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Effect of hamstring flexibility on isometric knee flexion angle–torque relationship

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The purpose of this study was to examine the relationship between hamstring flexibility and knee flexion angle–torque relationship. Hamstring flexibility was assessed in 20 subjects (10 men, 10 women) using the straight leg raise (SLR) and active knee extension (AKE) tests. Isometric knee flexion strength was measured at five knee flexion angles while subjects were seated with the test thigh flexed 40° and the trunk flexed 80°. Lower extremities were classified as tight or normal based on the SLR and AKE tests. Peak knee flexion torque, angle of peak torque, and angle–torque relationship were compared between flexibility groups. Peak knee flexion torque was not different between tight and normal groups (SLR $P = 0.82$; AKE $P = 0.68$) but occurred in greater knee flexion (shorter muscle length) in the tight group compared with the normal group (SLR $P < 0.01$; AKE $P < 0.05$). The tight group had higher torque than the normal group at the shortest muscle length tested but lower torque at longer muscle lengths (SLR $P < 0.001$; AKE $P < 0.001$). In conclusion, the angle–torque relationship was shifted to the left in less flexible hamstrings such that knee flexion torque was increased at short muscle lengths and decreased at long muscle lengths when compared with more flexible hamstrings.

Muscle strength and musculo-skeletal flexibility have been studied extensively with regard to risk of muscle strain injury (for a review, see, Gleim & McHugh, 1997; McHugh, 2004). Despite the fact that both factors are routinely studied with respect to injury risk, the relationship between strength and flexibility is not well understood. Static (Gleim & McHugh, 1997) and dynamic (Wilson et al., 1994) flexibility measures appear to be weakly associated with measures of muscle strength such that less flexible individuals have greater absolute strength. The practical significance of these associations remains unclear. Furthermore, little is known about factors affecting muscle strength throughout the range of motion. Theoretically, flexibility should affect the angle–torque relationship. The angle of peak torque may occur at shorter muscle lengths in individuals with lesser flexibility. In an animal model (Lieber et al., 2000) and in humans (McHugh & Hogan, 2004) passive muscle tension develops on the descending limb of the length–tension curve. Because static flexibility is limited by the development of passive muscle tension at the end range of motion, individuals with less flexibility (less range of motion) would have decreased contractile force production at longer muscle lengths. Therefore, the purpose of this study was to examine the relationship between measures of static hamstring flexibility and the angle–torque relationship for maximum isometric knee flexion contractions. It was hypothesized that the angle of peak knee flexion torque would occur at shorter muscle lengths in less flexible hamstrings and that the angle–torque curve would be shifted to the left (shorter muscle lengths) compared with more flexible hamstrings.

Materials and methods

Subjects

Twenty healthy subjects, 10 men and 10 women ranging in age from 18 to 47 years participated with informed consent. The means and standard deviations for their age, height, and mass were 29 ± 7 years, 170.1 ± 12.0 cm, and 72.7 ± 17.3 kg, respectively. The subjects were limited to those without a previous hamstring injury. Institutional Review Board approved the study and all participating subjects gave written informed consent before testing.

Flexibility assessment

Hamstring flexibility was evaluated using two standard physical therapy techniques; the straight leg raise test (SLR) and the active knee extension test (AKE) (Gajdosik & Lusin, 1983; Baltaci et al., 2003).

SLR test

The subject was positioned supine on a padded plinth. The examiner used one hand to elevate the limb meanwhile the other hand was placed on the contralateral anterior superior iliac spine to monitor for posterior rotation. The subject's leg was moved passively into hip flexion until firm resistance was felt and the pelvis tilted posteriorly. This was defined as the end of range of motion and a goniometric measurement of hip flexion was taken (Norkin & White, 1995). The examiner closely monitored the knee to ensure that full knee extension was maintained during the test. The SLR test was performed on both limbs.

AKE test

The subject was supine on a padded plinth. A hip and knee flexion angle of 90° was maintained by an adjustable bench placed underneath both lower extremities. The subject actively extended one knee as far as possible and a goniometric measurement was taken in degrees of motion with a standard goniometer (Norkin & White, 1995). This was then repeated on the contralateral side.

Isometric knee flexion strength assessment

Strength measurements were made on an isokinetic dynamometer (Biodex System 2, Shirley, New York, USA). The set up for knee flexion strength measurements was such that at least two torque measurements could be made at muscle lengths greater than the angle for peak torque in most subjects. The subject was seated with a hip flexion angle of 40°on the test side (as defined by the angle between the femur and the horizontal plane) and a trunk flexion angle of 80° (as defined by the angle between the thorax and the horizontal plane). This yielded a thigh–trunk angle of 40° which placed the hamstring in a position of significant stretch as the knee was extended. The distal lower extremity, of the test side, was secured into the dynamometer arm just proximal to the lateral malleolus and the knee axis of rotation was aligned with the rotating axis of the dynamometer. The knee was positioned at five different knee flexion angles (89°, 76°, 63°, 50°, and 37°) and two, 4 s isometric contractions were performed at each angle. Subjects were given 30 s rest between contractions at a given angle and 90 s rest between test angles. The sequence of testing was 89°, 76°, 63°, 50°, and 37° for all subjects and the right leg was tested first for each subject. These test angles represent the actual knee flexion angle with 0° representing full extension at the knee. The combined effect of limb mass and passive muscle tension at each angle was measured during 4 s relaxations at each angle. This torque was subtracted from the measured torque to provide a measure of contractile force production. The protocol was then repeated on the contralateral lower extremity.

Data analysis

Based on normative data for the SLR test lower extremities were classified as tight (<60°), normal (60–90°), or loose (>90°) (Gleim et al., 1990). Sixteen lower extremities were classified as tight and 23 as normal and one as loose. For subsequent analysis, the one loose hamstring was included in the normal group. Because large sample normative data for the AKE test were not available AKE tests were classified based on clinical experience. AKE tests $\geq 10°$ were classified as tight ($n = 19$) and tests $<10°$ were classified as normal ($n = 21$). For the AKE test, a larger number equates to decreased flexibility while for the SLR test, a larger number equates to greater flexibility. Peak knee flexion torque (N m/kg) and angle of peak torque were compared between the tight and normal groups for each flexibility test using independent *t*-tests. The effect of knee flexion angle on knee flexion torque was compared between flexibility groups using angle by group ANOVA. For these analyses, torque values were expressed as a percentage of the torque at the angle of peak torque for that lower extremity.

Results

Peak knee flexion torque was not different between tight and normal groups (SLR $P = 0.82$; AKE $P = 0.68$; Fig. 1). Peak knee flexion torque occurred in greater knee flexion (shorter muscle length) in the tight group compared with the normal group (SLR $P<0.01$; AKE $P<0.05$; Fig. 2). The angle–torque relationship was significantly affected by hamstring flexibility such that the tight group had higher torque than the normal group at 89° knee flexion (short muscle length) but lower torque than the normal group at 63°, 50°, and 37° (flexibility × angle SLR $P<0.001$ Fig. 3, AKE $P<0.001$; Fig. 4).

Men had significantly higher knee flexion torque (N m/kg) than women ($P<0.01$) but angle of peak torque was not affected by gender ($P = 0.99$). AKE angle was lower (greater flexibility) in women ($P<0.05$) but SLR angle was not affected by gender ($P = 0.25$).

Discussion

The two main findings in this study were that (1) hamstring flexibility did not affect peak knee flexion torque but that (2) hamstring flexibility did affect the angle at which peak torque occurred and the shape of the angle–torque relationship. Peak torque occurred

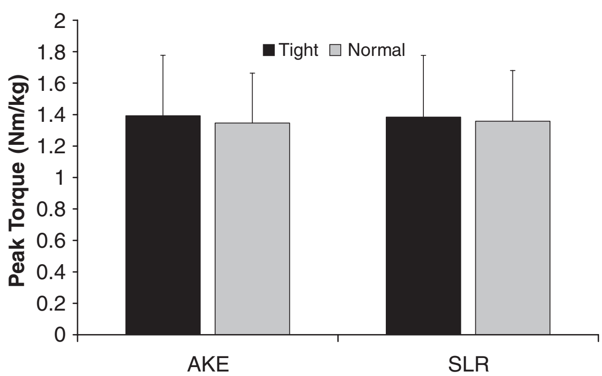

Fig. 1. Effect of hamstring flexibility on peak knee flexion torque: active knee extension test (AKE) $P = 0.68$; straight leg raise tests test (SLR) $P = 0.82$. Mean ± SD displayed.

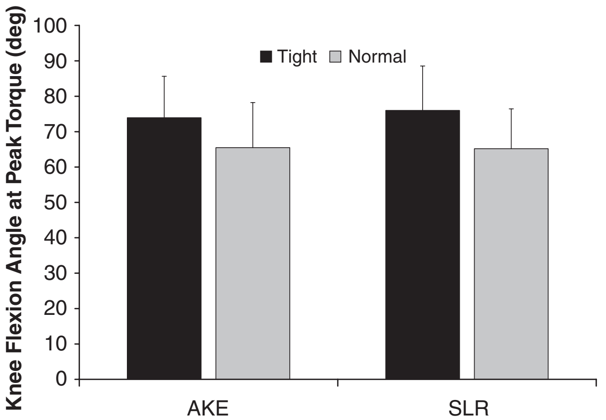

Fig. 2. Effect of hamstring flexibility on the angle of peak knee flexion torque: active knee extension test (AKE) $P<0.05$; straight leg raise tests test (SLR) $P<0.01$. Mean ± SD displayed.

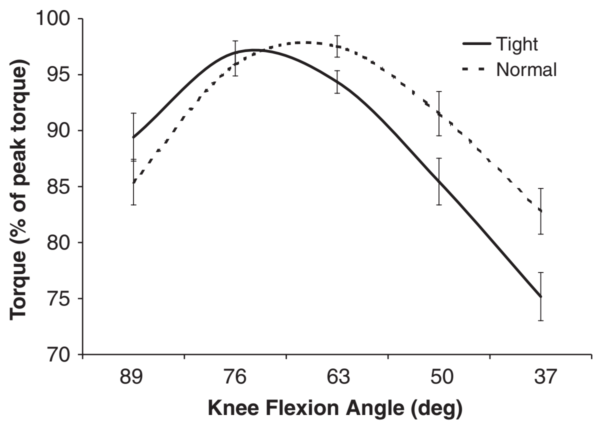

Fig. 4. Effect of hamstring flexibility on the angle–torque relationship for maximum isometric knee flexion contractions: tight vs normal classification based on the active knee extension test (AKE), flexibility by angle $P<0.001$. Mean SE displayed.

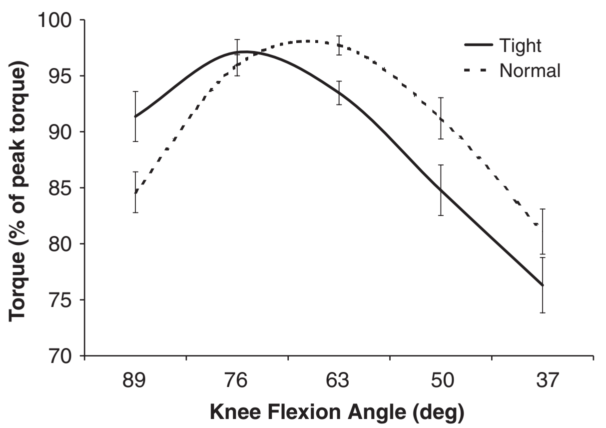

Fig. 3. Effect of hamstring flexibility on the angle–torque relationship for maximum isometric knee flexion contractions: tight vs normal classification based on the straight leg raise test (SLR), flexibility by angle $P<0.001$. Mean ± SE displayed.

at a shorter muscle length in hamstrings classified as tight. Accordingly, the angle–torque curve was shifted to the left in tight hamstrings such that they could produce higher torque at short muscle lengths and lower torque at longer muscle lengths when compared with hamstrings with normal flexibility.

The effect of hamstring flexibility on the angle–torque relationship can be explained by the effect of muscle length on sarcomere mechanics (length–tension relationship) (Huxley & Peachey, 1961; Gordon et al., 1966; Rassier et al., 1999). According to the length–tension relationship, there is an optimal sarcomere length for force production. At sarcomere lengths greater than optimum, force will be decreased due to decreased cross-bridge formation. At sarcomere lengths shorter than optimum, force will be decreased by a combination of factors that includes repulsive forces due to thick filaments crimping against the Z-bands, increased lateral distance between the actin and myosin filaments, the double overlap of thin filaments, and increased fluid and osmotic pressures. It is proposed that when isometric knee flexion contractions were performed with the hamstrings in a position of significant stretch, tight hamstrings achieved less myofilament overlap and therefore less torque production. The fact that knee flexion torque production was higher at short muscle lengths in tight hamstrings indicates that the decreased flexibility does not decrease the functional range of motion in which the muscle group operates, rather just shifts it to shorter muscle lengths (i.e., presumably the area under the angle–torque curve was not different between the tight and normal groups).

The apparent leftward shift in the length–tension relationship in tight hamstrings seen here may explain the previous finding that individuals with stiffer hamstrings were more susceptible to exercise-induced muscle damage (McHugh et al., 1999). While hamstring stiffness was not measured during the SLR in this study, it has been established that SLR ROM is highly correlated with hamstring stiffness (McHugh et al., 1998). Therefore, the effect of SLR ROM on the angle–torque relationship for isometric knee flexion maximal voluntary contractions supports the theory that increased susceptibility to muscle damage in stiffer hamstrings may have been due to decreased myofilament overlap during the eccentric contractions. In further support of this interpretation, it is well known that exercising muscle length is the primary determinant of the extent of muscle damage caused by a bout of eccentric contractions (Newham et al., 1988; Child et al., 1998; Talbot & Morgan, 1998; McHugh & Pasiakos, 2004). Furthermore, recent work has shown that inter-individual variability in strength loss following a bout of eccentric exercise can be explained, in large part, by inter-individual differences in the angle–torque relationship (McHugh & Pasiakos, 2004). Individuals with greater relative force production at longer muscle lengths were less susceptible to muscle damage. The current results provide some clinical relevance for these previous muscle damage studies by demonstrating a link between the SLR test (a standard hamstring flexibility test) and the angle–torque relationship.

An obvious limitation in this study was that passive hamstring stiffness was not measured. In making between subject comparisons of hamstring stiffness, it is important to accurately correct for the effect of limb mass on the measured passive torque. This is easily achieved when resistance to passive stretch is measured during a SLR (McHugh et al., 1998, 1999) because the force at the initiation of the stretch (0° hip flexion) represents the limb mass with negligible contribution form passive structures. However, it is more problematic to account for the limb mass contribution to passive torque in the seated position used in this study. Firstly, it is difficult to determine at what angle passive hamstring or quadriceps tension are negligible. Secondly, the torque values at angles where passive tension might be negligible (e.g., 89° or 76° knee flexion) are so low that measurement error is a significant factor. Ideally, the leg should be horizontal at the angle at which quadriceps and hamstring tension are negligible to maximize the measured force and thereby minimize the potential confounding effect of measurement error. This is the case for stiffness measurements using an SLR test but not for measurements in the modified sitting position used here.

An additional limitation is that muscle fatigue might have occurred in some subjects during the series of 20 isometric contractions (two contractions at each angle separated by 30 s and five test angles separated by 90 s). However, since the sequence of testing (short muscle length to long muscle length) was the same for all subjects any fatigue affect should not have affected the between group comparisons.

The hamstrings were studied here because this muscle group is one of the most commonly injured muscle groups in sports (McHugh, 2004). Both strength and flexibility have been studied extensively with regard to prevention and treatment of hamstring strains (Jönhagen et al., 1994; Orchard et al., 1997; Orchard, 2001; McHugh, 2004). Strength, but not flexibility, appears to be a risk factor for hamstring strains (Orchard et al., 1997). However, the effect of the angle–torque relationship on risk of hamstring strains has not been previously investigated. Interestingly, in athletes who had sustained a previous hamstring strain, peak knee flexion torque occurred at a shorter muscle length on the previously injured side compared with the uninjured contralateral side and compared with uninjured control athletes (Brockett et al., 2004). Furthermore, the previously injured side was more susceptible to eccentric contraction-induced muscle damage (Brockett et al., 2004). The increased susceptibility to muscle damage was attributed to the shift in angle of peak torque. The results of the present study provide further understanding of the mechanics of muscle contraction and the angle–torque relationship. Specifically, the ability to generate joint torque with the agonist muscle in an extended position is enhanced by having greater passive range of motion in that joint. Therefore, greater passive flexibility may allow muscles to effectively resist potentially injurious lengthening forces. This appears to be the case for exercise-induced muscle damage (Brockett et al., 2004; McHugh & Pasiakos, 2004) and warrants investigation with respect to muscle strain injury. There is indirect evidence that a rightward shift in the angle–torque relationship for the hamstrings (greater strength at longer muscle lengths) protects against muscle strain injury. Eccentric strength training of the hamstrings has been shown to shift the optimal angle for torque production to longer muscle lengths (Kilgallon et al., 2007) and eccentric strength training has also been shown to reduce the risk of subsequent hamstring strains (Askling et al., 2003; Arnason et al., 2008). It has been proposed that the optimal angle for knee flexion torque production is an important risk factor for strain injury (Proske et al., 2004).

The relationship between passive hamstring flexibility and risk of hamstring strain has not been specifically examined in a large sample of athletes from a particular sport with a high incidence of hamstring strains (e.g., Australian rules football or soccer). While hamstring flexibility was shown not to be a risk factor for subsequent strain injury in Australian rules football players (Orchard et al., 1997), the sample was small ($n = 37$) and the sit and reach test used to assess hamstring flexibility is regarded as a less specific measure of hamstring flexibility than the SLR test.

In conclusion, hamstring flexibility affected the ability to generate isometric torque as muscle length changed. The angle–torque relationship was shifted to the left in less flexible hamstrings such that knee flexion torque was increased at short muscle lengths and decreased at long muscle lengths when compared with more flexible hamstrings.

Perspectives

While the roles of flexibility and strength have been studied extensively with respect to injury risk in sports, the relationship between these two factors is not well understood. This study clearly demonstrates that musculo-skeletal flexibility affects the mechanics of muscle contraction. Hamstring tightness was associated with increased strength at short muscle lengths but decreased strength at long muscle lengths when compared with more flexible hamstrings. From a clinical perspective greater hamstring flexibility may allow the hamstrings to effectively resist potentially injurious lengthening forces during dynamic movements.

Key words: straight leg raise, length-tension, muscle extensibility, muscle length, range of motion.

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