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Identifying athletes at risk of hamstring strains and how to protect them

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Summary

1. One common soft-tissue injury in sports involving sprinting and kicking a ball is the hamstring strain. Strain injuries often occur while the contracting muscle is lengthened, an eccentric contraction. We have proposed that the microscopic damage to muscle fibres which routinely occurs after a period of unaccustomed eccentric exercise, can lead to a more severe strain injury.

2. An indicator of susceptibility for the damage from eccentric exercise is the optimum angle for torque. When this is at a short muscle length, the muscle is more prone to eccentric damage. It is known that subjects most at risk of a hamstring strain have a previous history of hamstring strains. By means of isokinetic dynamometry, we have measured the optimum angle for torque for 9 athletes with a history of unilateral hamstring strains. We also measured optimum angles for 18 athletes with no previous history of strain injuries. It was found that mean optimum angle in the previously injured muscles was at a significantly shorter length than for the uninjured muscles of the other leg and for muscles of both legs in the uninjured group. This result suggested that previously injured muscles were more prone to eccentric damage and therefore, according to our hypothesis, more prone to strain injuries than uninjured muscles.

3. After a period of unaccustomed eccentric exercise, if the exercise is repeated a week later, there is much less evidence of damage because the muscle has undergone an adaptation process which protects it against further damage. We propose that for athletes considered at risk of a hamstring strain, as indicated by the optimum angle for torque, a regular program of mild eccentric exercise should be carried out. This approach seems to work since evidence from one group of athletes, who have implemented such a program, shows a significant reduction in the incidence of hamstring strains.

Introduction

Hamstring strains are a common soft-tissue injury in sports such as Australian football and track and field events, including sprinting and hurdling. The Australian Football League (AFL) has the hamstring strain at the top of its injury list with 16% of all injuries attributed to it. Worse still, the re-injury rate for players who have at some time incurred a hamstring strain currently lies at 34%.[1] These figures indicate that current preventative strategies for this kind of injury remain inadequate.

Epidemiological evidence suggests that hamstring strains are associated with eccentric contractions, where the contracting muscle is lengthened.[2,3] Hamstrings undergo eccentric contractions during sprinting, kicking the ball and picking up the ball. Indeed, it is regularly observed that during these activities, players incur hamstring strains. This fact has led us to propose a new approach to hamstring strains, indeed, to all muscle strains, based on recent research.

We have been studying the mechanical changes in a muscle subjected to a series of eccentric contractions. Eccentric exercise is the only form of exercise which is routinely accompanied by muscle damage. For a review of the topic see Proske and Morgan.[4] Here we have gone one step further and proposed that under certain conditions, the microscopic damage at the level of muscle fibres from eccentric contractions may, at times, progress to a more major strain injury.

Muscle damage from eccentric exercise

Eccentric exercise, in someone unaccustomed to it, produces stiffness and soreness next day. This is because the exercise has led to muscle damage which, in turn, leads to sensitisation of nociceptors.[5] Why eccentric exercise produces muscle damage can be explained in terms of a theory based on sarcomere dynamics.[6] This proposes that the descending limb of the length-tension curve for skeletal muscle is a region of instability. When a sarcomere, which is weaker than it neighbours, lengthens on the descending limb, it becomes progressively weaker. In addition, when the yield point of the force-velocity relation is reached, lengthening is rapid and uncontrolled, without the development of additional force. The rapid lengthening will only stop when tension in passive structures associated with the sarcomere has risen sufficiently to balance the tension being generated in adjacent still-functioning sarcomeres. Then the next weakest sarcomere begins to lengthen uncontrollably. This process continues for the duration of the applied lengthening during the eccentric contraction.

Once a sarcomere has been stretched to the point of no overlap, when the muscle relaxes, the sarcomere risks becoming disrupted, that is, the myosin and actin filaments no longer interdigitate properly.[7] A non-functioning, disrupted sarcomere represents a point of weakness in the muscle. During repeated eccentric contractions the area of

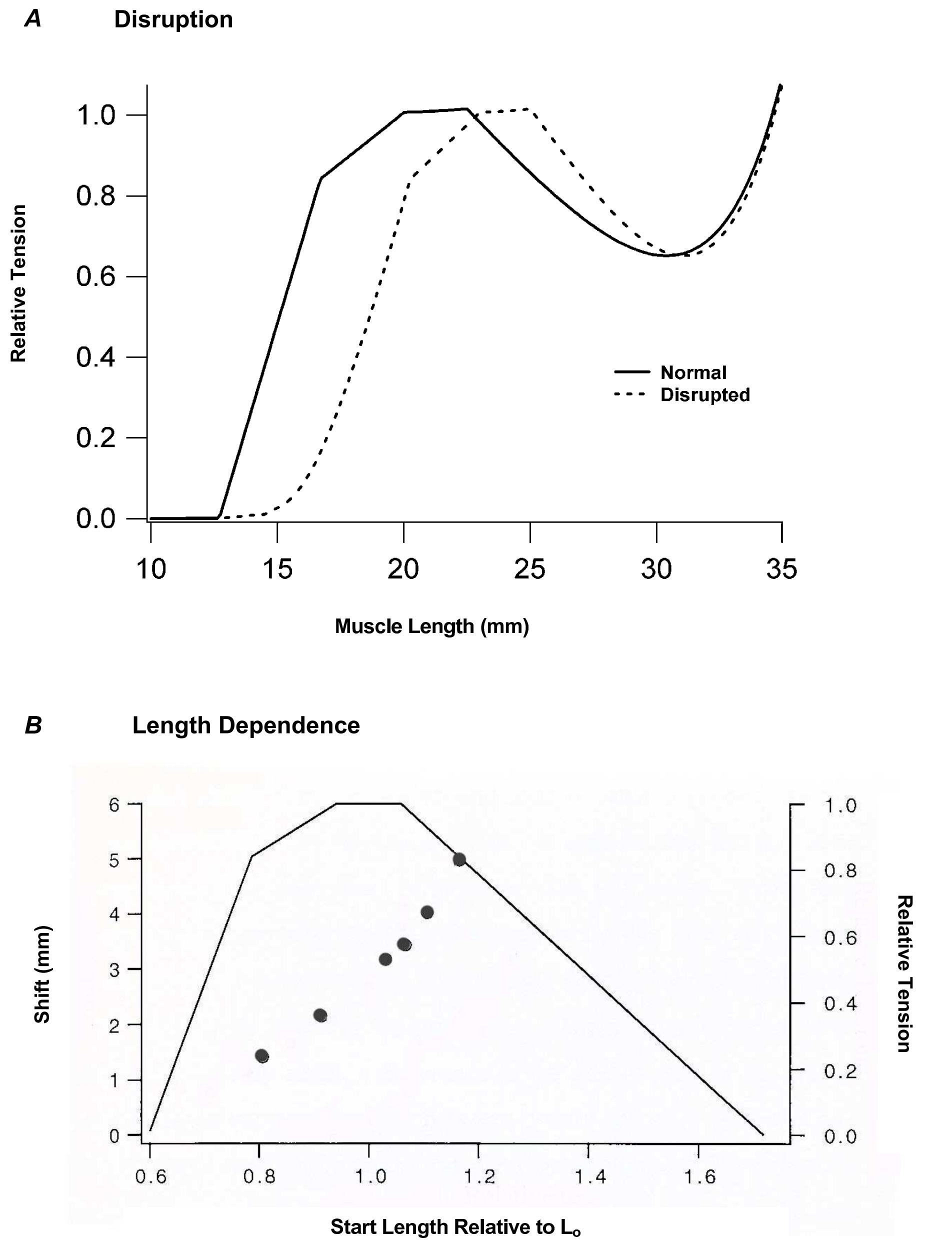

Figure 1. A: Changes in sarcomere length-tension relation following a series of eccentric contractions. *A computer-simulated curve of total sarcomere tension has been represented, based on the active length-tension relation*[11] *to which the estimated, exponentially rising passive tension has been added. Tension has been normalized relative to the maximum active tension. Length is of a fibre postulated to comprise 10,000 sarcomeres with a sarcomere length of 2.5 µm at optimum length. The control curve (solid line) is on the left. After a series of eccentric contractions, 10% of sarcomeres have their tension output set to zero to simulate disruption. That shifts the length-tension relation in the direction of longer lengths by 3 mm, as shown by the dashed curve on the right. Redrawn from Proske and Morgan.*[4]

B: Dependence of the shift in length-tension relation on the starting length. *The filled circles represent the data from each of 6 toad sartorius muscles subjected to 20 eccentric contractions. These were active stretches of 3 mm (10% L_o) at 3 muscle lengths s^{-1}. They were applied at progressively longer lengths, the first at a starting length of 0.8 L_o, the last at 1.2 L_o. At longer starting lengths, the resultant shifts in optimum were larger. To provide an indication of where on the sarcomere length-tension relation these shifts lay, a superimposed active sarcomere length tension curve has been shown (from Gordon* et al.[11]*) Figure redrawn from Talbot.*[12]

disruption is likely to grow and a point is reached where membranes are torn and the muscle fibre begins to contract uncontrollably, leading to a rise in whole-muscle passive tension.[8] Ultimately some of these fibres are likely to die.[4]

Signs of damage

Evidence for the presence of disrupted sarcomeres in series with still functioning sarcomeres is provided by a

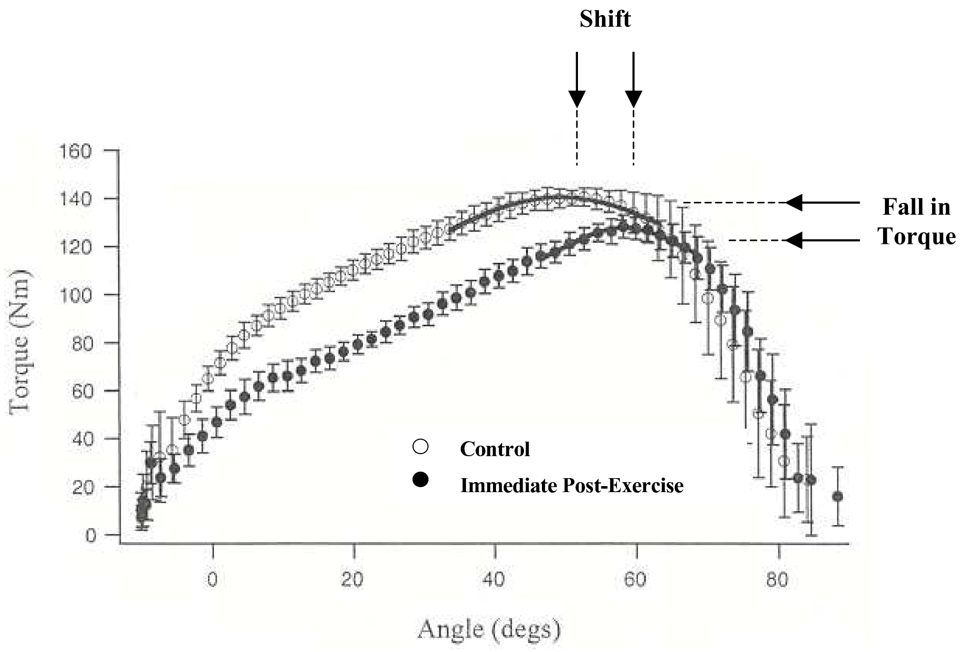

***Figure. 2. Torque-angle curves for human hamstring muscles, before and after a series of eccentric contractions.** Torque and angle values were obtained from a series of maximal knee extensions carried out on an isokinetic dynamometer. Gaussian curves were fitted by computer to the top 10% of the digitised and averaged values (continuous lines). These gave values for peak torque and optimum angle. Open circles (± S.E.M.), data acquired immediately before the exercise (Control), filled circles (± S.E.M.), immediately after the exercise (Immediate Post-Exercise). The exercise consisted of a series of controlled forward falls, using hamstrings to brake the fall. Figure redrawn from Brockett* et al.*[13] Downwards directed arrows indicate the shift in optimum angle (7.2°). Horizontal arrows show the drop in torque (12.6 N).*

shift in the muscle's length-tension relation in the direction of longer muscle lengths.[9,10] This can be modelled by means of a sarcomere length-tension curve based on Gordon, Huxley and Julian.[11] A disruption of 10% of 10,000 sarcomeres, each with a length of 2.5 µm at optimum, produces, in a muscle 25 mm long, a shift of 3 mm, in the direction of longer lengths (Fig. 1A).

Since the instability of sarcomeres is present only on the descending limb of the length tension curve, the single, most important determinant of the amount of damage and disruption from eccentric contractions is the length range over which the muscle is stretched. For amphibian muscle, the size of the shift in optimum length is directly dependent on the starting length for the stretch. The shift is small (1 – 2 mm) when the starting length is below the optimum. It increases steeply up to 5 mm when it exceeds the optimum (Fig. 1B).[12]

There has been much debate over the reliability of the various damage indicators after eccentric exercise. In our view the drop in force is not as reliable an indicator as a shift in optimum length. This is because during repeated eccentric contractions, as occurs in most sports, the force drop may be confounded by fatigue effects. The shift in optimum is present immediately after the exercise, not delayed like soreness, and the size of the shift is a direct indication of the amount of damage that has occurred.[4]

Our approach to the problem of hamstring strains is based on the proposal that damage at the level of single muscle fibres can, at times, lead to a major tear, the muscle strain.[13] If we are right, it means that evidence for a predisposition for eccentric damage is also an indication of vulnerability for strain injury.

We have tested this proposal by, first of all, measuring torque-angle curves for hamstring muscles in untrained subjects. Curves were constructed using an isokinetic dynamometer. Subjects were asked to carry out a series of isokinetic contractions and the torque and angle signals during each contraction were digitised, sorted according to length and averaged. A computer fitted a curve to values above 90% of torque to determine the optimum angle. Subjects were then asked to carry out a series of eccentric contractions with their hamstring muscles. For this they were asked to kneel on a padded board with their feet strapped to the board at the ankle. Subjects were instructed to lower their trunk down onto the board, using their hamstrings to brake the fall. Subjects carried out a series of such 'hamstring lowers' and then a second torque-angle curve was constructed immediately afterwards.

An example of a pair of torque angle curves constructed before and after a period of eccentric exercise is shown in Figure 2. For 10 subjects tested it was found that there was a fall in optimum torque, by an average of 25% (± 4%), and a shift of the optimum angle of 7° (± 3°).[13] This result confirmed that it was indeed possible to obtain evidence for muscle damage in hamstrings after a series of eccentric contractions.

Previously injured athletes are more prone to injury

As mentioned earlier, more than one third of all AFL players with a previous history of hamstring strains, subsequently re-injure. If we are right in our predictions, a greater-than-normal vulnerability for eccentric damage should mean an increased likelihood for a strain injury. This leads to the prediction that previous hamstring-injured subjects should show a greater-than-normal susceptibility for eccentric damage. It was decided to test this hypothesis.

Hamstring angle-torque curves, as described previously, were measured for 9 elite athletes, 5 AFL players and 4 track and field athletes all of whom had previously incurred one or more hamstring strains in one leg, 4 weeks or more previously. At the time of testing they had all returned to full training and no one experienced any soreness during testing. Measurements made on the previously injured hamstrings were compared with hamstrings of the other, uninjured leg. In addition measurements were made on both legs of 18 AFL players, none of whom had a previous history of hamstring strains.[14]

The values for optimum angles revealed dramatic differences. The mean optimum angle for the previously injured hamstrings was 12.1° (± 2.7°) shorter than for the uninjured muscle (Fig. 3). A shorter-than-normal optimum length means that more of the muscle's working range is on the descending limb of the length-tension relation, the region of instability and damage. Interestingly, the uninjured muscles of the other leg not only had longer optima but these were not significantly different from values for both legs of the uninjured subjects. So the uninjured muscles of subjects with a history of unilateral hamstring strains show no signs of a susceptibility for damage. If, as experience shows, differences between hamstrings on the two sides are usually small, this finding suggests that at-risk subjects within a population of uninjured players may not always be identified by their optimum angles. It also suggests that for the initial injury other factors are likely to play a role.

It has previously been proposed that a measure of susceptibility for hamstring strains is the quadriceps:hamstrings torque ratio.[15] Other observations suggest that this ratio is not a reliable predictor of strain injuries.[16] We have calculated quadriceps:hamstrings torque ratios for the muscle of the previously injured leg, the muscle of the other, uninjured leg and for the muscles of both legs in the athletes with no history of hamstring strains. Plotting ratios for muscles of one leg against the other leg showed no significant difference for the previously injured leg (Fig. 3B).

The "repeated bout effect" from eccentric training

We have all had the experience that a period of unaccustomed exercise, biased towards eccentric exercise, like walking downhill, leaves us stiff and sore next day. However the same exercise a week later is followed by much less stiffness and soreness. This is the "repeated bout effect".[17] Following damage from the first period of exercise, the muscle adapts to prevent further damage. It has been proposed that the adaptation process involves the incorporation of additional sarcomeres, in series, in muscle fibres.[6] It is known that such an addition of sarcomeres can occur in less than a week.[18] The presence of additional sarcomeres in myofibrils means that the average sarcomere length for a given fibre length becomes less, leading to a shift in the direction of longer muscle lengths of the optimum length for force. That, in turn, makes it less likely for the muscle, within its normal working range, to be stretched onto its descending limb, the region of potential damage.

We have measured the training effect in hamstrings. In non-athletic subjects optimum angle shifted by 7° immediately after a first period of eccentric exercise (see above). By 8 days after the exercise, there remained a persistent 6° (±4°) shift. Following a second period of exercise at day 8, there was a further 1° shift accompanied by a smaller-than-previous drop in force and less soreness.[13] Our interpretation is that the shift in optimum length after the first period of eccentric exercise reverses only partially since repair of damaged muscle fibres is accompanied by incorporation of additional sarcomeres. This, in turn, means that the second period of exercise is not stretching muscle fibres quite as far as previously, so avoiding the descending limb of the length-tension curve. As a consequence there is less damage and disruption. If we are right, and a susceptibility for eccentric damage signals a vulnerability for strain injuries, the training effect is likely to be a means of providing protection against further injury.

Training with eccentric exercise reduces the incidence of hamstring strains

In order to test some of our ideas, over the last 3 years we have been collaborating with one of the AFL clubs. In cooperation with the club's fitness coordinator a new training program has been implemented for all players. Our approach is based on the proposition that the precursor event to a hamstring strain is microscopic damage in muscle fibres from eccentric exercise. It follows that if it is possible to reduce the muscle's susceptibility for eccentric damage, this will lead to a reduced incidence of strain injuries.

Pre-season training before we began our study was mainly aimed at achieving greater aerobic fitness. The new program emphasised kicking and other exercises that stretched the active hamstrings. In addition, players carried out some specific, targeted eccentric exercises. These included "straight-legged deadlifts" and carrying out "knee-curls" on a GHG (gluteus-hamstrings-gastrocnemius) machine. For players who had incurred a hamstring strain, initially a rather mild program of exercise was given and this was gradually increased as the subject recovered from the injury.

In the 2001 season, which was before we began working with the club, they had reported a total of 16

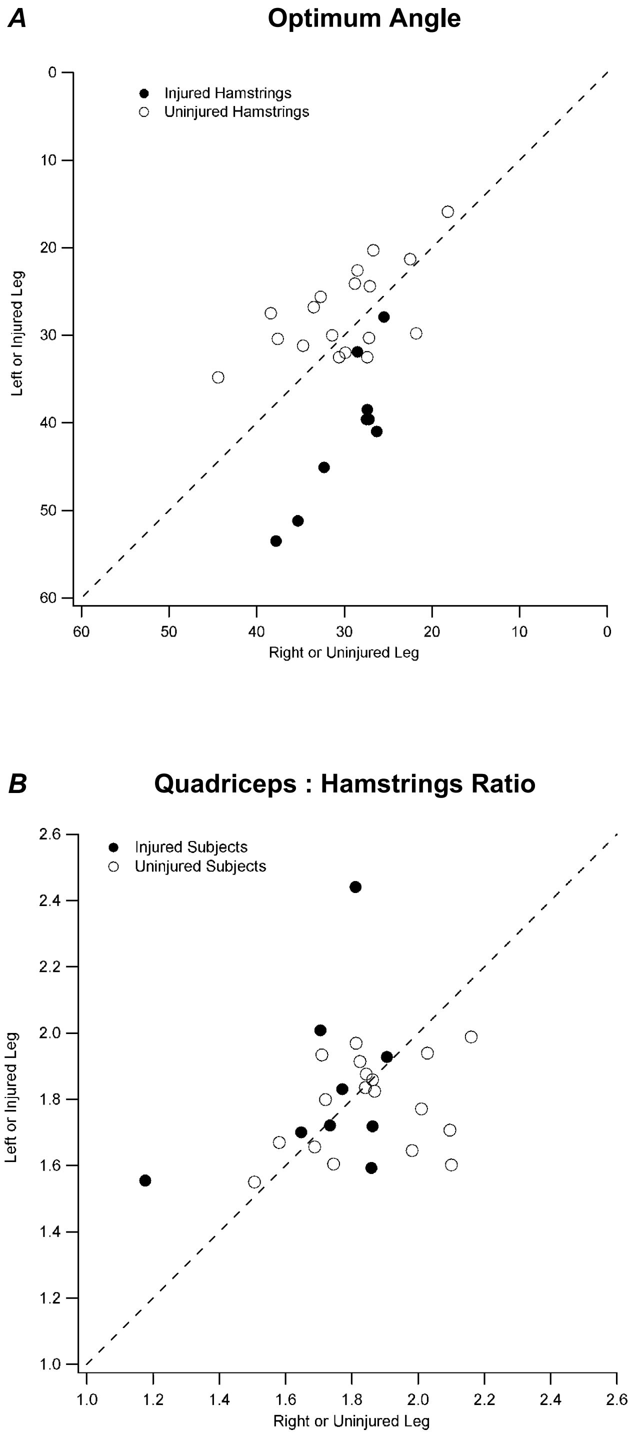

Figure 3. A: *A plot of the optimum angle for torque in hamstrings for the left, or the injured leg against optimum angle for the right or the uninjured leg. Data from 9 athletes with a previous history of a unilateral hamstrings strain (filled circles) and from 18 athletes with no previous history of strain injuries (open circles). The dashed line indicates where values would lie if they were equal. Optimum angle has been expressed in degrees of knee flexion, where 0° is when the knee is fully extended and 110° when it is fully flexed. Optimum angles for the previously injured muscles were at significantly shorter muscle lengths, that is, a more flexed knee, than for muscles with no history of injury (Figure redrawn, in part, from Brockett* et al.[14]*).*

B: *Ratio of peak torque in quadriceps to peak torque in hamstrings. Values for athletes with a previous history of unilateral hamstring strains shown as filled circles. Values from athletes with no history of injury shown as open circles. Differences in ratios between injured and uninjured muscles were not significant.*

hamstring strains amongst players. After introduction of the new training program, 5 hamstring strains were reported during the 2002 season. For the 2003 season, the club reported only 2 hamstring strains. This data remains preliminary, but is encouraging. Currently testing is continuing and other AFL clubs are beginning to participate. So we are hoping that in the future widespread implementation of a program of targetted eccentric exercise will lead to a dramatic fall in the incidence of hamstring strains.

Conclusions

The outcome of this first cooperative study has obviously delighted the AFL club. But it has also provided additional supporting evidence for our proposal of a link between the microscopic damage routinely incurred after eccentric exercise and development of a more major muscle tear. If protection against eccentric damage can be achieved with a regular program of eccentric exercise, this will be the means of preventing the occurrence of all such strain injuries. The evidence suggests that in athletes with a history of unilateral hamstring strains, the uninjured muscle is indistinguishable in its properties from muscles of athletes with no history of such injuries. It may, therefore, make it difficult, at times, to detect at risk athletes in an uninjured population. It means that all participants in sports known to be associated with the occurrence of hamstring strains should be subjected to regular eccentric exercise programs, carried out in combination with measurements of optimum angle for torque, to make sure that the exercise has led to the desired adaptive changes.

Now it remains for other AFL clubs, indeed, other sporting bodies confronted with the problem of hamstring strains, to participate in similar training programs, to help eliminate this kind of injury.

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