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Influence of Tibial Rotation on EMG Activities of Medial and Lateral Hamstrings During Maximal Isometric Knee Flexion

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Abstract

Background: The hamstring muscles in the lower extremity are highly important for knee joint stability and can be classified into medial and lateral hamstrings according to the anatomical position, which have some different functions. To measure the strength of the individual hamstring muscles, manual muscle testing is clinically performed by dividing rotation postures into internal and external postures. However, this has no sufficient scientific background.

Objects: This study aimed to test the difference that the tibial rotation would cause in the muscle activity of the medial and lateral hamstrings.

Methods: The muscle activities of the biceps femoris, semitendinosus, and semimembranosus were measured in a total of three different postures (neutral position and internal and external rotations) with 3 replications. During the maximal isometric contraction, resistance was constantly provided by the string attached to the strap, not by manual resistance of the examiner. Before and after electromyography measurements, the participants underwent hamstring flexibility measurement using the active knee extension test in the supine position on the treatment table.

Results: The semitendinosus had a 12.56% reduction in muscle activity in external rotation as compared with that in neutral position. The biceps femoris and semimembranosus showed reduced muscle activities in both external and internal rotations as compared with those in neutral position. Only the women showed significant decreases in the comparison between pre and post-active knee extension.

Conclusion: Only the semitendinosus muscle was consistent with the anatomical speculation. However, the reduction in the muscle activity of the semitendinosus as compared with that in neutral position was only 12.56%, the clinical value of which may be difficult to justify.

Key Words: Electromyography; Hamstrings; Isometric contraction; Tibial rotation.

Introduction

The lower extremities are more developed than the rest of the body parts to support the entire body against gravity and to maintain the standing position. In the lower extremities, the hamstring muscles particularly maintain the stability of the knee joints during movement, enabling smooth motions. Thus, in case of anterior cruciate ligament injuries, strengthening the hamstring muscles is considered the most important factor in the rehabilitation of the lower extremities (Li et al, 1999; Pandy and Shelburne, 1997; Wilk and Andrews, 1992). The hamstring muscles are composed of four muscles, namely the biceps long and short heads, semitendinosus (ST), and semimembranosus (SM). While simultaneous contractions of all the hamstring muscles produce flexion of the knee joint, each muscle has a different orientation from the origin to the insertion, which, accordingly, makes a difference in individual func-

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tions (Lewek et al, 2004; Lynn and Costigan, 2009). In detail, the hamstring muscles are largely divided into the medial hamstring (MH) and lateral hamstring (LH) based on the anatomical location. The biceps femoris originates from the ischial tuberosity and inserts in the lateral side of the head of the fibula, whereas the ST and SM originate from the ischial tuberosity surface and attached to the medial tibia and medial tibial condyle, respectively. Owing to the attached site, the biceps femoris rotates laterally during flexion of the knee joint, while the ST and SM medially rotate on the femur.

To configure clinical rehabilitation programs appropriate for individual patients, the extent of the injury and the resulting muscle strength deficits must be accurately assessed. Currently, muscle strength is measured in various ways, using a wide range of measuring devices, from specialized devices such as Biodex, which has high validity and reliability for measurement, to portable devices such as a handheld dynamometer. However, manual muscle testing (MMT), in which therapists manually apply resistance for measurement, is used widely in clinical practices owing to its convenience for measurement and affordability. MMT is a highly valuable method that can easily measure the force generated in the contractile unit of the muscle. It has been in use since the early 1900 and is now widely applied in clinical practice (Martin and Lovett, 1915). In general, in MMT, measurements are performed in a single posture predetermined for each muscle, except for the hamstring muscles, which are sometimes measured in external or internal rotation owing to their anatomical characteristics.

For MMT measurement, many clinicians include Daniels and Worthingham's Muscle Testing and Muscles: Testing and Function, with Posture and Pain (Avers and Brown, 2018; Kendall et al, 2005). For measurement of the biceps femoris, the authors described that the knee joint needs to be externally rotated so that the toes face outside while bending the knee <90°, and then, the subject should induce contraction of the LH to isolate it with downward resistance in inward directions. At this point, the biceps femoris must be maintained with the foot ends facing outward during knee flexion. By contrast, the ST and SM are measured while applying downward resistance in outward directions after internal rotation of the knee joint. Although the two references are widely used in clinical practice and cited in many papers, they do not describe the scientific evidence for these measurements. Wide clinical use cannot be used as a logical basis. In other words, whether different amounts of muscle activity are actually generated in the MH and LH according to tibial rotation must be quantitatively measured. The present study aimed to investigate if the medial and lateral compartments of the hamstring muscles have differences in quantitative contractions in tibial torsion, for which an electromyography device was used.

Methods

Subjects

Thirty-five young and healthy college students participated in the study (Table 1). They had no injury or disease in the hip and knee joints and were given a full explanation about the study. They provided informed consent prior to participation in the study. This study was approved and monitored by the Institutional Review Board of Woosong University (approval number: 1041549-180419-SB-59).

Instrumentation

Surface electromyography (EMG) signal was collected using a Trigono™ Wireless EMG system (Delsys Inc., Boston, MA, USA). The EMG data were collected from the selected Hamstrings. Delsys EMGworks® Acquisition and Analysis software was used for the analysis. The raw EMG signals were sampled 2,000 ㎐ and were processed into a root mean square with a window of 125 ms. A band pass

Table 1. Subjects characteristics and changes in hamstring flexibility (N=35)

	Male (n_1=19)	Female (n_2=16)
Age (y)	22.0±2.6[a]	21.1±1.1
Height (㎝)	174.3±5.5	160.8±5.7
Weight (㎏)	72.7±13.3	55.2±7.5
Pre-AKE[b] (°)	39.7±13.6	36.6±10.5
Post-AKE (°)	39.1±11.6	31.3±8.9

[a]mean±standard deviation, [b]active knee extension.

fileter of 20-450 ㎐ was used together with notch filters at 60 ㎐.

Procedure

The participants comfortably lied down in the prone position on the treatment table and bent the knee joint to 60° (Albertus-Kajee et al, 2011; Fauth et al, 2010; Onishi et al, 2002). The pelvis and contralateral lower extremity were fastened to the table with a belt. As for the long head of biceps femoris (BF), the electrodes of the EMG sensor were placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia. For the ST, the electrodes must be placed 50% on the line between the ischial tuberosity and medial epicondyle of the tibia. For the SM, the electrodes were attached laterally to the ST tendon in the apex of the "V" between ST tendon and the biceps femoris. Sensor was placed in accordance with SENIAM (surface EMG for non-invasive assessment of muscles) guidelines and the text book of Anatomical guide for the electromyopgapher (Perotto, 2011). Before EMG attachment, the skin was fully shaved. During measurement of the maximal isometric contraction of the hamstring muscles, resistance was constantly provided by the string attached to the strap, not by manual resistance of the examiner. One end of the strap was tied at 3 ㎝ below the lateral malleolus, and the other end was tied to a fixed post to prevent movement during contraction. The string connected to the strap was made perpendicular to the ankle. The three measurement postures were neutral position and internal and external rotations. Each subject was measured in a random order of the postures. The value measured in neutral position was set as the maximum voluntary isometric contraction (MVIC), and values obtained in internal and external rotations were calculated as the %MVIC relative to that in neutral position. In flexion, the subjects were instructed to maximally contract the leg after internal or external rotation, in which resistance was applied in the opposite direction to the contraction. The MVIC was measured 3 times per posture (5 sec/time, 15 sec in total), and the mean value was used. Before and after the EMG measurements, the participants were also subjected to the hamstring flexibility measurement in the supine position on the treatment table using the active knee extension test (AKE). The AKE defined by the longitudinal axes of the tibia and femur was recorded at maximal knee extension and was subtracted from 180°.

Data Analyses

All the statistical analyses were performed using IBM SPSS Statistics ver. 23 experimental data (IBM Corp., Armonk, NY, USA). One-sample t-test was performed to test the difference in %MVIC depending on the tibial torsion within individual muscles (internal or external rotation), and the Bonferroni correction was applied. Pre- and post-AKE were compared using the paired sample t-test. Statistical significance was set at p values of <.025. All the results were expressed as mean ± standard deviation.

Results

When the %MVIC of the hamstring muscles in the knee joint was examined during rotation in comparison with that in neutral position, statistically significant differences were found in the BF and ST, but not in the SM. First, the BF showed a significant decrease in %MVIC in both external (p=.006)

Table 2. Changes in %MVIC of medial and lateral hamstrings at external and internal rotation

	Biceps femoris	Semitendinosus	Semimembranosus
External rotation	92.13±15.84[a]*	87.44±17.47*	91.81±18.20*
Internal rotation	88.94±14.85*	106.77±18.06	95.86±16.58

[a]mean±standard deviation, *significant different compared with neutral position (p<.025).

and internal rotations (p<.001) as compared with that measured in neutral position, with greater MVIC reduction in internal rotation (Table 2). Second, the ST showed a significant reduction in %MVIC measured in external rotation (p<.001) in comparison with that in neutral position, while the %MVIC measured in internal rotation had no significant difference (p=.033). Increased %MVIC value in internal rotation was only observed in the ST. Finally, the SM had decreased %MVIC measured both in internal and external rotations in comparison with that in neutral position, but the difference was statistically significant in internal rotation (p=.012). Only the women showed significant decreases (p=.020) in the comparison between pre and post-AKE (Table 1).

Discussion

As the lower extremities must continuously perform high-intensity activities during movement and tolerate resistance against strain, they often sustain injuries due to overload or overuse. The hamstrings maintain stability by controlling the movements of the lower extremities during eccentric contraction. In addition, it plays a role in shock absorption during high-intensity exercise, thereby relieving shock transmission to the trunk (LaStayo et al, 2003; Roberts and Azizi, 2010). The hamstring muscles have already been studied extensively owing to their importance. Despite the anatomical difference between the muscles, only few studies have examined the performance of individual muscles. This study examined how the muscle activities of the medial and lateral hamstrings change in external and internal rotations in comparison with the changes in the neutral position.

Theoretically, the medial compartment of the hamstring should have a higher muscle activity in internal rotation than in external rotation. This also applies to the lateral compartment of the hamstring. However, the present study found that the anatomical characteristics of the muscles except the ST were not consistent with the corresponding prediction of their muscle activities. As for the ST, which showed similar results with the theoretical prediction, the ST and SM, a medial compartment, showed a reduction in muscle activity of 12.56% in external rotation as compared with that in neutral position. However, it was not statistically significant in internal rotation as compared with that in neutral position. Unexpectedly, the BF had reduced muscle activities both in external and internal rotations relative to the neutral position. As for the difference between the two muscles, the BF had a statistically significant reductions in both external and internal rotations, whereas the SM had no statistically significant reductions. In general, the attachment position of the muscles on the bone determines the direction of joint motion. For example, the biceps brachii muscle of the upper limb muscles is attached to the part of the posterior aspect of the radial tuberosity and bicipital aponeurosis (Landin et al, 2017). A study proved that it generated the largest torque in the forearm supination state, aligning the direction in parallel (ter Haar Romeny et al, 1982; ter Haar Romeny et al, 1984). As the radius of the forearm rotates around a fixed ulna during pronation, the muscle activity of the brachialis muscle, which was attached to the coronoid process and the tuberosity of the ulna, was relatively higher than that of the biceps brachii. In addition, muscle elongation makes it difficult to effectively contract the contractile proteins of the muscle (Gielen and van Zuylen, 1986). Therefore, a full supination motion of the forearm is added to elbow flexion during the MMT of the biceps brachii.

However, the lower leg, unlike the forearm, has only a little rotation movement. Although the rotation range-of-motion (ROM) angle seems to be large because of the additional rotation of the toes inward or outward during tibial rotation, the angle of rotation in the knee joint alone is not large. The potential ROM angle of knee joint rotation is considerably smaller than the pronation-supination ROM angle (Iwaki et al, 2000; Johal et al, 2005; Ristanis et al, 2003). In other words, we speculated that because the tibial rotation angle was not large, the anatomical location of muscle attachment was not significantly associated with the difference in muscle activity depending on tibial torsion. In the lower extremities, the knee joints are bent to approximately 40° in the standing position to independently activate the soleus from the triceps surae (Perry et al, 1981). In this case, the soleus maintained the maximum muscle activity, whereas the gastrocnemius had a reduction in muscle activity by approximately 21% from the maximum activity. Most studies on the lower extremities have focused on abnormal or excessive torsion in gait or single-limb stance rather than tibial torsion (Hicks et al, 2007; Passmore et al, 2016). Only few studies on muscle activity were based on the understanding of the anatomical location characteristics of the hamstring muscles. Nevertheless, some studies, similar to the present study, were performed in the submaximal position using surface EMG. In a study by Fiebert et al, the muscle activity of medial hamstring decreased in external rotation, which is similar to the result of the present study. In addition, the muscle activity of the lateral hamstring was also significantly reduced in internal rotation (Fiebert et al, 1997). However, Fiebert et al (1997) set resistance as low as 5% of the body weights of subjects, which implies that it may not be much meaningful clinically. Although muscle activity might have a significant difference under a weak resistance depending on posture, the difference might have been masked under maximum contraction, as in this study. Perhaps, this may be because the ROM of the knee joint was limited as described earlier.

In the present study, the subjects were provided with resistance to prevent them from moving during maximum contraction in prone posture to measure the MVIC of the hamstring muscles. Although the posture was not a common stretching posture to increase the flexibility of the hamstring muscles, the muscles are contracted at maximum intensity against the resistance during the MMT, similarly to the hold-relax procedure in proprioceptive neuromuscular facilitation techniques. In the present study, the hamstring muscles were expected to have a higher flexibility after isometric contraction (Ferber et al, 2002). The actual flexibility measurement resulted in a significant increase in flexibility in the women, whereas no significant change was observed in the men. We speculated that because females have a lower muscle proportion than males, their soft tissues have a generally low stiffness, which increases flexibility.

As the subjects of the present study were healthy adults in their early 20 s, the results would be difficult to generalize to healthy people in other age groups, athletes, or patients who have limitations in tibial rotation due to anterior cruciate ligament reconstruction (Bush-Joseph et al, 2001; Hara et al, 2000; Reinschmidt et al, 1997; Steiner et al, 1990). In addition, with the surface EMG device used in the present study, the short head of biceps femoris was difficult to measure, and the device had a cross-talk problem (Fiebert et al, 1997). Thus, more accurate measurements using intramuscular EMG will be required in the future.

Conclusion

Studies have different recommendations regarding the MMT measurement posture for the medial or lateral compartment, which may be because the lower extremities, unlike the forearm, have not been fully studied concerning the difference in muscle activity depending on knee joint rotation. Thus, the MMT has been performed in clinical practice under the assumption that muscle activity would differ by rotation, in the absence of accurate and clear evidence or scientific experimentation. Some of the results in this study were consistent with the existing assumption, while the others were inconsistent. The experimental results did not agree with the assumption, which may be due to the anatomical and functional characteristics of the knee joint.

The results of this study are controversial with regard to the adequacy of the posture for MMT, which is widely used in clinical practice, of the hamstring muscles. In addition, it may be difficult to give a clinical significance because of the small difference in the actual internal and external rotations in comparison with the neutral position, if any. In case of adult subjects with neither disease nor injury in clinical practice, measurement for the hamstring only once in neutral posture, rather than in two different postures, may be sufficient.

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