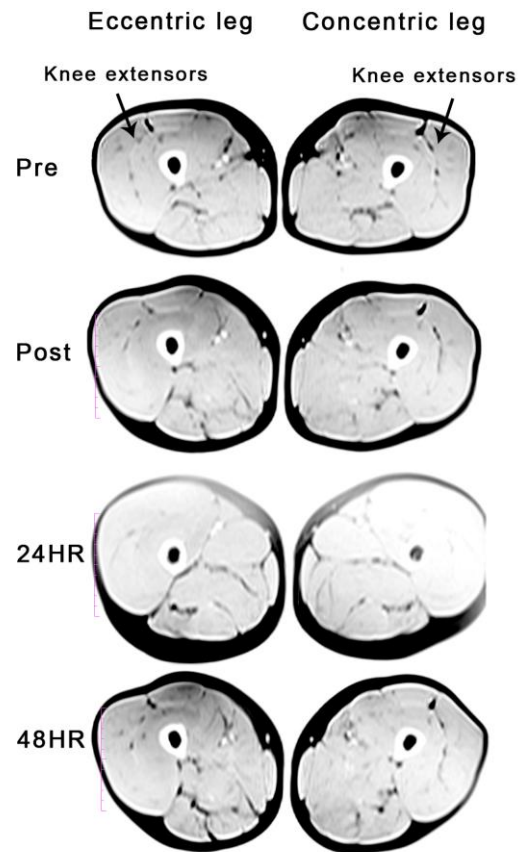
Figure 3. Mid-thigh single slice T2 weighted images from Subject P at each time point. Images are oriented so that the anterior direction is to the top.

Table 3. *Absolute multi-echo T2 values (ms) for the knee extensor compartment of Subject P.*

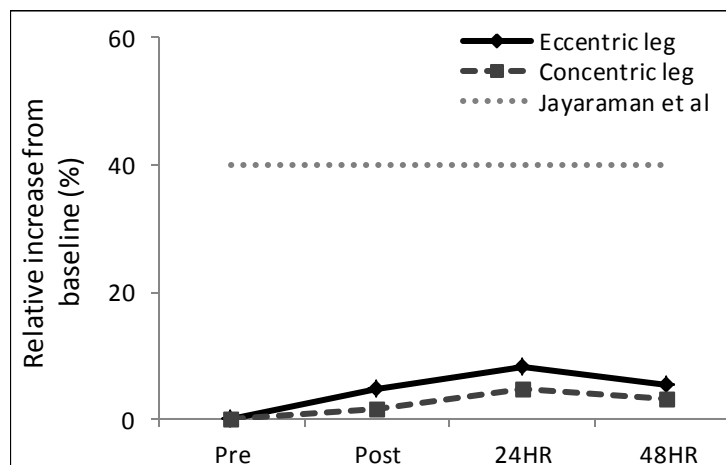|	Eccentric leg	Concentric leg
Pre	51.95	54.15
Post	54.38	54.95
24HR	56.25	56.74
48HR	54.81	55.87

Figure 4. Relative increase in T2 values over time for Subject P. The dotted line represents the peak group mean change observed in Jayaraman, et al. (2004).

Strength measures

Isometric MVC torque declined in both legs relative to baseline at POST and 24HR, but began to recover by 48HR (Fig. 5). Again for comparison, the peak decrease in strength reported by Jayaraman, et al. (2004) has been represented in Figure 5 by a dotted line. Peak relative decrease in strength occurred at 24HR and was a 14.8% loss in the eccentric leg and a 15.3% loss in the concentric leg; differences between legs were less than 2% at all time points.

At baseline, voluntary activation in both legs was approximately 95%, which is higher than a previously reported average found using the same technique in the quadriceps of 11 healthy males of the same age group (Krishnan & Williams, 2010). Subject P's voluntary activation declined at all time points after baseline (Fig 5). Due to an oversight during testing protocol, no interpolated twitch was given during testing for the eccentric leg at 24HR. Figure 6 represents this absence through a dotted line connecting the data points for POST and 48HR. At 48HR the subject reached 86.9% activation in the eccentric leg and 83.7% activation in the concentric leg, both of which are below the mean reported by Krishnan and Williams (2010).

Figure 7 shows relative changes in twitch torque of a potentiated twitch following MVC over time. In the concentric leg, potentiated twitch torque declined slightly by 5.2% and 5.6% at POST and 24HR respectively. At 48HR a peak decline at of 19.8% below baseline was observed. In the eccentric leg, a decline of 32.2% was observed at POST which continued to 35.2% at 24HR. At 48HR potentiated twitch showed a substantial recovery to only 18.0% below baseline.
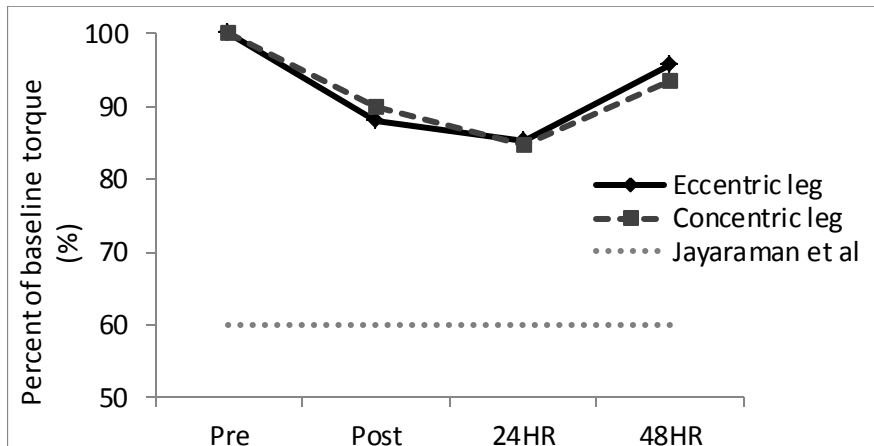

Figure 5. Decrease in MVC torque relative to baseline over time. Dotted line represents the peak group mean change in MVC torque observed in Jayaraman, et al. (2004).
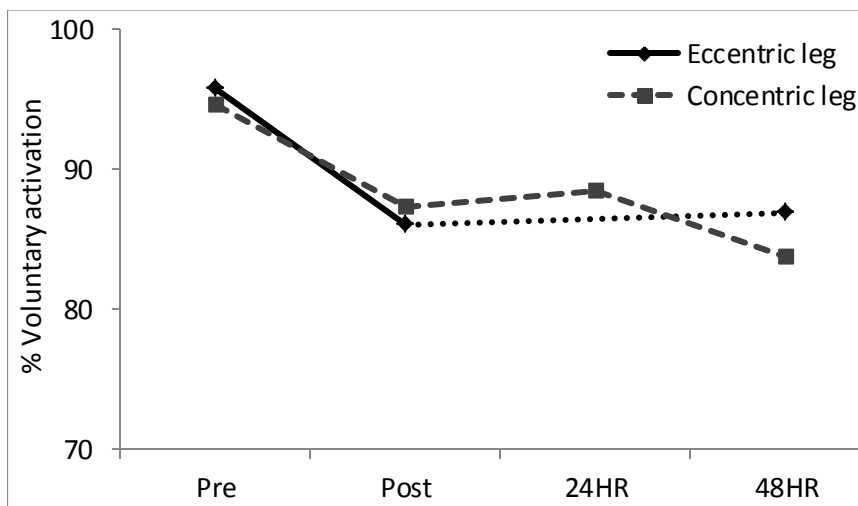

Figure 6. Estimated voluntary activation during MVC for Subject P. Reported as estimated percent of motor unit recruitment. The dotted line connects the POST and 48HR points for the eccentric leg—data for 24HR is missing due to an error during data collection.
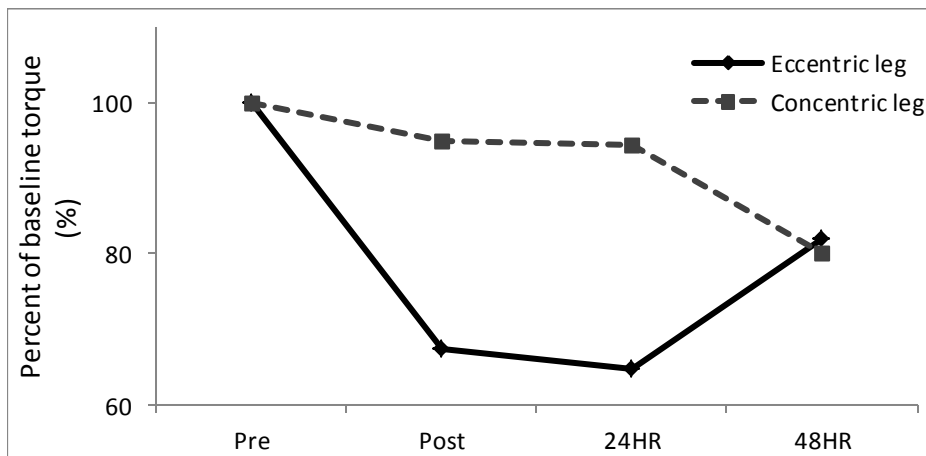
Figure 7. Change in potentiated twitch torque relative to baseline in Subject P.

Discussion

In the eccentric leg only, Subject P exhibited symptoms typical of DOMS. Only a small change in perceived pain was reported following exercise, while a large change was reported the day following exercise which lasted for at least 24 hours. The qualitative observations of frequent complaints of soreness and changes in gait support the conclusion that DOMS was induced in the eccentric leg.

Contrary to the findings of other investigations of injury following eccentric exercise protocols, Subject P did not show large changes in other criterion believed to represent muscle damage. Though isometric MVC torque did decline to a small degree (15%), it did so equally in both legs. For comparison, in a similar study of muscle damage in the quadriceps following eccentric exercise Jayaraman, et al. (2004) found a peak group mean decrease in isometric MVC force of 40%. Because estimated voluntary activation also declined in both legs, it may be suggested that the loss in MVC torque is related to the change in ability to activate motor units. This could also provide an explanation for the lack of difference between legs; the sensation of ambient pain in the eccentric leg may affect central fatigue—an underappreciated factor in voluntary torque generation—producing a bilateral decrement in activation and voluntary strength. To test this idea, it would be necessary to compare electrically stimulated contraction
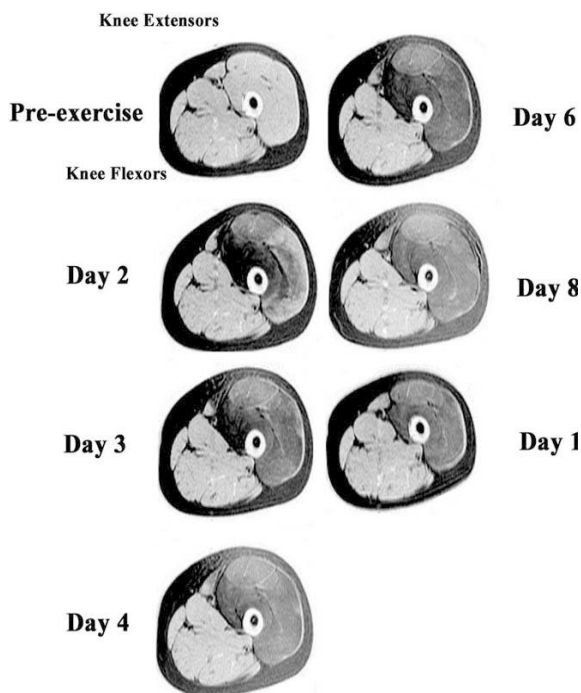
Figure 8. Representative mid-thigh T2 weighted images of one subject from a study conducted by Jayaraman, et al. (2004). The anterior direction is to the right and the medial direction is upward. Darker colors represent more signal. Reproduced from Jayaraman, et al. (2004).

torques and voluntary contraction torques in subjects experiencing contralateral DOMS. However, voluntary activation did not demonstrate the same recovery as strength at the 48HR time point. This seems to suggest that the decrease in voluntary strength was related to both motor unit activation and the ability of the muscle to generate force.

While T2 relaxation times in the eccentric leg demonstrated a change in the expected direction, they did not provide convincing evidence of muscle damage. The increase in mean T2 value for the eccentric leg peaked at only 8% while Jayaraman, et al. (2004) report a peak group mean increase of 40%. the observed 8% change corresponds to an increase of 4.3 ms, while a 40% change would have been an increase of 22.5 ms. Secondly, the difference between the eccentric and concentric legs was minimal, and both displayed the same pattern of peak at 24HR followed by a partial recovery at 48HR. Qualitative assessment of the T2 weighted images supports the conclusion that the eccentric leg did not experience EIMD. A representative set of MR images from Jayaraman, et al. (2004) (Fig.8) shows a clear change in signal for the knee extensor compartment relative to the knee flexor compartment over time. Subject P's MR images (Fig. 3) show no apparent change in signal.

Potentiated twitch torque was the only measure aside from perceived pain that demonstrated a difference between legs. In the eccentric leg, a 32% decrease from baseline was observed at POST, while the concentric leg decreased only 5.2%. This change was still evident at 24HR. At 48HR, however, the

eccentric leg experienced a partial recovery in potentiated twitch torque, while the concentric leg experienced a decrease in torque. Future research should therefore investigate the relationship between DOMS and post activation potentiation or the relationship between eccentric contractions and changes in potentiation.

As noted, some comparisons have been made with Jayaraman, et al. (2004). Some differences must be noted between their study and the current case that may limit the validity of these comparisons. Most importantly, the exercise protocols used cannot be directly compared. The current study set loads based on estimated 1RM weight, performed 5 sets of on average greater than ten repetitions, and performed sets to failure of the concentric leg; in contrast, Jayaraman, et al. (2004) set loads based on 100% MVC torque, performed 6-8 sets of 5-10 repetitions, and performed sets until eccentric lowering could not be performed satisfactorily. As such, the exercise conducted in the current study should be interpreted as greater in volume and lower in intensity than the protocol conducted by Jayaraman, et al. (2004). Comparisons between changes in MVC may also be complicated by differences in joint angle employed by the current study and Jayaraman, et al. (2004) (90° and 165° respectively). Due to the force-length relationship of muscles, peak isometric torque production will vary with joint angle.

Prescribed loads for the exercise protocol based on a dynamic 1RM produced an interesting result. 80% of 1RM was chosen because this load typically represents an eight repetition maximum. When work was then divided into purely concentric or eccentric contractions, the concentric leg reached an 18 repetition maximum in the first set. This implies that the eccentric portion of dynamic weightlifting is a considerable contribution to the work performed and has a large effect on the number of repetitions to failure. Future research separating eccentric and concentric actions must take into account the change in total work being performed. Also, DOMS experienced by athletes following traditional weightlifting may be a product of the eccentric work performed in a typical lift-and-lower exercise.

Conclusions

Without considering the concentric leg, the MVC torque decreases and T2 value increases in the eccentric leg resemble what would be expected had Subject P experienced very minimal EIMD. It may be possible that mild muscle damage was induced to the same degree in both the concentric and eccentric legs; however, pain increased greatly only in the eccentric leg, and thus muscle damage cannot account for the DOMS experienced in only the eccentric leg. To the knowledge of the researchers involved in conducting this study, this case—an individual experiencing DOMS without appreciable signs of muscle damage—is unique in the published research.

Because this is a single case, the findings of this study may be affected by inter-subject variability in the validity of the chosen measures of muscle damage. A study by Evans, Haller, Wyrick, Parkley, and Fleckenstein (1998) employing T2 relaxation times as a measure of damage after a submaximal eccentric exercise protocol reported high standard deviations for changes in perceived pain and T2 relaxation times. Because the current study is only a single case, it may be possible that Subject P is an outlier within the general population and experiences only small changes in T2 relaxation times with muscle damage. However, other studies utilizing T2-weighted MRI have not reported large variability (Jayaraman, et al., 2004; Yanagisawa, Kurihara, Kobayashi, & Fukubayashi, 2011), and no study was found reporting sufficient variability of changes in measures of strength to explain the absence of a unilateral decrease in MVC torque for the leg experiencing DOMS.

Because the physiological implication of the current case—that muscle damage is not the primary cause of DOMS—is contrary to the assumptions of many prior studies, some speculative explanation is required. Most of the research employing eccentric exercise protocols to study DOMS utilizes a very high intensity protocol to ensure a positive result. It may be that such intense exercise is not required to produce DOMS, and in seeking a positive result for soreness, researchers have coincidentally stressed muscles more than is necessary and have induced muscle damage. Then, the coincidence of DOMS and other measures of damage has been interpreted as evidence of a causal relationship between DOMS and

muscle damage, though correlational evidence has been shown to be weak (Nosaka, Newton, & Sacco, 2002; Rodenburg, et al., 1993; Nurenberg, et al., 1992; Warren, et al., 1999). Instead, the findings of the present study would indicate that the underlying causes of DOMS are related to the physiological differences between eccentric and concentric contractions. These differences must be well understood and isolated before the cause of DOMS can be properly established.

Subject P provides only an isolated case, and further research is necessary to extend these findings. Future investigations should utilize as many additional measures of muscle damage associated with EIMD as possible, such as circulating chemical markers of damage, histological analysis, and changes in range of motion in an attempt to confirm the findings of this case. If the results of this case can be replicated in other subjects using a similar protocol, it will indicate that DOMS is not caused by muscle damage. If true, this conclusion would have a large impact on past and future research attempting to characterize and treat DOMS. It would be necessary to critically reassess past research on DOMS, EIMD, and any eccentrically induced injury so that clear and separate definitions of each term could be developed. Once these terms have been clearly defined, it will be possible to more effectively design experiments for both treatments of DOMS and further investigations of the underlying physiological causes.

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