Damage to the human quadriceps muscle from eccentric exercise and the training effect

E.J. BOWERS,1 D.L. MORGAN2 and U. PROSKE1*

1Department of Physiology and 2Department of Electrical and Computer Systems Engineering, Monash University, Melbourne, VIC 3800, Australia

Accepted 23 October 2003

Nine participants performed two bouts of a step exercise, during which the quadriceps muscle of one leg acted eccentrically. Before and after the exercise, isokinetic torque was measured over a range of knee angles to determine the optimum angle for torque. Immediately after the first bout of exercise, the quadriceps showed a significant \( P < 0.05 \) shift of \( 15.6 \pm 1.4^\circ \) (mean \( \pm s_\text{D} \)) of its optimum angle in the direction of longer lengths, suggesting the presence of damage. A drop in peak torque, together with delayed soreness and swelling, confirmed that damage to muscle fibres had occurred. After the second bout of exercise, 8 days later, the shift in optimum angle was \( 10.4 \pm 1.0^\circ \), which was significantly less than after the first bout \( (P < 0.05) \). Other indicators of damage were also reduced. In addition, the muscle exhibited a sustained shift in optimum angle \( 3.4 \pm 0.9^\circ \), suggesting that some adaptation had taken place after the first bout of exercise. We conclude that muscles like the quadriceps can show evidence of damage after a specific programme of eccentric exercise, followed by an adaptation response. This is despite the fact that the quadriceps routinely undergoes eccentric contractions in everyday activities.

Keywords: adaptation, eccentric exercise, muscle damage, quadriceps.

Introduction

Muscles exert an eccentric action when they are lengthened while generating active tension. This occurs when muscles act as brakes to slow or stop the motion of the body such as during walking downstairs or lowering a weight. It has been well documented that unaccustomed eccentric exercise leads to damage in the exercised muscle fibres (Armstrong et al., 1983; Friden et al., 1983b; Newham et al., 1983a; McCully and Faulkner, 1985; Jones et al., 1986; for reviews, see Morgan and Allen, 1999; Proske and Morgan, 2001). This is followed by sensations of stiffness and soreness in the exercised muscles the next day (Hough, 1902). The soreness is commonly referred to as delayed-onset muscle soreness (Asmussen, 1956; Armstrong, 1984) and has been linked with the inflammatory response triggered by damage to the muscle fibres (Armstrong et al., 1983; Smith, 1991).

One of the indicators of muscle damage present immediately after eccentric exercise is a shift in the direction of longer muscle lengths of the muscle’s length–tension relation (Wood et al., 1993; Morgan et al., 1996; Jones et al., 1997; Brockett et al., 2001). This shift has been attributed to the over-extension of sarcomeres following eccentric contractions, which produces an increase in compliance in series with active sarcomeres (Morgan, 1990). It has been shown to reverse over periods ranging from a few hours (Talbot, 1997) to 2 days (Jones et al., 1997). The reversal is presumably the result of some over-extended, disrupted sarcomeres recovering their normal function, as myofilaments re-interdigitate (Talbot and Morgan, 1996).

There are two other damage indicators present immediately after a period of unaccustomed eccentric exercise. One is the drop in force due to damage to muscle fibres. However, this is confounded by the effects of fatigue. The second is a rise in whole muscle passive tension (Jones et al., 1986; Whitehead et al., 2001, 2003). Muscle soreness and swelling do not become apparent until 24 h after the exercise.

Length–tension relations for human muscle can be described using torque–angle curves. Immediately after a period of eccentric exercise, a shift in the optimum

* Address all correspondence to e-mail: uwe.proske@med.monash.edu.au
angle for peak torque towards longer muscle lengths has been shown for the human forearm flexors (Saxton and Donnelly, 1996), triceps surae (Jones et al., 1997) and hamstrings (Brockett et al., 2001) and has been shown to correlate with other indicators of damage (Proske and Morgan, 2001).

It is known that a muscle is able to adapt to eccentric exercise so that a second period of the same exercise, repeated a week after the first, is accompanied by much less soreness and stiffness and a more rapid recovery of strength (Friden et al., 1983a; Clarkson and Tremblay, 1988; Nosaka et al., 1991; Brockett et al., 2001). This training effect is accompanied by a shift of the length–tension curve in the direction of longer muscle length (Brockett et al., 2001) as a result of incorporation of extra sarcomeres in muscle fibres (Morgan, 1990; Lynn and Morgan, 1994).

So it is proposed that there are two shifts in the active length–tension relation of muscle following unaccustomed eccentric exercise. The first shift is due to the presence of damage, the second due to an adaptation response. In studies of human muscles, measurements of length–tension relations after eccentric exercise in the triceps surae have revealed the initial shift in optimum length due to damage, but not a significant training shift (Jones et al., 1997). For the hamstrings, on the other hand, both shifts in optimum could be identified (Brockett et al., 2001). One possible explanation for this is that the triceps surae undergoes eccentric contractions during everyday activities and so may already be in a partially trained state, whereas the hamstrings do not routinely contract eccentrically and so are more prone to damage.

A muscle like the quadriceps carries out concentric contractions during level walking and when climbing stairs, whereas it is subjected to eccentric contractions during walking downstairs. So this muscle group is routinely exposed to eccentric exercise. This raises the question, is the quadriceps, like the triceps surae, already in an adapted state and therefore protected against further damage?

The aim of this study was to determine whether the quadriceps is susceptible to damage from a targeted programme of eccentric exercise. To test this, a programme of eccentric exercise was devised whereby participants carried out a simple step test of a kind encountered in everyday life, but with a larger step than would normally be encountered. After the exercise, evidence was sought both for a transient shift in optimum length due to damage and a subsequent, maintained shift representing a training effect. These kinds of measurements are important for identifying muscle groups at risk of becoming damaged and sore during sport and exercise.

Methods

Participants

A total of nine participants (4 males, age 22.0 ± 0.7 years; 5 females, age 24.0 ± 2.1 years) took part in the study. All gave their written, informed consent to participate in the experiments, which had been approved by the Monash University Human Ethics Committee. All participants were in good health. They were neither involved in current weight training of their lower limb muscles or exercise programmes, nor did they have any existing musculoskeletal injuries.

Apparatus

The apparatus used to test the torque–angle relationship of the knee extensors was a Biodex® System 3 Quick Set dynamometer (Shirley, NY, USA). The digital signals from the Biodex® were directly available through the system’s software. All data were digitally stored and analysed using the program Igor Pro® (Wavemetrics, Lake Oswego, OR, USA).

The test protocol consisted of seven isokinetic concentric contractions of the hamstrings and quadriceps, performed at 1.04 rad·s⁻¹. Previous experiments (Brockett et al., 2001) have shown that torque–angle curves can be reliably generated with concentric contractions at that angular speed.

Muscle measurements

Participants lay in the prone position. This ensured that the bi-articular knee extensors were extended at the hip. The ankle of the experimental (right) leg was firmly attached to the force-recording arm of the dynamometer, with extra care taken to align the extension–flexion axis of the knee joint with the axis of rotation of the arm of the apparatus. Straps were placed over the participants’ lower back and thighs to minimize movements other than knee flexion and extension of the experimental leg.

The knee angle, the angle subtended between the front of the thigh and the shin, was assigned 0° when the arm of the dynamometer was horizontal and 90° when it was perpendicular (Fig. 1a). Zero angle was checked each day with a spirit level. The sequence of movements began with full knee extension, which was slightly beyond the reference 0°. Participants contracted their hamstrings to produce knee flexion, until the leg was beyond the reference 90°. They then performed a maximal contraction of the quadriceps to return to the starting position. Torque values were taken as negative during flexion (hamstrings) and as positive during extension (quadriceps) (Fig. 1b). Each sequence of contractions was carried out over a range of knee angles.
of approximately 115°. An increase in knee angle represented an increase in quadriceps length.

**Eccentric exercise**

To exercise the quadriceps, participants performed a step test, where the quadriceps of the right leg acted eccentrically as the participant stepped down from a platform. The height of the step was adjusted so that it was level with the apex of the patella. This ensured that for participants of different sizes, the muscle moved through a similar length range. It also meant that the length range the muscle went through was greater than during normal walking down stairs. This procedure had been used previously and was shown to lead to muscle soreness (Newham et al., 1983b).

The participants were asked to step up onto the platform, leading with their left leg and place the left foot flat on the platform, followed by the right leg. Raising the body involved a concentric contraction of the left knee extensors. Once both feet were on the platform, the participant stepped slowly off the platform, again leading with the left leg, so that the quadriceps of the right leg contracted eccentrically as it supported the weight of the body and controlled flexion at the knee during the downward phase of the step. The left foot was placed flat on the ground, followed by the right foot.

All participants were instructed that the movement was to be performed in a slow and controlled manner and the foot must be placed flat on the ground so that only the right quadriceps and no other muscles, particularly the left ankle extensors, acted eccentrically. Participants were required to carry out 12 sets of 20 steps (240 in total) with a rest period after each set. When participants felt comfortable enough to return to the exercise, the step test was continued.

**Experimental protocol**

The participants performed two bouts of step exercises. The second bout of exercises was performed 8 days after the first.

Measurements of the indicators of muscle damage (decrease in peak torque, shift in the torque–angle curve, soreness and swelling) were made before the first bout of eccentric exercise and immediately afterwards, then at 2 h and 1, 2, 3 and 6 days after exercise. Measurements were made at the same times after the second bout of exercise, with an additional measurement made at 16 days to determine whether any sustained shift in the torque–angle curve had been achieved. The measurements taken before the first bout of eccentric exercise were used as controls. The 2-h post-exercise measurement was included as the earliest possible time at which there was no longer significant metabolic fatigue (Faulkner et al., 1993).

**Experimental measures**

**Optimum angle for torque and peak torque**

To construct a torque–angle curve, a recording was made of the extension and flexion movements about the
knee. Torque (N·m) and angle (degrees) were sampled at 1-ms intervals throughout each of the seven contractions of the quadriceps and hamstrings muscles (Fig. 1b). The sampled torque data were then ordered according to direction of motion and knee angle to produce a composite torque–angle curve for the seven cycles (Fig. 2a).

To determine optimum angle – that is, the knee angle at which the quadriceps generated maximum torque – a curve was fitted to the points higher than 70% of the peak values. As the torque–angle curves were clearly not symmetrical, an asymmetric curve was used to ensure a good fit to the data. The curve consisted of two inverted parabolic segments, each with its peak at the peak of the plot. The parameters that were adjusted during the fitting were the position of the peak, the height of the peak and curvature to the left and right of the peak. The optimum angle for torque generation was determined from the peak of the fitted curve and maximum torque was measured at that point.

The composite torque–angle curve for the seven contraction cycles was then decimated using the program Igor Pro¹ (Wavemetrics, Lake Oswego, OR, USA) to provide an average plot comprising 60 data points (Fig. 2b). The data were stored in this compressed form.

Soreness

Soreness was reported subjectively using a visual analogue scale of 0 to 10, where 0 represented ‘no pain’ and 10 represented ‘intolerably intense pain’. The participants were required to indicate the severity of soreness in their quadriceps in response to muscle compression at the start of each measurement session.

Swelling

Swelling was measured by taking girth measurements of the thigh at three sites (upper, middle and lower thigh). The locations were marked with permanent ink to ensure that repeat measurements were made at the same sites at each session.

Statistical analysis

For all parameters measured, means and standard errors of the mean (±s) were calculated. Changes in the optimum angle were calculated for each participant. Peak torque was expressed as a percentage of control values (100%).

Two-factor analysis of variance (ANOVA) was used to test for significance in the changes throughout the 16 experimental sessions for each parameter. The two factors were participant and session. The statistics program Data Desk (Ithaca, NY, USA) was used. Statistical significance was set at P < 0.05. Where an ANOVA was significant, a Least Significant Difference (LSD) post-hoc test was used to identify the sessions in which significant changes had occurred.

To compare the changes after the first and second bout of exercise, the sessions from 2 h to 8 days after the first bout were grouped and called ‘test set 1’ and compared with the group of sessions from 2 h to 16 days after the second bout of exercise (called ‘test set 2’) using a two-factor ANOVA. The two factors were participant and test set.

![Fig. 2.](image-url) (a) To estimate the optimum angle, torque records were ordered according to direction of the movement and knee angle (°) to produce a composite torque–angle curve for the seven repetitions. A curve was fitted to the points above 70% of the peak, to locate the optimum angle. The arrows indicate the directions of limb movement during the contractions. (b) To facilitate storage of the data, they were compressed by a decimation process that calculated the average of the seven traces over 60 segments of the records. Each dot represents an average value.
Results

The length–tension relations for the quadriceps were measured by means of isokinetic dynamometry. This yielded reliable torque–angle curves, similar to those previously described for the hamstrings (Brockett et al., 2001).

Shift in optimum angle

Torque–angle curves for the quadriceps were used to determine the optimum angle for peak torque. A typical example of the torque–angle relation measured before and immediately after the two bouts of eccentric exercise for one participant is shown in Fig. 3. The optimum angle for this participant was initially 73°. It then shifted by 10° immediately after the first bout of exercise to 83°, while torque dropped by 18 N•m, a 9% decrease. After the second bout of eccentric exercise 8 days later, torque dropped by 4% while the optimum angle shifted by 5°.

Because values for optimum angle varied from one participant to the next, we decided not to plot actual measurements but changes in optimum angles from control values. Differences in values for the two control measurements were small. Therefore, the mean optimum for the control sessions was scored zero and the actual differences (±s) for each control measurement have been plotted (Fig. 4).

Immediately after the first bout of exercise, and over the next 8 days, there was a shift in optimum angle in the direction of longer muscle lengths ($P < 0.05$; two-factor ANOVA, participant and session). The average shift was 15.6 ± 1.4° (Fig. 4). LSD post-hoc tests showed that the mean optimum angle measured over the 8 days after the first bout of exercise was different from the control value ($P < 0.05$). By the eighth day it was still different ($P < 0.05$; LSD post hoc test), being 3.4 ± 0.9° greater than the control value.

Immediately after the second bout of exercise, the mean optimum angle showed a shift to a value 10.4 ± 1.0° greater than the value before the first exercise ($P < 0.05$; LSD post hoc test). This was followed by a slight fall over the next 3 days to a value that was largely maintained for the remainder of the period of measurement. At day 14, the optimum angle was longer than the original pre-exercise control value by 4.0 ± 0.7°. At day 24, it was 3.5 ± 0.4° longer. Mean shifts for all values were different from pre-exercise values up to and including the sixteenth day after the second bout of exercise ($P < 0.05$; LSD post-hoc tests). The shift immediately after the second bout of exercise was smaller than that after the first bout ($P < 0.05$; two-factor ANOVA, participant and test set). For both bouts of exercise, the shift in optimum reached its peak immediately after the exercise.

Further analysis compared the two control measurements with that made on day 24. An ANOVA with shift in optimum angle as the dependent variable and session and participant as factors showed, for sessions 1 and 2 (controls) and session 16 (day 24), that both participant and session were significant. A Bonferroni post-hoc test

![Fig. 3. Torque–angle relations for the quadriceps before and immediately after eccentric exercise for one participant. Open circles indicate torque–angle curves before eccentric exercise and solid circles torque–angle curves after eccentric exercise. Arrows indicate optimum angle for torque. Panel (a) shows a shift in optimum angle to longer muscle lengths of 10° immediately after the first bout of eccentric exercise. Torque fell from 226 N•m to 208 N•m, representing a 9% decrease. (b) The shift in optimum angle and drop in torque were less pronounced after the second bout of eccentric exercise. The optimum angle shifted by 5° to longer lengths while torque fell by 4%.](image-url)
showed that sessions 1 and 2 were not different from one another \((P = 0.19)\), but both sessions 1 and 2 were different from session 16 \((P < 0.01)\).

**Fall in peak torque**

Mean peak torque fell by 25.3% to 74.8% ± 2.9% of the control value immediately after the first bout of exercise \((P < 0.05; \text{LSD post-hoc test})\) (Fig. 4). Peak torque gradually recovered, returning to near control values over the following 8 days. Peak torque on the eighth day had ceased to be different from the control values. Following the second bout of exercise, torque fell by an average of 11.7%, to 84.3 ± 1.8% of control values \((P < 0.05; \text{LSD post-hoc test})\). However, this time torque recovered more rapidly and it was no longer significantly different from control values by 24 h. The overall reduction in peak torque after the second bout of exercise was less than that after the first bout \((P < 0.05; \text{two-factor ANOVA, participant and test set})\).

The results showed that there was a significant relationship between fall in torque and shift in optimum angle \((P < 0.05; \text{two-factor ANOVA})\). A regression analysis carried out on the individual values for shift in optimum angle and drop in torque showed a weak correlation \((r^2 = 28.9\%)\).

**Swelling and soreness**

All participants experienced delayed-onset muscle soreness in the quadriceps of their experimental leg after both bouts of eccentric exercise, with reports that soreness was felt whenever the muscle was palpated, contracted or stretched during knee flexion. Soreness was delayed and did not become apparent until 24 h after the exercise. It peaked at 48 h after the first bout of exercise with a mean rating of 5.5 ± 0.34 on a scale of 0–10 (Fig. 5). Soreness gradually decreased over time and had disappeared by 6 days post-exercise. After the second bout of exercise, soreness peaked slightly earlier, at 24 h after the exercise, and was less than the soreness experienced after the first bout \((1.44 ± 0.34; P < 0.05; \text{two-factor ANOVA, participant and test session})\).

Using a Wilcoxon signed rank test, soreness at 24 and 48 h after the first bout of exercise was compared with soreness 24 and 48 h after the second bout. For both
times, soreness after the first bout was significantly greater ($P < 0.01$). All participants reported that soreness had disappeared within 72 h of completing the second bout of exercise (Fig. 5).

As well as the drop in torque and shift in optimum angle, another indicator of muscle damage was an increase in leg girth as a result of muscle swelling (Fig. 5). A small amount of swelling was evident after both bouts of exercise. After the first bout of exercise, girth measurements peaked at 72 h ($0.6 \pm 0.06$ cm; $P < 0.05$) and then gradually subsided so that, by the eighth day, girth had returned to control values. The pattern after the second bout of exercise was similar, with girth at the middle thigh again peaking at 72 h. However, the increases were much smaller ($0.28 \pm 0.05$ cm), although still greater than control values ($P < 0.05$).

**Discussion**

The present experiments were designed to test the hypothesis that the quadriceps muscle, which acts both concentrically and eccentrically during everyday activities, can become damaged after a programme of eccentric exercise and that subsequently the muscle is able to show an adaptation response. Indicators of damage used were a shift in optimum angle for torque in the direction of longer muscle lengths, a fall in torque, development of delayed-onset muscle soreness and muscle swelling.

Muscle damage in the quadriceps was produced by what participants considered to be moderate exercise. Neither was the step test performed at any particular speed, nor did it require maximal strength. It meant that the participants did not tire during the exercise and, by implication, fatigue remained at low levels. Therefore, the post-eccentric changes could not simply be assigned to the effects of fatigue. The exercise required participants to take bigger steps than during normal walking down stairs. It meant that the muscle was stretched to longer lengths than normal, and therefore was more likely to become damaged. Consistent with that view was the finding that, immediately after the first bout of eccentric exercise, peak force had dropped by 25.3% with very little recovery by 2 h post-exercise. It meant that most of the drop in force was due to damage, not fatigue. All of this suggests that

![Fig. 5. Mean soreness ratings scored on a scale of 0–10 and maximum muscle swelling expressed as mean change in circumference of the thigh (cm) for nine participants after two bouts of eccentric exercise (means $\pm s_e$). * Significantly different to the average of the pre-exercise values. Vertical dashed lines indicate the time of eccentric exercise.](image-url)
exhausting exercise, employing near maximal forces, is not necessary to produce muscle damage in humans (see Friden et al., 1983b; McCully and Faulkner, 1985).

**Damage indicators**

The fall in peak torque immediately after the eccentric exercise confirms previous reports for the ankle extensor muscles (Jones et al., 1997), knee flexor muscles (Brockett et al., 2001), as well as other muscle groups (Armstrong, 1990; Proske and Morgan, 2001). A drop in torque immediately after exercise is expected to include metabolic fatigue as well as damage to muscle fibres (Proske and Morgan, 2001).

Both delayed-onset muscle soreness and swelling were evident in all participants after eccentric exercise, a result reported previously (Hough, 1902; Newham et al., 1983b; Armstrong, 1984; Jones et al., 1986). Soreness peaked at 48 h after the first bout of exercise and at 24 h after the second bout of exercise. Circumference of the thigh, indicating swelling, was shown to peak at 72 h after both bouts of exercise. Therefore, consistent with previous findings (Clarkson et al., 1992), swelling peaks at a time when soreness is beginning to subside and is therefore unlikely to be directly responsible for the pain.

While girth measurements determine thigh circumference and therefore include both the hamstrings and quadriceps, it is unlikely that any swelling was due to the hamstrings. No participant reported any soreness in the hamstrings of the test leg after the exercise, and therefore an inflammatory response was unlikely to have developed in this muscle group.

The present experiments used a shift in optimum angle of the muscle’s active length–tension relation as the primary indicator of muscle damage. Previous experiments have shown that such a shift, measured immediately after exercise, is a more consistent indicator of eccentric exercise-induced muscle damage than the drop in torque (Wood et al., 1993; Jones et al., 1997; Talbot and Morgan, 1998). The fall in torque may be complicated by the effects of fatigue. Both swelling and soreness are delayed by 24 h in their onset.

Immediately after the eccentric exercise, the optimum angle of the quadriceps muscle shifted in the direction of longer muscle lengths (Fig. 3). The explanation for the shift is based on a postulated primary event that leads to eventual muscle damage. It has been known for some time that the descending limb of the length–tension curve is a region of sarcomere length instability (Gordon et al., 1966). It has been proposed that during an active stretch, most of the length change will be taken up by the weakest sarcomeres in the myofibrils (Morgan, 1990). These sarcomeres over-extend to the point of no myofilament overlap. At the end of the stretch, when the muscle relaxes, myofilaments in most of the over-extended sarcomeres manage to re-interdigitate to resume their normal length and function. However, a few may fail to do so, resulting in ‘disrupted’ sarcomeres (Talbot and Morgan, 1996). The presence of these over-extended, disrupted sarcomeres increases the effective series compliance of the muscle. This should be seen as a non-linear compliance leading to an increase in rest length of the damaged fibres and therefore a high compliance at short lengths (Whitehead et al., 2001). The increase in compliance leads to a shift in the muscle’s optimum length for tension, in the direction of longer muscle lengths.

In the quadriceps, the amount of damage present after a first period of eccentric exercise, when expressed as a shift in optimum angle, was 15.6°. This was rather larger than the 7.7° reported for the hamstrings (Brockett et al., 2001) and 3.9° reported for the triceps surae (Jones et al., 1997). The simplest explanation for this difference is that each kind of exercise – stepping backwards on a moving treadmill for the triceps surae, a series of controlled falls for the hamstrings and the step test for the quadriceps – involved active stretches that covered different regions of each muscle’s length–tension relation, thus resulting in different amounts of damage.

**The training effect**

In this study, 2 h after the first bout of exercise, the optimum angle for the quadriceps began to reverse, gradually returning towards control values. However, a complete reversal of the shift to pre-experimental values did not occur. By the eighth day after the first bout of exercise, the optimum angle had a value representing a muscle length that was still significantly longer than the pre-exercise control value (Fig. 4).

We chose to carry out the second bout of exercise 8 days after the first. This is rather sooner than the interval used by previous researchers (Newham et al., 1987). We argued that since by 8 days all of the damage indicators – a drop in torque, swelling and pain – had become non-significant, the repair process was almost complete. It therefore made it unlikely that these factors would confound the effects of the second period of exercise.

After the second bout of exercise, which was similar in intensity and covered a similar length range as the first, although there was some evidence of damage, all of the damage indicators were less pronounced. The shift in optimum angle measured immediately after the exercise was less, there was less soreness and swelling and a smaller fall in torque. Interestingly, there was also
a sustained shift in optimum angle. When measured at 24 days it was significantly longer than the original control value (Fig. 4) and similar to the value measured at 8 days. This result suggests that an adaptation process had taken place in the muscle, which was responsible for about 3.5° of shift in optimum. A second bout of the same exercise did not increase the adaptation response any further.

While details of the mechanism responsible for the adaptation process are still to be elucidated, it has been proposed (Morgan, 1990) that after a bout of unaccustomed eccentric exercise, muscle damage is repaired and additional sarcomeres are incorporated into the repaired muscle fibres, effectively reducing sarcomere length for a given fibre length. This means that during an eccentric contraction fewer sarcomeres are likely to be stretched onto the descending limb of their length–tension curve, the region of instability. Supporting evidence comes from experiments which showed that in rats that had been trained to run downhill, the muscle fibres of the vastus intermedius showed an increase in numbers of sarcomeres in series, compared with animals trained to run uphill (Lynn and Morgan, 1994). However, the length of fibres for a given joint angle remained the same. With more sarcomeres in series, over the same length, optimum length for tension will shift towards longer lengths. This makes it less likely that within its normal working range, the muscle is stretched onto the descending limb of its length–tension relation. Therefore, the adaptation response provides protection against further damage from subsequent eccentric exercise.

So during everyday activities that involve eccentric contractions like, for the quadriceps, walking down stairs, we do not typically become sore because our muscles are adapted to this exercise. Only if the muscle is stretched further than its normal working range is any soreness likely to set in.

It is a common experience that a bout of unaccustomed exercise, but with the muscle apparently working within its normal range (e.g. during running), can still lead to some soreness. Our interpretation is that during the eccentric phase of activities like running, small amounts of damage do occur. However, the exercise must be continued for long enough for the damage to spread to the point where it manifests itself as soreness the next day.

The quadriceps routinely performs concentric contractions when we walk up stairs and eccentric contractions when we walk down stairs. Previous work from our laboratory has shown that a period of training with concentric exercise leads to an increase in a muscle’s susceptibility for damage from eccentric exercise (Whitehead et al., 1998). So, if the eccentric contractions in the quadriceps lead to a protective training effect, the concentric contractions would be expected to work in the opposite direction. That means that a working muscle like the quadriceps is likely to be in a constantly changing dynamic equilibrium, depending on the particular demands of the exercise being performed at the time.

In conclusion, we have demonstrated that changes in muscle properties, consistent with the presence of muscle damage, can be demonstrated for the quadriceps muscle after a simple step-test exercise. In addition, there was evidence of a training effect, since a second bout of exercise was followed by fewer signs of damage. The evidence for damage and the training effect have been shown in a muscle that in everyday life is routinely subjected to eccentric exercise. However, given that quadriceps also regularly undergoes concentric contractions, it is not clear what state of protection it is in, although it is obviously sufficient to prevent the onset of any soreness. What our results do indicate is that most muscles, regardless of their everyday activities, are likely to exhibit a degree of vulnerability to specific, targeted programmes of eccentric exercise, provided the exercise is performed over the appropriate length range. This means that if someone unaccustomed to eccentric exercise wants to ensure that they do not suffer the debilitating effects of muscle damage and delayed-onset muscle soreness, they should participate in a programme of eccentric exercise vigorous enough to provoke an adaptation response, yet mild enough not to leave them seriously debilitated afterwards.

References


