Acute Effects of Dynamic Stretching on Peak and End-Range Functional Hamstring/Quadriceps Strength Ratios

Dinamik Germe Egzersizinin Zirve ve Eklem Hareket Açıklığının Uç Açılarındaki Fonksiyonel Hamstring/Quadriceps Kuvvet Oranları Üzerine Etkisi

Ufuk ŞEKİR, MD,[a]
Ramiz ARABACI,[b]
Bedrettin AKOVA, MD[a]

[a]Department of Sports Medicine, Uludağ University Faculty of Medicine,
[b]Physical Education and Sport, Uludağ University Faculty of Education, Bursa

Geliş Tarihi/*Received:* 08.09.2008
Kabul Tarihi/*Accepted:* 19.01.2009

Yazışma Adresi/*Correspondence:*
Ufuk ŞEKİR, MD
Uludag University Faculty of Medicine, Department of Sports Medicine, Bursa, TÜRKİYE/TURKEY
ufuksek@gmail.com

ABSTRACT Objective: Although recent studies have shown that dynamic stretching may improve individual muscle strength performance, its effects on the functional hamstring/quadriceps (H/Q) strength ratio and thus on injury risk characteristics has not been investigated in depth. The aim of this study was to assess the effects of dynamic stretching on functional H/Q strength ratios for isokinetic knee extension and flexion at peak and end range moments in elite women athletes. **Material and Methods:** A total of twelve healthy elite competitive female athletes (mean age 20 ± 2 years, mean height 166 ± 6 cm, mean weight 58 ± 7 kg) volunteered to participate in the study. All subjects completed a non-stretching (control) or a dynamic stretching intervention protocol in a randomized fashion on separate days. The quadriceps and hamstring muscles were stretched during these protocols. Before (pre) and after (post) the intervention, the functional H/Q strength ratio was calculated at 60°•s-1 and 180°•s-1 angular velocities. **Results:** The strength ratio for knee extension displayed a significant increase and for knee flexion a significant decrease following dynamic stretching during the entire and end range of motion at both angular velocities ($p< 0.05$). **Conclusion:** The effects of dynamic stretching on functional H/Q strength ratios suggest that the functional H/Q ratio do change positively following a dynamic stretching routine.

Key Words: Muscle stretching exercises; postural balance; muscle strength; women

ÖZET Amaç: Her ne kadar bilimsel son yayınlar dinamik germe egzersizlerinin bireysel kas kuvvetini arttırdığını göstermiş olsa da, dinamik germe egzersizinin fonksiyonel H/Q oranına ve böylece de yaralanma riski özellikleri üzerine olan etkisi ayrıntılı incelenmemiştir. Bu çalışmanın amacı bayan sporcularda dinamik germe egzersizlerinin izokinetik diz ekstansiyon ve fleksiyonu için zirve ve son açılardaki fonksiyonel H/Q kuvvet oranları üzerine olan etkisini incelemekti. **Gereç ve Yöntemler:** Sağlıklı 12 elit bayan sporcu (ortalama yaş: 20 ± 2 yıl, ortalama boy: 166± 6 cm, ortalama vücut ağırlığı: 58 ± 7 kg) çalışmaya gönüllü olarak katıldı. Deneklere farklı günlerde rasgele seçimle kontrol ve dinamik germe protokolü uygulandı. Bu protokoller sırasında quadriceps ve hamstring kaslarına germe egzersizleri yaptırıldı. Germe ya da kontrol uygulamasından önce ve sonra 60°/sn ve 180°/sn açısal hızlardaki fonksiyonel H/Q kuvvet oranları hesaplandı. **Bulgular:** Dinamik germe egzersizleri sonrasında tüm eklem hareket açıklığı ve eklem hareket açıklığının son açıları için her iki açısal hızdaki kuvvet oranları diz ekstansiyonu için anlamı olarak artış ve diz fleksiyonu için ise anlamlı olarak azalma göstermiştir ($p< 0.05$). **Sonuç:** Dinamik germe egzersizlerinin fonksiyonel H/Q oranları üzerine olan bu etkisi, dinamik germelerin fonksiyonel H/Q kuvvet oranını olumlu yönde değiştirebileceğine işaret etmiştir.

Anahtar Kelimeler: Kas germe egzersizleri; postural dengesi; kas kuvveti; kadın

Turkiye Klinikleri J Med Sci 2010;30(1):164-73

To improve muscular performance during sport activities, many athletes use some type of pre-participation warm-up routine to prepare themselves for athletic practice or competition. Traditionally, these warm-ups include some form of stretching which is common in a multitude of sports.[1] It is typically believed that increasing joint range of motion or flexibility would promote greater sporting ability by improving muscular performance and reducing the risk of musculoskeletal injury.[2,3] Athletes and coaches use many different types of stretching that are usually based on their personal preference only. No optimal type or amount of stretching, however, has been identified. There are various techniques of stretching, including ballistic, proprioceptive neuromuscular facilitation (PNF), static and dynamic stretching.[2] Although recent studies show that dynamic stretching exercises does not seem to affect 1RM strength in the bench and leg presses and not result in an increase in vertical jump height or force,[4,5] some evidence still exists indicating that dynamic stretching exercises may improve muscle strength performance.[6,7] This has implications for athletes involved in sports that require high levels of strength and force production. Therefore, researchers have proposed that static stretching prior to competition may hinder performance, prompting recommendations that static stretching be omitted or replaced by dynamic stretching during warm-ups.[6-9] On the other hand, since no study to date has directly investigated the effects of dynamic stretching on musculoskeletal injury risk characteristics, the role of dynamic stretching remains unknown.

It has been suggested that thigh muscle imbalance between the quadriceps and hamstring muscles is a potential mechanism for increased injury to the lower extremities.[10] Although there are a variety of measurement techniques, the hamstring/quadriceps (H/Q) ratio has been used in both clinical and laboratory research as a balance of strength indicator among muscles spanning the knee joint, as it expresses the function of two opposing (agonist and antagonist) muscle groups and provides a comprehensive description of reciprocal muscle function.[11,12] Previous authors have suggested that the agonist-antagonist strength relationship for knee extension and flexion may be better described by a functional knee flexion/knee extention (KF/KE) ratio of eccentric hamstring to concentric quadriceps muscle strength (ECC_{KF}/ CON_{KE}, representative of knee extension) or concentric hamstring to eccentric quadriceps muscle strength (CON_{KF}/ECC_{KE}, representative of knee flexion) rather than the conventional ratios that are often used (CON_{KF}/CON_{KE}).[11,13] It was shown that such reciprocal muscle group ratios provide information on knee function, injury risk and knee joint stability.[14] Any imbalance in the functional ratio implicates a predisposing factor towards injury.[15,16] Interestingly, a previous study that used conventional and functional ratios of the knee demonstrated that an ECC_{KF}/CON_{KE} ratio of less than 0.6 at 60°•s-1 represents a 77.5% probability of hamstring muscle injury in elite soccer players.[17] It was reported that the alteration of normal reciprocal strength balance about the knee joint may be affected by injury, detraining or training.[18,19] In the literature, however, the effects of dynamic stretching during the pre-participation training routine on these functional strength ratios has not been reported.

The purpose of this study, therefore, was to investigate the effects of dynamic stretching of both the quadriceps and hamstring muscles on functional H/Q strength ratios for knee extension and flexion at peak and end range moments in elite women athletes.

MATERIAL AND METHODS

SUBJECTS

A total of twelve healthy Caucasian females volunteered to participate in the study. The mean value for age was 20 ± 2 years, for height was 166 ± 6 cm, and for weight was 58 ± 7 kg. All subjects were elite competitive athletes and members of National Athletic Clubs. They participated in regular athletic sports activities, such as hammer throw, triple jump, heptathlon, high jump, 100 meter hurdles, and long- and middle-distance track events. Training backgrounds were determined according to declarations made by the team coaches and the athletes. On average, they were regularly trained for 10 ± 3 hours per week for 7 ± 2 years. The test procedure assessed the dominant leg, which was the right leg for all subjects. Limb dominance was determined by asking subjects which leg they would use to naturally kick a ball. Subjects were excluded from the study if they had a current or recent lower back, hip, knee, or ankle-related injury, had complained of pain, swelling, or functional limitations in these joints or had apparent limitations in knee range of motion. After being informed of the study and test procedures and any possible risks and discomfort that might ensue, their written informed consent to participate was obtained in accordance with the Helsinki Declaration.[20]

EXPERIMENTAL PROCEDURE

Prior to the experiments, each subject visited the laboratory to receive instructions and to participate in a familiarization trial to practice testing knee extensor and flexor strength in concentric and eccentric modes at selected angular velocities. During the second laboratory visit, all subjects completed a non-stretching (control) and dynamic stretching intervention protocol in a randomized order on separate days. The test procedure was conducted on two nonconsecutive days and was completed within one week. Before (pre) and immediately after (post) the stretching or control intervention, concentric and eccentric isokinetic peak torque for knee extension and flexion were measured and the functional H/Q strength ratios were calculated. Each subject performed a five-minute warm-up at 50 W on a stationary cycle ergometer prior to the initial isokinetic testing on all test days. The average duration of the dynamic stretching procedure was 6 ± 1 minute. In the non-stretching (control) period, each subject was given a five-minute rest interval in a sitting or supine position with both legs extended.

DYNAMIC STRETCHING EXERCISES

In order to stretch the quadriceps and hamstring muscles in the dominant limb, two dynamic unassisted stretching exercises were designed for both the extensor and flexor muscle groups. Each subject contracted the antagonist of the target muscle (either the quadriceps or hamstring) intentionally in standing upright position and flexed or extended some joints once every 2 seconds so that the target muscle was stretched. Prior to performing each stretching exercise, we explained to the subjects the muscle groups which should be contracted. The subjects performed two repetitions of every stretching exercise. Each stretching was performed five times, slowly at first, and then 10 times as quickly and powerfully as possible without bouncing. Between each stretching repetition and at the time of changing the stretching exercise and the muscle group, subjects stood upright for a 15 second rest period. Total duration of the dynamic stretching was 6 ± 1 minute. Although it is generally recommended that stretches were held for longer periods of time, the given time was chosen because it was the amount of time that the athletes typically held stretches prior to activity.

Quadriceps: (a) in standing upright position the subject contracted her hamstrings intentionally and flexed her knee joint so that her heel touched her buttock.

(b) in standing upright position the subject leaned forward and raised her foot from the floor with her hip and knee lightly flexed. Then, the subject contracted her hip extensors and hamstring muscles so that her leg was extended to the posterior aspect of the body while the hips nearly come to full extension and the knee to full flexion.

Hamstring: (a) in standing upright position the subject contracted the hip flexors intentionally with knee extended and flexed her hip joint so that her leg was swung up to the anterior aspect of her body.

(b) in standing upright position the subject contracted her hip flexors and flexed her hip joint, raising her thigh parallel to the ground with her knee joint flexed at about 90°. Then, the subject contracted her quadriceps with the height of her thigh maintained and extended her knee joint so that her leg extended to the anterior aspect of her body.

ISOKINETIC TESTING PROCEDURE

The Cybex NORM isokinetic system (Lumex, Inc., Ronkonkoma, New York, USA) was used to measure the concentric and eccentric peak torque (PT) of the quadriceps and hamstring muscles. The Cybex NORM dynamometer is a hydraulically driven and microcomputer-controlled device that operates with a continuous passive motion, in isometric, isotonic and isokinetic concentric and eccentric modes. The Cybex dynamometer was calibrated as part of the regular equipment maintenance schedule for this testing device.[21]

The knee to be tested was placed on the knee flexion-extension plate of the Cybex NORM device and was secured with Velcro straps, according to the manufacturer's instructions for isolating knee flexion and extension.[21] The length of the dynamometer was adapted to the length of the knee for each subject. Standard stabilization strapping was placed across the distal thigh and chest, and placements were limited to grasping the waist stabilization strap. Range of motion was set between 10° and 90° knee range of motion angles (0° indicating full knee extension). To familiarize themselves with the testing device, subjects were instructed to perform three active repetitions of knee movement ranging from 90° to 10° knee range of motion before the testing session began. The same investigator performed all tests to ensure standardization. Subjects were instructed to exert 100% effort and received positive feedback during testing. The concentric and eccentric PT measurements were carried out separately; the eccentric measurement followed the concentric measurement. At the beginning of the test condition, subjects were allowed three submaximal contractions of the quadriceps and hamstring muscle group to familiarize themselves with the test conditions. Subjects were then given four maximal contractions at the angular velocities of 60°•s-1 and 180°•s-1. Eccentric strength measurement was performed at the same angular velocities as for the concentric measurement. A one-minute rest was allowed between each test, and a minimum of a three-minute rest was permitted between the concentric and eccentric measurements to prevent the build-up of fatigue. The best PT of the four maximal contractions for each test condition during the entire range of motion and end range of knee extension and flexion (see below) was collected and used in the functional H/Q muscle strength ratio analysis.

FUNCTIONAL HAMSTRING/QUADRICEPS MUSCLE STRENGTH RATIO

Four different H/Q strength ratios were obtained. Hamstring to quadriceps muscle functional strength ratios were calculated based on the peak moment obtained during the entire range of knee extension and flexion (90° to 10° and 10° to 90°, respectively). In addition, since the antagonist muscles are more important during the end range of motion to decelerate limb movement, we also calculated the functional ratio in the end range of knee extension (30° to 10°) and flexion (60° to 90°). This was also done to better approximate the functional dynamics of the knee. The functional H/Q strength ratio representative of knee extension (ECC_{KF}/CON_{KE}) was determined as the maximal eccentric hamstring moment divided by the maximal concentric quadriceps moment. For knee flexion (CON_{KF}/ECC_{KE}), the ratio was calculated by taking the maximal concentric hamstring moment divided by the maximal eccentric quadriceps moment. All ratios were calculated separately at each of the respective joint ranges of movement: (a) entire knee extension (90° to 10°), (b) entire knee flexion (10° to 90°), (c) end range of knee extension (30° to 10°), and (d) end range of knee flexion (60° to 90°).

STATISTICAL ANALYSIS

Statistical analysis was performed with SPSS version 10.0 software (SPSS Inc, Chicago, IL, USA). Means and standard deviations were used to describe all variables. All tests were two-tailed and the level of significance was set at $p< 0.05$.

Non-parametric statistical testing was chosen because of the limited number of subjects included in this study. Statistical differences between the groups (non-stretching (control) and dynamic stretching) before and after the stretching intervention were investigated using a Mann-Whitney U test. In addition, the statistical differences within the groups between pre- and post-stretching were investigated using Wilcoxon's signed rank test.

RESULTS

Tables 1 and 2 represent the functional H/Q strength ratios during the entire and end range of motions in the two groups for the knee extension and flexion movements, respectively. As shown in Table 1, there were no significant differences for knee extension between the groups at the pre- and post-intervention measurements, both during the entire and end range of motion (p> 0.05). On the other hand, this strength ratio for knee extension displayed a significant increase following dynamic stretching during the entire and end range of motion at both angular velocities (p< 0.05), whereas no change was obvious in the control intervention (p> 0.05).

Similarly, the functional strength ratio for the knee flexion movement (Table 2) exhibited also a no significant interaction between the groups before and after the intervention (p> 0.05). However, the functional strength ratio represented a significant decrease following dynamic stretching during the entire and end range of motion at both angular velocities (p< 0.05), whereas no change was evident in the control intervention (p> 0.05).

TABLE 1: Functional H/Q muscle strength ratios for knee extension during the entire and end range before and after stretching intervention in the two groups (Mean ± SD).

	Control		Dynamic	
	Before	After	Before	After
ER-Ext-60	1.07 ± 0.28	1.06 ± 0.26	0.96 ± 0.28	1.03 ± 0.28*
ER-Ext-180	1.48 ± 0.40	1.50 ± 0.38	1.48 ± 0.39	1.56 ± 0.35*
Ext-60	0.68 ± 0.18	0.70 ± 0.15	0.63 ± 0.18	0.67 ± 0.16*
Ext-180	1.17 ± 0.28	1.18 ± 0.24	1.19 ± 0.27	1.23 ± 0.26*

Extension, 60: 60°•s-1 angular velocity, 180: 180°•s-1 angular velocity,
*p< 0.05 (between pre- and post-intervention).
p> 0.05 (between the groups at pre- and post-intervention).
H/Q: Hamstring/Quadriceps; ER: End range.

TABLE 2: Functional H/Q muscle strength ratios for knee flexion during the entire and end range before and after stretching intervention in the two groups (Mean ± SD).

	Control		Dynamic	
	Before	After	Before	After
ER-Flex-60	0.54 ± 0.21	0.54 ± 0.22	0.53 ± 0.15	0.47 ± 0.11*
ER-Flex-180	0.45 ± 0.10	0.44 ± 0.09	0.47 ± 0.17	0.39 ± 0.11*
Flex-60	0.60 ± 0.12	0.59 ± 0.10	0.62 ± 0.14	0.57 ± 0.10*
Flex-180	0.48 ± 0.10	0.47 ± 0.08	0.47 ± 0.11	0.42 ± 0.09*

Flex: Flexion, 60: 60°•s-1 angular velocity, 180: 180°•s-1 angular velocity,
*p< 0.05 (between pre- and post-intervention).
p> 0.05 (between the groups at pre- and post-intervention).
H/Q: Hamstring/Quadriceps; ER: End range.

DISCUSSION

As stretching exercises are traditionally recommended before most physical activities, it is important to determine the extent to which a stretching routine may influence performance of the main activity as well as the injury risk of the related joints or muscles. Despite the existence of many various study results about the effects of dynamic stretching on some functional tasks[5,22-25] and muscle strength,[4,6,7,9,26] its effects on injury risk characteristics have not been investigated in depth. It is known that the musculature around the knee plays an important role in the prevention of injuries. In addition to the strength of these individual muscles, an additional factor in injury prevention or risk determination is the ratio of strength between agonist and antagonist muscles.[27,28] In rehabilitation and sports medicine, various lower limb strength imbalance ratios are commonly used to monitor rehabilitation programs and to identify possible risk factors for developing knee or hamstring injury and re-injury.[17,29] Besides, the eccentric antagonist/concentric agonist strength ratio has also been investigated in the shoulder and ankle joints.[30,31] On the other hand, the strength ratio that has received the most attention in the literature is the hamstring to quadriceps (H/Q) strength ratio. The measurement of the balance of strength between the hamstring and the quadriceps muscles seems to be important for injury prevention. A "normal" H/Q strength ratio of 0.6 is frequently used as an injury prevention and rehabilitation goal.[17,29] In addition, Knapik et al demonstrated that female collegiate athletes with low H/Q strength ratios presenting with high speed isokinetic measurements had a higher incidence of ACL injury.[15] Given that dynamic stretching results in acute strength increments of a specific musculature, no study to date has demonstrated a clear relationship between dynamic stretching and injury risk characteristics through the measurement of an imbalance in thigh muscle strength (deducted from functional H/Q strength ratio). Therefore, the aim of the current study was to evaluate the acute influence of dynamic stretching on functional H/Q ratios. In brief, the results of our study, which was carried out with elite women athletes, revealed that dynamic stretching routines, which include dynamic stretching exercises of the knee extensors and flexors, did alter the functional H/Q strength ratios for knee extension and flexion during the entire range of motion or end ranges.

Studies have reported that evaluation of the H/Q strength ratio and of antagonist co-activation may contribute to identification of normal knee function and muscle balance with which pathological states could be compared.[28] This may help to explain the causes of hamstring and knee injuries, and may help athletic trainers develop a preventive approach through correct training and rehabilitation.[12] The H/Q strength ratio has, until recently, been based on the concentric strength of these two muscle groups and been expressed in a conventional manner.[32] This situation, however, does not arise during functional movements. Instead, eccentric antagonist co-activation and serial elastic tension resist concentric agonist contraction eccentrically.[33] Aagaard et al suggested that a more functional ratio calculated by dividing eccentric strength of the hamstrings by the concentric strength of the quadriceps may better describe the capacity for muscular knee/joint stabilization compared with the traditional CON_{KF}/CON_{KE} ratio.[11,13] Indeed, during knee extension, the concentric action of the quadriceps muscle (the prime mover) is combined with an eccentric contraction of the hamstring (the stabilizer). This co-activation of knee flexor muscles helps to counteract the shear and rotation of the tibia that occurs during maximum knee extension[11,13] by increasing the posterior pull and joint stiffness and reducing anterior laxity force during quadriceps loading to oppose its force.[34] This helps to prevent overextension, decelerating the leg prior to full extension and stabilizing the knee joint throughout the range of motion.[34] In other words, the hamstring must lengthen during knee extension and, if it is relatively weaker than the quadriceps, a strain may occur. The same is valid during knee flexion, in which case the eccentric strength of the quadriceps muscle resists the concentric strength of the hamstring muscle in order to stabilize the knee joint in this direction. Evaluation of isokinetic eccentric antagonistic strength relative to concentric agonist strength may therefore provide useful information that describes the maximal potential of the antagonistic muscle group. This could be more useful in determining an injury risk compared to the conventional H/Q strength ratio. Conversely, it is possible that the antagonist co-activation is more important at the end range of motion in order to control limb movement. To control for this, we calculated the functional H/Q strength ratio at the end ranges of knee extension (30° - 10°) and flexion (60°-90°), as well as during the entire range.

When the functional H/Q strength ratio for knee extension was taken into consideration, the ratio obtained from the peak torque values during the entire range of motion before the intervention was 0.68 and 0.63 at low angular velocity (60°•s-1) and 1.17 and 1.19 at high angular velocity (180°•s-1) for the control and dynamic stretching groups, respectively. Although no change was seen in the control intervention, dynamic stretching significantly increased the functional strength ratio both at 60°•s-1 (from 0.63 to 0.67) and 180°•s-1 (1.19 to 1.23) test velocities. Dynamic stretching, therefore, did alter the functional H/Q strength ratios, parallel to observations reported in previous studies for individual muscle strength performance. Based on the higher functional H/Q strength ratios after stretching for the knee extension, our results suggest that dynamic stretching performed in a preparticipation warm-up routine could decrease injury risk characteristics. Further research in this area is also necessary to address the injury risk features that follow dynamic stretching. The enhanced strength ratio after stretching could be due to three factors: 1) an increase in eccentric hamstring strength; 2) a decrease in concentric quadriceps strength; or 3) a combination of both. Based on the previous literature that dynamic stretching has positive effects on muscle performance,[6,7] our opinion is that dynamic stretching has increased eccentric hamstring strength more than concentric quadriceps strength, in spite of decreasing only concentric quadriceps strength. On account of this, higher eccentric hamstring strength as to concentric quadriceps strength means that this could help reduce excessive anterior displacement of the tibia on the femur during knee extension. By this way the knee joint goes to a more stabilized condition and thus injury risk characteristics are lowered. In addition, the hamstring has the capacity to lengthen during knee extension and a strain injury occurrence could be reduced also.

The functional H/Q strength ratios in our study are consistent with those reported in previous studies that calculated the functional ratio for knee extension during the entire range.[1,19,35-40] Donne and Luckwill reported an average ECC_{KF}/ CON_{KE} moment ratio of 0.63 throughout the range of motion.[36] It is important to note that they did not take muscle length (i.e., joint angle) into account in their analysis. Dvir showed that the ratio derived from low/medium test velocities were typically within the range of 0.95-2.05 for healthy adults.[37] Taking joint angle and a change in angular velocity into consideration, Aagaard et al. showed that the functional ECC_{KF}/CON_{KE} strength ratio increased above 1.00 with increasing velocity.[11,13] The obtained ratios were 0.6 at 30°•s-1 and 1.0 at 240°•s-1.[13] Tourney-Chollet et al reported that the functional ratios in experienced male soccer players were 0.8 at 60°•s-1 and 0.88 at 120°•s-1 angular velocity.[40] De Ste Croix et al evaluated the functional H/Q strength ratio for knee extension and flexion in different age groups of healthy female subjects.[35] They reported a functional ratio for knee extension at 60°•s-1 angular velocity of 0.8 for 17-year-old and 0.78 for 24-year-old females. Holcomb et al assessed the functional H/Q strength ratio in female collegiate soccer players and found ratios that were similar to ours at identical angular velocities (0.7 at 60°•s-1 and 1.1 at 180°•s-1).[19] Another study conducted in male amateur soccer players showed a ratio of 1.11 at 120°•s-1 test velocity.[39] Finally, the reliability study reported by Impellizzeri et al indicated a functional ratio of 0.71 at 60°•s-1 velocity.[38] The functional H/Q strength ratios reported in our study were higher for the end ranges of knee extension (0.96-1.07 for 60°•s-1 and 1.48-1.56 for 180°•s-1) than during the entire range of knee extension. Similar results were obtained from the few studies that calculated this ratio at the end ranges of extension.[13,41] Aagaard et al stated that the functional H/Q strength ratio increases at more extended knee joint positions.[13] Their results displayed an increase from 0.6 to 1.0 for 30°•s-1 and from 1.0 to 1.4 at the end ranges of knee extension. The functional H/Q strength ratios from the study of Kellis and Katis were also higher (2.2 for 60°•s-1 and 2.7 for 180°•s-1) for corresponding end ranges (30°-10°).[41]

Based on the measurements of peak moments from the entire and end ranges of knee extension, the functional H/Q ratios of 1.17 to 1.23 presently observed for fast knee extension (180°•s-1) suggest that the "braking" action of the hamstring muscles is equal to or greater in magnitude than the maximal quadriceps knee extension moment. Furthermore, this capacity for muscular knee joint stabilization was progressively augmented at gradually more extended knee joint positions, as indicated by the values of 1.48 to 1.56 observed at the end ranges of knee extension (30° to 10°). This was also valid for the slow angular test velocity (60°•s-1). The functional H/Q ratio for the entire range was 0.63-0.70, and increased to approximately 0.96-1.07 as the end ranges were approached. It is possible that this trend may help reduce anterior displacement of the tibia on the femur and prevent hyperextension of the knee when necessary. Our higher ratios obtained at the end range supports the idea that, in a typical movement, the agonist muscles produce the main force for the movement and the antagonist activity is higher at the initial and final phases of the movement to decelerate the limb and control the joint.[42] Osternig et al showed that eccentric hamstring activation increased sharply during the last 25° of a concentric knee extension.[33] The values reported for the functional H/Q ratios appeared to be consistent with the contractile force to length properties of the agonist-antagonist muscle synergies about the knee joint. It has been shown that the knee extensors peak moments occur at knee angles of approximately 60-70°, while the peak moments generated by the knee flexors occur at 20-30°.[10] Furthermore, there is a decrease in the concentric quadriceps moment from 90° of knee flexion to 0° (full extension) throughout the range of motion and a relative constant eccentric hamstring moment, yielding an increase in the ratio as a full knee extension is approached.[13] The high functional H/Q strength ratios observed for knee extension at end ranges are the result of the relationships of contractile force to muscle length and thus peak moment. At the end range of knee extension, the hamstring muscles approach their optimal length and peak moment, whereas the length to tension conditions of the quadriceps muscles are increasingly compromised.

Our finding that the functional H/Q ratios for knee flexion were lower (Table 2) than for knee extension are consistent with previous findings.[13,35,39,41] Conversely, dynamic stretching of the quadriceps and hamstring muscles decreased the functional H/Q ratio for knee flexion. It is therefore likely that dynamic stretching does alter the functional H/Q ratios for knee flexion, and thus could decrease the injury risk characteristic. The declined strength ratio after stretching could be due to three factors: 1) an increase in eccentric quadriceps strength; 2) a decrease in concentric hamstring strength; or 3) a combination of both. Based on the previous literature that dynamic stretching has positive effects on muscle performance, our opinion is that dynamic stretching has increased eccentric quadriceps strength more than concentric hamstring strength, in spite of decreasing only concentric hamstring strength.[6,7] On account of this, higher eccentric quadriceps strength as to concentric hamstring strength means that this could help reduce excessive posterior displacement of the tibia on the femur during knee extension. By this way, the knee joint goes to a more stabilized condition during knee flexion and thus injury risk characteristics are lowered. In addition, the quadriceps has the capacity to lengthen during knee flexion and a strain injury occurrence could be reduced also.

In addition, the ratios were lower at the end ranges (0.47-0.54 for 60°•s-1 and 0.39-0.47 for 180°•s-1) than the ratios from the entire range (0.57-0.62 for 60°•s-1 and 0.42-0.48 for 180°•s-1). This finding indicates that the hamstring muscles have a reduced capacity for dynamic knee joint stabilization during forceful knee flexion movements coupled with simultaneous eccentric quadriceps muscle contraction approaching end ranges of knee flexion.[13] It has been formerly suggested that the greater mass of the quadriceps may provide a greater visco-elastic effect, thereby enhancing the ability to passively control and decelerate the flexion motion.[43] This reduced capacity could also be attributed to the basic physiological principles of the length to force relationship, as the specific length to force properties were impaired for the hamstring muscles and enhanced for the quadriceps muscles during end ranges of knee flexion. Alternatively, current literature suggests that this could also be a manifestation of the fact that hamstring muscles are used to a much greater extent than quadriceps muscles for limb deceleration during knee extension movements.[36]

It is also necessary to consider the reason why dynamic stretching could impact on concentric and eccentric quadriceps and hamstring muscle strength. Previous studies suggested that dynamic stretching exercise might produce positive effects on muscular performance by an elevation of muscular temperature or post-activation potentiation caused by voluntary contractions of the antagonist of the target muscle.[6,7,23,24,44-46] Bishop cited possible factors related to temperature and signified to decreased stiffness of the muscles and joints; increased sensitivity of nerve receptors and increased transmission rate of nerve impulses; changes in the force-velocity relationship; and increased glycogenolysis, glycolysis, and high-energy phosphate degradation.[45] Another possible mechanism is post-activation potentiation (PAP). PAP is commonly defined as an increase in the efficiency of the muscle to produce force after a conditioning contractile activity.[47] The principal mechanisms of PAP are considered to be phosphorylation of myosin regulatory light chains, which renders the actin-myosin interaction more sensitive to Ca^{2+}

released from the sarcoplasmic reticulum. Increased sensitivity to Ca^{2+} has the greatest effect at low myoplasmic levels of Ca^{2+}, and thereby improving muscular performance.[47] Yamaguchi and Ishii hypothesized that the increase in force output after dynamic stretching were caused by an enhancement of neuromuscular function, and they implied that the dynamic stretching had PAP effect on performance.[6,7] To explain the possible mechanism for the probable increase in eccentric strength, activity of the muscle spindles could be scrutinized. Normally, in response to a quick discontinuous stretch, as is in dynamic stretching, the muscle spindle is stimulated which ultimately heightens activation of the motor neurons innervating the stretched muscle.[48] This increased neural drive to the stretched muscle may have elevated the eccentric torque production of the quadriceps and hamstring muscles.

CONCLUSION

It is generally thought that dynamic stretching increases individual muscle strength. It has therefore been suggested that dynamic stretching be replaced for static stretching during pre-participation routines in order to prevent a negative influence on performance. Our study shows that functional H/Q strength ratios do change in a positive manner following a dynamic stretching routine. Athletes not involved in strength-based sport activities can confidently perform dynamic stretching during warm-up.

REFERENCES

1. Franklin BA, Whaley MH, Howley ET, Balady GJ. Exercise prescription. In: Franklin BA, Whaley MH, Howley ET, Balady GJ, eds. ACSM's Guideline for Exercise Testing and Prescription. 6th ed. Baltimore: Williams and Wilkins; 2000. p.137-64.
2. Alter MJ. Sports Stretch. Sports Stretch. 2nd ed. Champaign, IL: Human Kinetics; 1997. p.1-232.
3. Shellock FG, Prentice WE. Warming-up and stretching for improved physical performance and prevention of sports-related injuries. Sports Med 1985;2(4):267-78.
4. Beedle B, Rytter SJ, Healy RC, Ward TR. Pretesting static and dynamic stretching does not affect maximal strength. J Strength Cond Res 2008;22(6):1838-43.
5. Jaggers JR, Swank AM, Frost KL, Lee CD. The acute effects of dynamic and ballistic stretching on vertical jump height, force, and power. J Strength Cond Res 2008;22(6):1844-9.
6. Yamaguchi T, Ishii K. Effects of static stretching for 30 seconds and dynamic stretching on leg extension power. J Strength Cond Res 2005;19(3):677-83.
7. Yamaguchi T, Ishii K, Yamanaka M, Yasuda K. Acute effects of dynamic stretching exercise on power output during concentric dynamic constant external resistance leg extension. J Strength Cond Res 2007;21(4): 1238-44.
8. Cramer JT, Housh TJ, Johnson GO, Miller JM, Coburn JW, Beck TW. Acute effects of static stretching on peak torque in women. J Strength Cond Res 2004;18(2):236-41.
9. Yamaguchi T, Ishii K, Yamanaka M, Yasuda K. Acute effect of static stretching on power output during concentric dynamic constant external resistance leg extension. J Strength Cond Res 2006;20(4):804-10.
10. Grace TG, Sweetser ER, Nelson MA, Ydens LR, Skipper BJ. Isokinetic muscle imbalance and knee-joint injuries. A prospective blind study. J Bone Joint Surg Am 1984;66(5):734-40.
11. Aagaard P, Simonsen EB, Trolle M, Bangsbo J, Klausen K. Isokinetic hamstring/quadriceps strength ratio: influence from joint angular velocity, gravity correction and contraction mode. Acta Physiol Scand 1995;154(4):421-7.
12. Coombs R, Garbutt G. Developments in the use of hamstring/quadriceps ratio for the assessment of muscle balance. J Sports Sci Med 2002;1(3):56-62.
13. Aagaard P, Simonsen EB, Magnusson SP, Larsson B, Dyhre-Poulsen P. A new concept for isokinetic hamstring: quadriceps muscle strength ratio. Am J Sports Med 1998;26(2): 231-7.
14. Gerodimos V, Mandou V, Zafeiridis A, Ioakimidis P, Stavropoulos N, Kellis S. Isokinetic peak torque and hamstring/quadriceps ratios in young basketball players. Effects of age, velocity, and contraction mode. J Sports Med Phys Fitness 2003;43(4):444-52.
15. Knapik JJ, Bauman CL, Jones BH, Harris JM, Vaughan L. Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. Am J Sports Med 1991;19(1):76-81.
16. Myer GD, Ford KR, Hewett TE. Rationale and Clinical Techniques for Anterior Cruciate Ligament Injury Prevention Among Female Athletes. J Athl Train 2004;39(4):352-64.
17. Dauty M, Potiron-Josse M, Rochcongar P. [Consequences and prediction of hamstring muscle injury with concentric and eccentric isokinetic parameters in elite soccer players]. Ann Readapt Med Phys 2003;46(9): 601-6.
18. Hiemstra LA, Webber S, MacDonald PB, Kriellaars DJ. Hamstring and quadriceps strength balance in normal and hamstring anterior cruciate ligament-reconstructed subjects. Clin J Sport Med 2004;14(5):274-80.
19. Holcomb WR, Rubley MD, Lee HJ, Guadagnoli MA. Effect of hamstring-emphasized resistance training on hamstring:quadriceps strength ratios. J Strength Cond Res 2007;21(1):41-7.
20. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA 2000;284(23):3043-5.
21. Ronkonkoma NY. Cybex Norm Int. Inc: Tesing and Rehabilitation System: Pattern Selection and set up: Automated Protocols; User's Guide. New York: Blue Sky Software Corporation; 1995. p. 6.1-7.10.
22. Fletcher IM, Jones B. The effect of different warm-up stretch protocols on 20 meter sprint performance in trained rugby union players. J Strength Cond Res 2004;18(4):885-8.

23. Little T, Williams AG. Effects of differential stretching protocols during warm-ups on high-speed motor capacities in professional soccer players. J Strength Cond Res 2006;20(1):203-7.

24. McMillian DJ, Moore JH, Hatler BS, Taylor DC. Dynamic vs. static-stretching warm up: the effect on power and agility performance. J Strength Cond Res 2006;20(3):492-9.

25. Holt BW, Lambourne K. The impact of different warm-up protocols on vertical jump performance in male collegiate athletes. J Strength Cond Res 2008;22(1):226-9.

26. Herda TJ, Cramer JT, Ryan ED, McHugh MP, Stout JR. Acute effects of static versus dynamic stretching on isometric peak torque, electromyography, and mechanomyography of the biceps femoris muscle. J Strength Cond Res 2008;22(3):809-17.

27. Clanton TO, Coupe KJ. Hamstring strains in athletes: diagnosis and treatment. J Am Acad Orthop Surg 1998;6(4):237-48.

28. Li RC, Maffulli N, Hsu YC, Chan KM. Isokinetic strength of the quadriceps and hamstrings and functional ability of anterior cruciate deficient knees in recreational athletes. Br J Sports Med 1996;30(2):161-4.

29. Kannus P. Isokinetic evaluation of muscular performance: implications for muscle testing and rehabilitation. Int J Sports Med 1994;15 (Suppl 1):S11-8.

30. Yildiz Y, Aydin T, Sekir U, Hazneci B, Komurcu M, Kalyon TA. Peak and end range eccentric evertor/concentric invertor muscle strength ratios in chronically unstable ankles: comparison with healthy individuals. J Sports Sci Med 2003;2(3):70-6.

31. Yildiz Y, Aydin T, Sekir U, Kiralp MZ, Hazneci B, Kalyon TA. Shoulder terminal range eccentric antagonist/concentric agonist strength ratios in overhead athletes. Scand J Med Sci Sports 2006;16(3):174-80.

32. Lund-Hanssen H, Gannon J, Engebretsen L, Holen K, Hammer S. Isokinetic muscle performance in healthy female handball players and players with a unilateral anterior cruciate ligament reconstruction. Scand J Med Sci Sports 1996;6(3):172-5.

33. Osternig LR, Hamill J, Lander JE, Robertson R. Co-activation of sprinter and distance runner muscles in isokinetic exercise. Med Sci Sports Exerc 1986;18(4):431-5.

34. Baratta R, Solomonow M, Zhou BH, Letson D, Chuinard R, D'Ambrosia R. Muscular coactivation. The role of the antagonist musculature in maintaining knee stability. Am J Sports Med 1988;16(2):113-22.

35. De Ste Croix M, Deighan M, Armstrong N. Functional eccentric-concentric ratio of knee extensors and flexors in pre-pubertal children, teenagers and adult males and females. Int J Sports Med 2007;28(9):768-72.

36. Donne B, Luckwill RG. Co-activation of quadriceps and hamstring muscles during concentric and eccentric isokinetic exercise. Isokinet Exerc Sci 1996;6(1):21-6.

37. Dvir Z. Isokinetics of the knee muscles. Isokinetics: Muscle Testing, Interpretation and Clinical Applications. 1st ed. New York: Churchill Livingstone; 1995. p.101-29.

38. Impellizzeri FM, Bizzini M, Rampinini E, Cereda F, Maffiuletti NA. Reliability of isokinetic strength imbalance ratios measured using the Cybex NORM dynamometer. Clin Physiol Funct Imaging 2008;28(2):113-9.

39. Olyaei GR, Hadian MR, Talebian S, Bagheri H, Malmir K, Olyaei M. The effect of muscle fatigue on knee flexor to extensor torque ratios and knee dynamic stability. AJSE 2006;31(2):121-7.

40. Tourny-Chollet C, Leroy D, Delarue Y, beuret-Blanquart F. Isokinetic-based comparison of hamstring-quadriceps ratio between soccer players and sedentary subjects. Isokinet Exerc Sci 2003;11(2):85-6.

41. Kellis E, Katis A. Quantification of functional knee flexor to extensor moment ratio using isokinetics and electromyography. J Athl Train 2007;42(4):477-85.

42. Enoka RM. Forces within the body. Neuromechanics of Human Movement. 3rd ed. Champaign, IL: Human Kinetics; 2002. p.145-60.

43. Lestienne F. Effects of inertial load and velocity on the braking process of voluntary limb movements. Exp Brain Res 1979;35(3):407-18.

44. Hedrick A. Dynamic flexibility training. Strength Cond J 2000;22(5):33-8.

45. Bishop D. Warm up I: potential mechanisms and the effects of passive warm up on exercise performance. Sports Med 2003;33(6): 439-54.

46. Robbins DW. Postactivation potentiation and its practical applicability: a brief review. J Strength Cond Res 2005;19(2):453-8.

47. Sale DG. Postactivation potentiation: role in human performance. Exerc Sport Sci Rev 2002;30(3):138-43.

48. Komi PV. Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. J Biomech 2000;33(10):1197-206.