Predicting Hamstring Strain Injury in Elite Athletes

CAMILLA L. BROCKETT[1], DAVID L. MORGAN[2], and UWE PROSKE[1]

[1]Department of Physiology and [2]Department of Electrical and Computer Systems Engineering, Monash University, Melbourne, Victoria, AUSTRALIA

ABSTRACT

BROCKETT, C. L., D. L. MORGAN, and U. PROSKE. Predicting Hamstring Strain Injury in Elite Athletes. *Med. Sci. Sports Exerc.*, Vol. 36, No. 3, pp. 379–387, 2004. **Introduction:** Eccentric exercise, where the contracting muscle is lengthened, produces microscopic damage in muscle fibers, and sensations of stiffness and soreness, the next day. These normally resolve within a week. A more major sports injury is the muscle strain. Because strain injuries are known to occur during eccentric contractions, it is hypothesized that the microscopic damage from eccentric exercise can, at times, progress to a muscle strain. As the amount of microscopic damage depends on the muscle's optimum length for active tension, it is further proposed that optimum length is a measure of susceptibility for muscle strains. The athletes most at risk of a hamstring strain are those with a previous history of such injuries. Here the prediction is tested that optimum lengths of previously injured hamstrings are shorter and therefore more prone to eccentric damage than uninjured muscles. **Methods:** Mean optimum angle for peak torque in a previously injured muscle of nine athletes with a history of unilateral hamstring strains was compared with the uninjured muscle of the other leg and with muscles of 18 uninjured athletes. Optimum angle was determined with isokinetic dynamometry. **Results:** In previously injured muscles, torque peaked at significantly shorter lengths than for uninjured muscles. Peak torque and quadriceps:hamstrings torque ratios were not significantly different. **Conclusions:** The shorter optimum of previously injured muscles makes them more prone to damage from eccentric exercise than uninjured muscles and this may account for the high reinjure rate. The shorter optimum may reflect the muscle's preinjury state or be a consequence of the healing process. To reduce the incidence of strain injuries, it is recommended that a combined program of eccentric exercise and muscle testing be carried out. **Key Words:** ECCENTRIC EXERCISE, MUSCLE STRAIN, MUSCLE FIBERS, ADAPTATION, TRAINING, SARCOMERES

With the advent of modern imaging techniques and a better understanding of the principles of biomechanics, many sports injuries can now be effectively treated or prevented. A group of injuries where less progress has been made is the soft tissue injuries, including the muscle strain. Muscle strains, particularly the hamstring strain, are prevalent in sports that involve sprinting, such as football and track-and-field athletics. In the Australian Football League (AFL), 16% of all playing time missed was through hamstring strains (26). Another feature of muscle strains is the recurrence rate, 34% of hamstring strains in the AFL being recurrences (26), making hamstring injuries one of the most common sources of injury and reinjury among footballers (24).

Many explanations have been put forward for the muscle strain. Factors thought to be involved include muscle weakness and lack of flexibility (7), fatigue, inadequate warm-up (34), and poor lumbar posture (14). One recent epidemiological study concluded that hamstring strains were significantly associated with a low hamstrings-to-quadriceps ratio of peak torque on the injured side and a low hamstrings side-to-side ratio of peak torque (23). However, others report that hamstring strains are not related to a low hamstrings-to-quadriceps strength ratio (2). Furthermore, there is evidence of normal strength after injury (35). It has led some authors to declare that there is "a complex, poorly understood neuromuscular coordination pattern that may help explain why the hamstrings are injured" (3).

Other epidemiological evidence suggests that hamstring muscle strains are associated with eccentric contractions, where the contracting muscle is lengthened (10,18,28). Muscles undergo eccentric contractions whenever they act as brakes to slow down a movement. Hamstrings contract eccentrically when they slow the forward swing of the leg to prevent overextension of the knee and flexion of the hips. Such movements occur during sprinting and when kicking a ball.

Eccentric exercise in a previously untrained subject leads to sensations of stiffness and soreness next day (15). These are believed to be the result of microscopic damage to muscle fibers, followed by a local inflammatory response. That response, in turn, is believed to sensitize muscle nociceptors (9,27) and mechanoreceptors (31). For the sequence of events in the damage process, see (21,25).

Address for correspondence: Uwe Proske, Department of Physiology, Monash University, Clayton VIC 3800, Australia; E-mail: uwe.proske@med.monash.edu.au.

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Hamstring strains are frequently associated with eccentric contractions (10,17,18,28), and such contractions also produce microscopic muscle damage, suggesting a causal link between the two processes. It is proposed here that the initial event that may, ultimately, lead to a strain injury is microscopic damage to muscle fibers. If the eccentric contractions continue, the microscopic areas of damage may provide a point of weakness from which a major tear may arise (5).

It has been proposed by one of us that the initial event, which leads to the microscopic damage from eccentric exercise, is nonuniform lengthening of sarcomeres (20). This is postulated to occur beyond the optimum length, on the descending limb of the muscle's length-tension relation, because this is a region of sarcomere length instability (12). A muscle with a short optimum length for active tension will therefore have more of its working range in the region where it is prone to microscopic damage. This view is consistent with reports of a length dependence of damage indicators after a series of eccentric contractions (16,29,33). However, there is no evidence yet for a similar length-dependence of strain injuries.

There is one group of athletes that shows a higher incidence of hamstring strains than any other. These are athletes with a previous history of hamstring injuries (23,26,30). It was decided to target this group and to study subjects with a history of hamstring strains in one leg only. Using isokinetic dynamometry (5), angle-torque curves were constructed for the previously injured muscles and compared with uninjured muscles of the other leg. These data were also compared with measurements from uninjured athletes. It was found that there was a strong correlation between optimum angle for peak active torque and a previous history of injury, consistent with the view that such muscles were at risk of reinjury. Here it is proposed that this associative link between the microscopic damage and more major tears points to a way of preventing such injuries.

METHODS

Subjects. Healthy human subjects gave their written, informed consent for these experiments, which had been approved by the Monash University Committee for Ethics in Human Experimentation. All participants in the study were elite or subelite athletes. Twenty-three were AFL players, whereas four were track-and-field athletes. Subjects were screened for previous injuries and placed into one of two groups, uninjured and previously injured. A primary criterion in the choice of subjects with a previous history of injury was that they had injured only the hamstrings of one leg.

The previously injured group included nine athletes, eight male and one female. Five males were AFL players (age range 26–33 yr), all of whom had had a clinical history of multiple hamstring strains over the last 4–5 yr. We defined an incident of hamstring injury as one which led the athlete to miss at least 1 wk of training or competition. Strains ranged from grade 1 to 3 tears. Players were tested early during a new season but had, in fact, incurred their last hamstring strain during the previous season. On interview, they were uncertain about what factors they thought might have contributed to the injury, but they repeatedly mentioned that strains seemed to occur after a burst of running while chasing an opponent or the ball. Two mentioned injuries arising from kicking the ball. The three male track-and-field athletes (age range 30–38 yr) included two professional sprinters and one long-distance runner who ran sprint races from time to time. All three had experienced multiple strain injuries in hamstrings of one leg during the last 5 yr. The most recent injury was in the long-distance runner. He had experienced the latest strain 1 month previously. He declared that he did not experience any discomfort on the day of testing but commented that his previously injured hamstrings felt "tight" whenever he ran. Injuries in the other track-and-field athletes were about a year old. The sprinters all mentioned that their injuries occurred during the last stages of the race. The female (age 22 yr) was a sprinter competing at subelite level. She, too, had a 5-yr history of hamstring strains in one leg. In addition, 5 yr previously she had a collateral cartilage of the knee removed. At the time of testing, no subject reported any discomfort in carrying out a maximum effort isokinetic contraction with their hamstrings. We considered that the injured muscles had been rehabilitated because, when they were tested, each athlete was carrying out a full program of training.

Rehabilitation programs for the injured muscles included the application of ice packs and compression bandages on the day of the injury, followed by a combination of heat treatment, ultrasound, massage, passive stretches, and several days rest. Gradually, as the pain subsided, nonweight-bearing exercises such as swimming and cycling were encouraged, followed by a program of running of increasing duration and a gradual return to high-loading knee flexion-extension exercises including hamstrings curls. None of the athletes mentioned, as such, any targeted period of eccentric exercise.

The second group included 18 athletes (all males) 19–28 yr old. They were all AFL players, and none of them had a previous history of hamstring injuries or, indeed, any other leg injuries that might complicate interpretation of the data.

Isokinetic dynamometry. An isokinetic dynamometer (Biodex System 3 Quickset; Biodex Medical Systems Inc., Shirley, NY) was used to generate angle-torque curves. An angle-torque curve is a measure of the torque as a function of knee joint angle produced when the muscle is maximally activated during isovelocity shortening. Details of the method for determining optimum angle and its verification can be found in Brockett et al. (5). Subjects were seated on the Biodex with their hip joint at approximately 90° flexion and their upper bodies secured with dual cross-over straps as well as a waist strap. The range of motion at the knee was approximately 110°. An angle of 0° was when the leg was fully extended at the knee and 110° when it was fully flexed. A thigh strap on the test leg was used to restrict any lateral movement at the knee, allowing only flexion and extension movements. The contralateral leg was stabilized with an ankle strap, keeping the knee at approximately 90°. This helped to minimize movements, especially at the hip while the other leg was exercising. Subjects also gripped side handles on the apparatus to help them stabilize their upper body.

Both legs were tested separately and in random order. The testing protocol consisted of seven repetitions of knee extension and flexion performed at a velocity of $60^\circ \cdot s^{-1}$ while subjects exerted a maximal effort. Torque and angle signals were transferred from the dynamometer to a computer and analyzed using the analysis program Igor Pro (Wavemetrics, Lake Oswego, OR).

Torque values from the seven repetitions were extracted and sorted according to the direction of movement and knee angle. The data were compressed, using a decimation function, which replaced each successive block of 20 data points with an average value. It produced a single average cycle of movement and torque for hamstrings and for quadriceps. Details have been described previously (5). Optimum angle for torque was determined by fitting a curve to the raw data using a combination of two parabolae, one for the ascending limb of the curve up to the optimum and one for the descending limb. The two parabolae had different curvatures, but both had zero slope at the optimum angle and the values at optimum were equal. Fitting parameters were optimum torque, angle for optimum torque, and the two curvatures. This allowed the fitting of smooth curves to the data, with optimum as a parameter, for nonsymmetrical curves. Only data points above 60% of maximum torque were included in the analysis.

Optimum angle and peak torque at this angle were recorded for hamstrings and quadriceps of both legs. The measurements for quadriceps provided data from an uninjured muscle in the previously injured leg of subjects. Differences in optimum angle and peak torque between legs were calculated by subtracting values for the uninjured muscles from values for the injured muscles. For the uninjured group, differences were determined by subtracting values for the left leg from values for the right leg. Mean (± SEM) were calculated for each group.

Statistical analysis. Analysis of variance, Student's *t*-tests, and LSD posthoc tests were used to determine the significance of any differences in optimum angle and peak torque for hamstrings and quadriceps of each leg for the previously injured and uninjured athletes. The statistical program used was Data Desk (Data Description, Ithaca, NY).

RESULTS

Uninjured subjects. An example of angle-torque curves for one subject is shown in Figure 1. The values for hamstrings of the right leg indicated an optimum angle of 32.0° and for the left leg 29.9°. The values for quadriceps were also very similar 66.1° for one side and 65.8° for the other. Note that knee angles corresponding to long muscle lengths lie to the right in both panels.

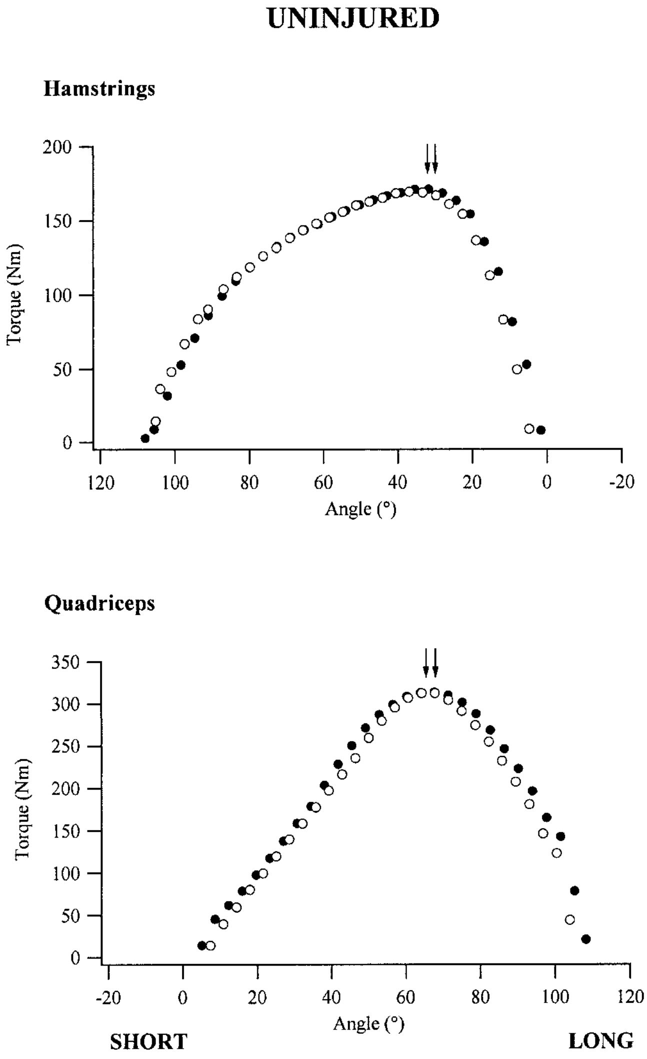

FIGURE 1—Torque and optimum angles for an uninjured subject. Superimposed angle-torque curves for right (*filled circles*) and left (*open circles*) hamstrings (upper panel) and quadriceps (lower panel) of an uninjured athlete. Data from seven repetitions has been averaged (every 20 data points). Optimum angles for peak torque (*arrows*) have been determined by fitting a curve to data points above 60% of maximum torque. An angle of 0° is when the leg was fully extended at the knee and 110° when it was fully flexed. The abscissa for quadriceps was reversed so that muscle lengthening is from left (SHORT) to right (LONG), as for hamstrings.

To demonstrate that values for muscles of both legs were similar within the uninjured group, the optimum angles and peak torques for hamstrings and quadriceps on the right side were plotted against their values on the left side for all 18 subjects (Fig. 2). Values for both torque and optimum angle lay scattered about the line of equality, indicating that differences between the two sides were small. Mean values are given in Table 1.

When differences in optimum angles between hamstrings and quadriceps on the two sides were plotted for each subject (Fig. 3; Table 1), values were found not to be significantly different from zero. Calculation of the ratios of peak torque for hamstrings of the left leg versus hamstrings

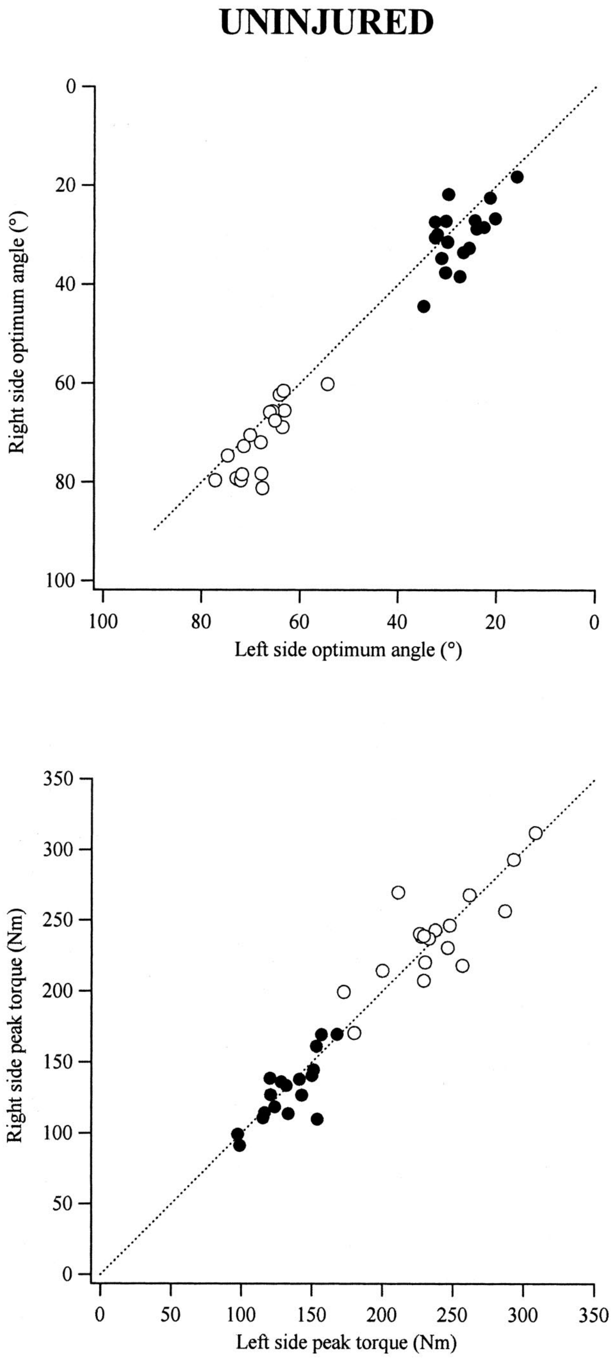

FIGURE 2—Relations between torque and optimum angle for muscles on the two sides in uninjured subjects. Upper panel: optimum angles for peak torque for hamstrings (*filled circles*) and quadriceps (*open circles*) for the right leg plotted against values for the left leg. Optimum angles were obtained from angle-torque curves. The *dotted line* indicates the line of equality between the two sides. Lower panel: peak torque measured at the optimum angle for hamstrings (*filled circles*) and quadriceps (*open circles*) of the right leg plotted against values for the left muscle. The *dotted line* is the line of equality.

of the right leg also yielded values that did not differ significantly from 100% (Table 1).

Previously injured subjects. An example of an angle-torque curve for hamstrings and quadriceps from a subject with a previous history of a hamstring injury in the right muscle is shown in Figure 4. This muscle had an optimum angle of 53.5°, which differed by almost 16° from the optimum of hamstrings on the left, uninjured, side (37.5°), so that torque generated by the previously injured muscle peaked at a much shorter length than on the uninjured side. Yet the value of peak torque for the previously injured muscle was higher, 71 N·m, c.f. 65 N·m for the uninjured muscle. By contrast, optimum angles for quadriceps on the two sides differed by only 0.2°, and peak torque ratios were close to 100%. So the only persisting sign of the previous injury was an optimum at a more flexed knee angle, that is, with the muscle at a shorter length than for the muscle of the other leg. This was despite the fact that peak torque for the previously injured muscle had recovered to a higher value than on the uninjured side.

When optimum angles for previously injured hamstrings of all nine subjects were plotted against optimum angles for the uninjured muscles of the other leg, they all lay below the line of equality (Fig. 5). However, plotting peak torque for the injured muscle against the value for the uninjured muscle had values scattered evenly about the line of equality (Fig. 5). Differences in optimum angles between the two sides showed values for hamstrings all lying below zero (Fig. 6). Differences in optimum angles for quadriceps lay scattered about zero. Torque ratios between the two sides for both muscles lay close to 100% (Fig. 6).

The pooled data for the nine subjects is given in Table 1. The only measure that was found significant was the difference in optimum angle between the two sides ($P < 0.01$). Differences in optimum angles for quadriceps were not significant. The mean quadriceps:hamstrings ratios were 1.8 for the previously injured leg and 1.7 for the uninjured leg. This compares with ratios of 1.8 for the two legs of uninjured players (Table 1). These differences were not significant.

The pooled data from all 27 subjects were analyzed statistically by means of an ANOVA, using the 54 sets of quadriceps:hamstrings pairs as independent samples. The dependent variable was whether or not hamstrings of a particular leg had been injured. Independent variables were the optimum angle of the knee flexors, the kind of sport played (football or track and field), and quadriceps to hamstrings torque ratio (7). The analysis was asking the question, which properties of the muscles of a leg were predictors for previous injury. The optimum angle for hamstring torque was the most significant predictor ($P < 0.0001$). Quadriceps:hamstrings ratios were not significant. Sport appeared to be significant but this was due to the absence of uninjured subjects in the track-and-field group. If the analysis was restricted to subjects with an injured leg, giving 18 pairs of muscles for comparison, sport was not significant nor was the quadriceps:hamstrings ratio whereas the optimum angle for hamstrings remained significant ($P = 0.006$).

DISCUSSION

The main object of this study was to measure properties of muscles of athletes with a previous history of hamstring injuries as it is known that in AFL football the

TABLE 1. Mean values for various parameters (± SEM), for hamstrings and quadriceps of 18 uninjured athletes and 9 athletes with a previously history of unilateral hamstring strains (injured).

	Uninjured			Injured		
	Right Side		Left Side	Injured Side		Uninjured Side
Hamstrings						
Optimum angle (°)	30.1 (1.5)		27.3 (1.2)	40.9 (2.7)		29.8 (1.5)
Difference in angles (°)		2.7 (1.2)			12.1 (2.7)	
Peak torque (N·m)	130.2 (5.3)		133.5 (4.7)	114 (8.1)		122.9 (8.3)
Torque ratio (°)		103.4 (2.8)			94.1 (4.4)	
Quadriceps						
Optimum angle (°)	71.3 (1.7)		67.7 (1.3)	67.2 (1.9)		67.1 (2.0)
Difference in angles (°)		3.6 (1.0)			0.6 (1.2)	
Peak torque (N·m)	239.2 (7.9)		237.6 (8.4)	208.7 (15.8)		210.6 (16.2)
Torque ratio (°)		99.6 (2.2)			99.8 (3.1)	
Q:H Torque Ratio	1.8 (0.03)		1.8 (0.03)	1.8 (0.09)		1.7 (0.07)

injury rate in this group is higher than in any other (23,26,30). It was predicted that hamstrings of such subjects would show evidence of a greater susceptibility for the microscopic damage from eccentric exercise, that is, a shorter optimum length for active tension, than uninjured muscles. That prediction was borne out. The optimum angle for the previously injured muscles was, on

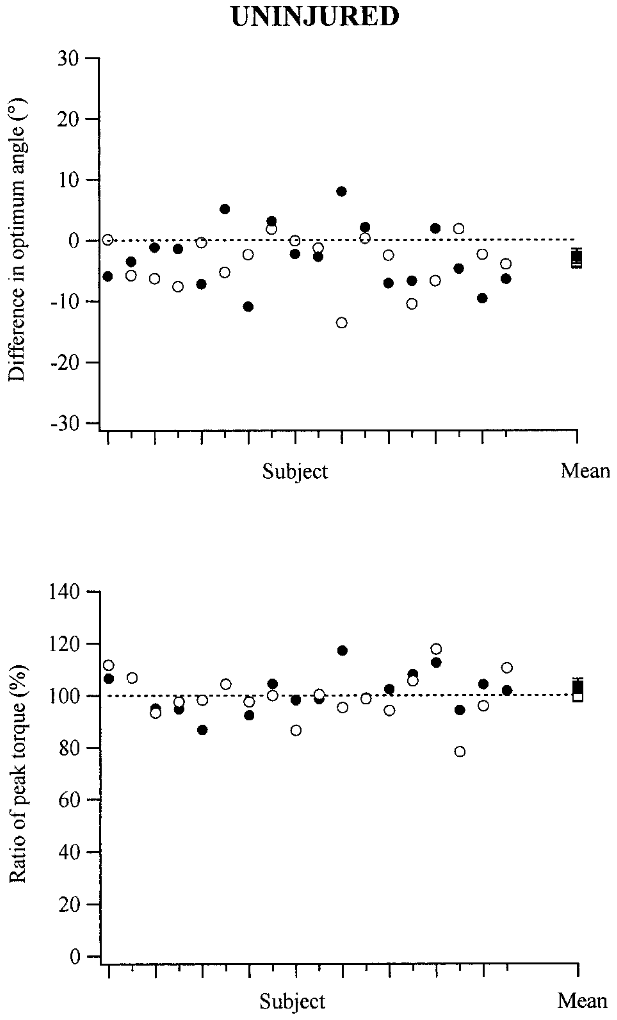

FIGURE 3—Differences in optimum angles and torque between the two sides in uninjured subjects. Upper panel: differences between optimum angles for hamstrings (*filled circles*) and quadriceps (*open circles*) of the left and right leg of 18 uninjured athletes. Mean (± SEM) is shown by the square on the right of the figure. *Dotted line* indicates zero difference. Lower panel: ratio of peak torque for hamstrings (*filled circles*) and quadriceps (*open circles*) for the two legs. Mean (± SEM) given to the right of the figure. *Dotted line* indicates ratio of 100%, that is, no difference between the two sides.

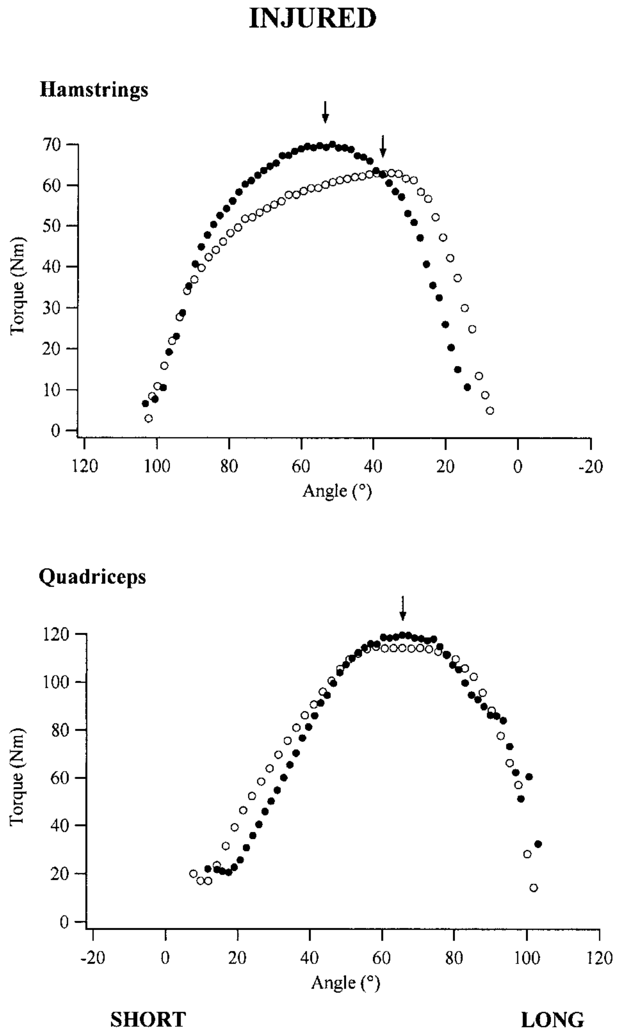

FIGURE 4—Subject with a previous unilateral hamstring strain. Upper panel: superimposed angle-torque curves for hamstrings on the previously injured side (*filled circles*) and on the uninjured side (*open circles*). *Arrows* indicate optimum angles for torque. Lower panel: superimposed angle-torque curves for quadriceps on the hamstring-injured side (*filled circles*) and on the uninjured side (*open circles*). Abscissa for quadriceps was reversed so that lengthening of the muscle is to the right.

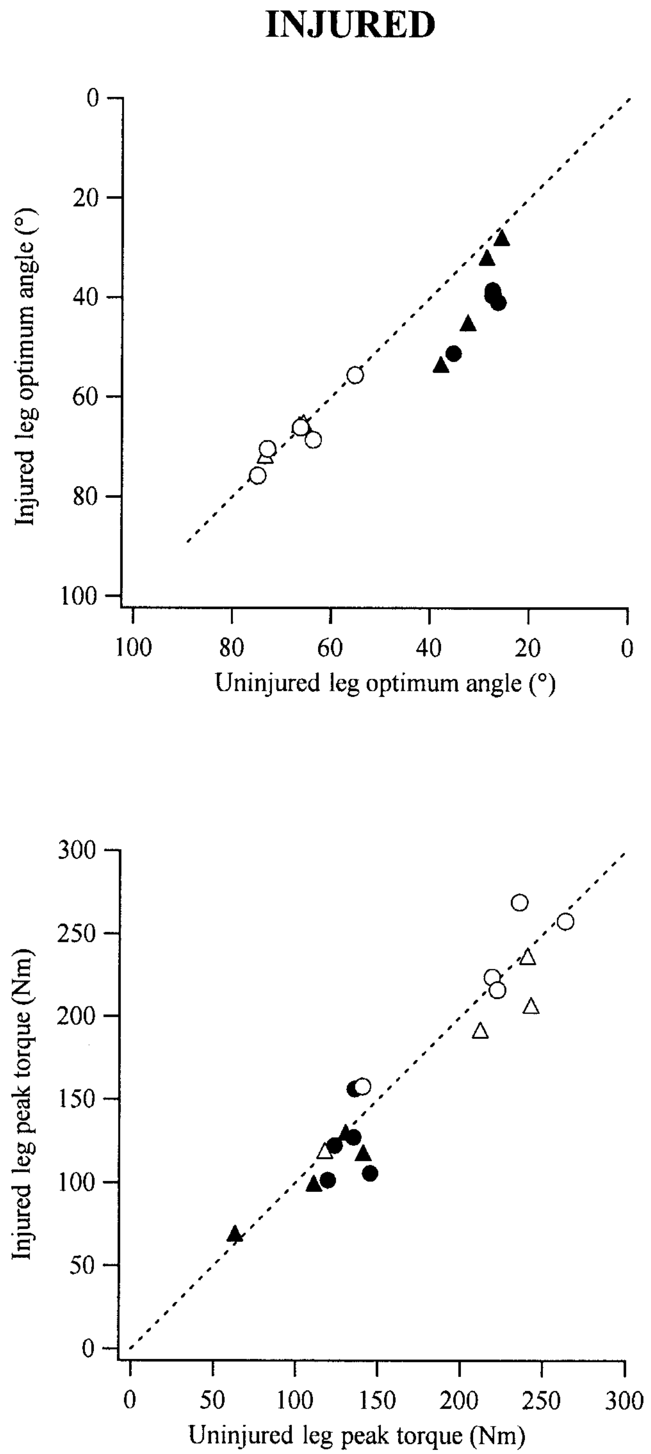

FIGURE 5—Optimum angles and torque from previously injured subjects. Upper panel: optimum angle for peak torque for hamstrings (*filled circles*) and quadriceps (*open circles*) on the injured side, plotted against values for muscles on the uninjured side. *Circles* indicate AFL players, *triangles* track-and-field athletes. The *dotted line* indicates the line of equality. Lower panel: peak torque for hamstrings (*filled circles*) and quadriceps (*open circles*) on the previously hamstrings-injured side plotted against values on the uninjured side. *Triangles*, track-and-field athletes. *Dashed line* is the line of equality.

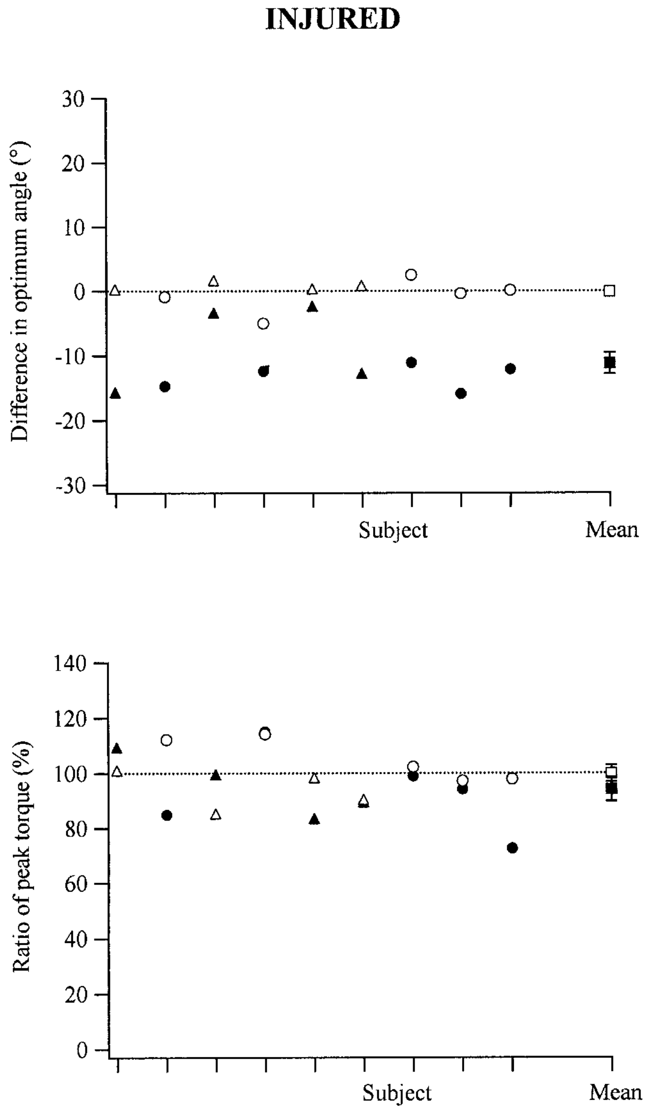

FIGURE 6—Differences in torque and optimum angles between the two sides in injured subjects. Upper panel: differences in optimum angles for hamstrings (*filled circles*) and quadriceps (*open circles*) between the injured and uninjured sides. Mean (± SEM) for the nine subjects is shown by the square on the right. *Dotted line* indicates zero difference. Lower panel: ratios of peak torque for hamstrings (*filled circles*) and quadriceps (*open circles*) on the injured and uninjured sides. *Dotted line* indicates a ratio of 100%, that is, no difference between the two sides. Mean (± SEM) is shown on the right. *Triangles* in both panels, track-and-field athletes.

average, 12° shorter than for the uninjured muscles of the other leg, and values for the uninjured muscles were not significantly different from hamstrings of the uninjured subjects. The result is the more remarkable as mean peak torque for hamstrings on the injured and uninjured sides differed by only 6% (± 4%). In addition, there were only small, insignificant differences in quadriceps:hamstrings torque ratios for the injured and uninjured legs. It means that the only significant difference in hamstrings of previously injured players is a short optimum angle, a trend consistent with the view that muscles with shorter optima are more likely to reinjure. It also argues against the proposition that strength differences between the two sides and quadriceps:hamstrings ratios are reliable predictors of hamstring strains (13,23).

Why does a shorter optimum length increase the risk of damage? When a muscle is stretched to beyond its optimum length, within a myofibril any sarcomere that is longer than others will preferentially take up the length change and lengthen rapidly until rising passive tension halts the motion (20). That is, the descending limb of the length-tension relation is a region of inherent instability, and it is in this length range where the initial events leading to damage and soreness take place (25). The rate of stretch and the level of force during the eccentric contraction are less important factors (29). If the optimum length for active tension is rather short, in terms of the muscle's working range, it follows that more of the descending limb will be included within the working range. That, in turn, increases the risk of damage.

The proposition that an optimum angle, representing a shorter muscle length, indicates a raised probability for reinjury is based on the proposal that a heightened susceptibility for microscopic damage from eccentric exercise also makes it more likely for a more major strain injury to occur. Here it is hypothesized that during the eccentric contractions sites of disruption act as foci for further damage, including the tearing of membranous structures, local release of Ca^{2+}, and development of injury contractures (25). The size of the lesion continues to grow during repeated eccentric contractions, and a point is reached where fibers rupture, leading to a tear across the muscle. Because tendon is physically stronger than muscle fibers, a tear in a pennate muscle that reaches the aponeurosis will continue longitudinally along the aponeurosis, as is often indicated by magnetic resonance imaging (MRI) (8).

An important question posed by this study was why the optimum angles for the previously injured muscles had such small values. Given that the incidence of strain injuries rises from 16% in previously uninjured players to 34% in players with a history of hamstring strains (26) that in itself suggests that events during rehabilitation are responsible. One possible explanation lies in the healing process. We did not have available MRI or ultrasound images of the injured muscles, so structural details of the damaged areas and their healing over the first weeks after the injury remain uncertain. It has been reported that there is ongoing muscle regeneration in the presence of mature scar tissue during healing (4). The presence of scar tissue raises the possibility that some muscle fibers link up with the region of scarring, rather than with the aponeurosis, making them shorter than they might otherwise have been. That would move the whole muscle optimum length for active tension in the direction of shorter lengths. One way of testing this would be to measure passive tension. It should be higher in the scarred muscle than in an uninjured muscle, due to the stiffness of the scar tissue.

Although we do not have detailed medical records for each subject, traditional treatment for a hamstring strain is to initially minimize inflammation with ice and compression bandages, and to administer anti-inflammatory drugs. This is followed by heat treatment, massage, ultrasound, passive stretching, and muscle-strengthening programs (6,8,18). These programs typically involve shortening (concentric) contractions of hamstrings and little eccentric activity. It is known that concentric exercise tends to reduce sarcomere numbers in muscle fibers and therefore shift optimum angles in the direction of shorter lengths to produce a training effect that raises the susceptibility to microscopic damage and soreness from eccentric exercise (11,32). So the high incidence of reinjury may be the result of a combination of factors, including the healing process itself and the program of exercise carried out during rehabilitation.

An interesting recent comment on the issue of hamstring reinjury was made by Orchard and Best (22). They noted that once AFL players return to the field, they remain at risk of reinjury for many weeks. This contrasts with other soft-tissue injuries where, once a player is fielded again, reinjuries are most likely in the first week. All of this suggests that whatever structural changes have occurred in the muscle after rehabilitation, they remain there for long periods.

If a higher probability for reinjury is associated with a shorter optimum angle for torque, the question arises whether the initial injury in these subjects had also been associated with a shorter-than-normal optimum angle. Although we do not have any preinjury data, it is possible to compare muscles on the uninjured side in the injured group with muscles of both legs in the uninjured group. The mean optimum angle for the uninjured hamstrings in the previously injured group was 29.8°. This compares with 30.1° on the right side and 27.3° on the left side for the uninjured group. None of these values were significantly different. So there is no evidence that the uninjured muscles of previously injured athletes show any greater-than-normal propensity for damage.

For the uninjured subjects, optimum angles lay in the range 16–34° of knee flexion (Fig. 2). If a typical value for an uninjured muscle is about 20°, subjects with values significantly above this are, perhaps, at risk of sustaining an injury in the future. The point is important because it raises the question of the effectiveness of the angle-torque curve as a predictor of hamstring strains. It may be that injuries arise in subjects with optimum angles lying within the normal range, so that such subjects will be difficult to detect. Alternatively, when a large enough sample has been compiled, it may be possible to identify optimum angles considered to lie within the high risk region.

Confirmation, by measurement, of a correlation between optimum angle and a previous history of hamstring strains, by itself, does not prove a link between the damage from eccentric exercise and a more major strain injury. The result does, however, encourage further measurement. It has been hypothesized that muscles adapt to the damage from eccentric exercise by increasing the numbers of sarcomeres in series in muscle fibers (20). Such an adaptation means that during any future eccentric contractions sarcomere length for a given joint angle will be less, shifting optimum angle toward longer lengths and reducing the risk of damage. There are some animal data to support such a view (19). Such a shift has been shown for human hamstrings, a week after a period of unaccustomed eccentric exercise, and this was associated with a reduction in damage indicators after a second period of exercise (5). More recently it has been reported that preseason training of soccer players with exercise, including eccentric contractions, led to a reduced occurrence and severity of hamstring strains (1). These studies highlight the importance of a program of eccentric exercise as a means of providing protection against strain injuries.

We conclude that anyone considered at risk of a strain injury should take part in an eccentric exercise training program. It will be important not to make the exercise too severe to avoid excessive soreness or risk injury from the training program itself. This could be done by regularly testing subjects and adjusting the muscle length range over which the exercise was carried out. The ultimate aim would be achievement of a shift in optimum angle as a result of an ongoing program of exercise. Such a training strategy is particularly important for subjects with a previous history of hamstring strains. They should be encouraged to begin a program of eccentric exercise as soon as they no longer experience any pain from the injury. The exercise should be accompanied by regular testing of angle-torque relations using isokinetic dynamometry, followed by any necessary adjustments to the severity of the exercise. Although it is generally recognized within the sports medicine profession that mild eccentric training is beneficial in a program of rehabilitation, such training is not typically accompanied by measurement of angle-torque relations. Only with such testing will it be possible to know whether the exercise is producing the required shift in optimum angle and at the same time is not so severe that it risks reinjury.

The longer-term implications of this work are that they provide an approach which will identify athletes at risk of injury, and following the appropriate training program, will significantly lower the incidence of strain injuries in hamstrings, indeed, in all muscles at risk of experiencing a strain injury.

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