



Changes in the quadriceps-to-hamstring muscle ratio during wall squatting according to the straight leg raise test angle

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Objective: The purpose of this study was to investigate the muscle activity ratio of the lower limb according to changes in straight leg raise (SLR) test angles on hamstring muscle shortening during squat exercises.

Design: Randomized controlled trial.

Methods: The subjects were 14 healthy adults who were informed of and agreed to the method and purpose of the study. The participants were classified into SLR groups according to two angles (over 80° or under 80°) assessed using the SLR tests. After training and practicing the wall squat posture to be applied to the experiment, electromyography (EMG) was used to measure changes in muscle activity during the performance of a wall squat. After stretching, a sequence of pre-stretch tests were performed again, and the active and passive SLR tests were also reconducted; thereafter, a wall squat was performed again by attaching EMG electrodes. The EMG results before and after stretching were compared.

Results: The muscle activity of the vastus lateralis oblique muscle increased in both groups. The muscle activity of the vastus medialis oblique muscle decreased in over both group. Rectus femoris activity increased in the under 80-degree groups but decreased in the over 80-degree group. The muscle activity of the biceps femoris muscle decreased after stretching in the over 80-degree group and increased in the under 80-degree group, and the semitendinosus muscle activity after stretching was decreased. The quadriceps-to-hamstring muscle (Q:H) ratio before and after stretching between groups showed that the hamstring muscle ratio decreased after stretching in both groups.

Conclusions: The results of this study showed that the Q:H ratio before and after stretching between groups was not significantly different.

Key Words: Isometric exercise, Myography, Pain, Straight leg raise

Introduction

Squats are the most basic knee joint exercises that strengthen the hips, femurs, and trunk muscles, which are important for running, jumping, and lifting movements. They can be used for various purposes, such as improvement of athletes' records, prevention of injury, and improvement

of daily life function [1]. The following are some of the reasons why squats improve records and prevent injuries. Proprioception, which is a mechanoreceptor sensitive to the pressure change of the capsule owing to the closed-chain movement used during squats, promotes the eccentric effect of the antagonistic muscle on the stability of the injured joint [2]. Strengthening of the quadriceps muscle using closed-

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chained movements with weight-bearing is known to promote the functional pattern of muscle mobilization according to the movement of the joint more than that of the muscle without weight-bearing [3]. The reason why squats have a positive affect the daily life function positively is that the sitting to standing posture [4], which is the mechanical characteristic of squats, is one of the most frequently used motions for performing tasks in various life patterns [5].

Despite these advantages, squats can cause knee injuries [6]. The knees are not independent of flexion, extension, or internal and external rotation movements. They constantly work with adjacent joints and can be damaged by the external environment. Therefore, it is essential to keep in mind of the interaction between the joints for effective treatment or intervention techniques [7]. The reason for this limited factor can be found in several areas as follows. First, it is the postural chain that affects posture. Behnke suggested that the pelvis could have an effect on the lumbosacral angle, which is nearby. For example, the pelvis produces tension in the hip joint flexor or the hamstrings. At the anterior tilt, the hip flexor is activated but at the posterior tilt, the hamstrings is activated [8]. Second, the kinetic chain is involved. A study on additional kinetic chains relating to the knees suggests that the range of motion (ROM) of the ankles with limited dorsiflexion is associated with greater knee lateral displacement during squatting and landing. Therefore, limited ankle dorsiflexion ROM may be related to a greater risk of anterior cruciate ligament injury since a large ground reaction force, valgus displacement, and limited knee flexion displacement upon landing are risk factors for such an injury [9]. Third, the myofascial chain is involved. Clinical studies on the Superficial Back Line (SBL) and knee muscles showed that hamstring, gastrocnemius, and tensor fasciae latae muscle shortening was present in persons with patellofemoral pain syndrome (PFPS) and that muscle intervention was also important in preventing PFPS [10]. Fourth, the pain control mechanism is also involved. Knee-related pain and motor control are often observed in knee joint injuries, as well as surgical or pathological problems. These may result in quadriceps muscle weakness, which is due to the arthrogenic muscle inhibition of the quadriceps muscle from the supraspinal pathway [11]. The above mentioned theories show that muscle imbalance affect not only the knees but also various other joints. It is a well-known fact that it is the primary consideration of rehabilitation and injury prevention [12]. Therefore, for an effective squat, it is very important to have various elements predominantly before visu-

al and auditory feedback to produce optimal motion in the common squat movement.

Recent studies have highlighted the quadriceps-to-hamstring muscle (Q:H) ratio. The isotonic Q:H ratio is 3:2 for healthy individuals, while it is lower in patients with osteoarthritis [13]. This theory shows that the Q:H ratio has an effect on knee injuries and pain. For the factors affecting the ratio, Adegoke *et al.* [13] stated that the isotonic strength of the quadriceps and hamstring muscles is important especially when the hamstring muscle is weaker than the quadriceps muscle. To maintain proper Q:H ratio, the role of the hamstrings is essential. Therefore, hamstring flexibility is considered when trying to increase hamstring involvement. However, it remains unclear whether flexibility would have a greater impact on muscle strength. Also, reduced hamstring length could increase the amount of stress placed onto the patellofemoral joint and is closely related to the occurrence of PFPS according to Tang *et al.* [14]. In particular, lateral and total patellofemoral joint stress significantly increased in the group with reduced hamstring length compared to the group without hamstring length reduction during squatting at 60° of knee flexion [15]. It is a known fact that this change in stress affects the Q:H ratio during squatting [16]. Waryasz and McDermott [10] theorized that changes in hamstring muscle length affects the quadriceps muscle strength. We could logically deduce from their findings that the length change would affect the Q:H ratio. In the previous theories, we thought that the actual Q:H ratio needed for a bad squat was affected by the hamstring muscle length and that further testing was needed to determine how it affects the actual squat. Therefore, in this study, we attempted to investigate the muscle-to-muscle ratio of the lower limb by analyzing the electromyography (EMG) findings according to the straight leg raise (SLR) test angle. Also, by identifying the muscle activity ratio (H:Q) of the lower limb according to the increased hamstring length, a more effective treatment method involving squats can be proposed.

Methods

Subjects

The study included a total of 14 healthy students at Sahmyook University in their 20s (7 male and 7 female). The exclusion criteria were previous knee surgery and severe muscle pain. All subjects voluntarily agreed to undergo the test and provided written informed consent prior to study

enrollment. This study was approved by the institutional review board of Sahmyook University (IRB No. 2-7001793-AB-N012018027HR) and adhered to the principles of the Helsinki Declaration.

Experimental and measurement methods

The active straight leg raise (ASLR) and passive straight leg raise (PSLR) tests are commonly used in clinical settings to assess hamstring tightness [17,18]. The participants were classified into SLR groups according to two angles (over 80° or under 80°) assessed using the ASLR and PSLR tests. The functional movement screen and selective functional movement assessment were used for this study [19]. The digital inclinometer (Dualer IQ Pro, 2005; JTECH Medical, Salt Lake City, UT, USA) was used and the mean value was recorded three times.

In addition, the same evaluator handled the instrument and provided the instructions for the exercises. To establish a consistent wall squat for each subject before the measurement, the shoulder width of the subjects was measured using a tether, and they were instructed to spread their legs according to the shoulder width, place their backs against the wall directly, bend the hip and knee joints to 90°, and slide along the wall. An 18-cm manual goniometer (Baseline, 2010; Fabrication Enterprises Inc., White Plains, NY, USA) was used to measure the angle of the hip joint during the squat (Figure 1). The knees were restricted from going forward beyond the foot, and the position of the foot was marked on the floor so that the squats could be performed in a consistent



Figure 1. Measuring electromyography in squat posture.

position. The subjects wore shorts so that the electrodes were clearly visible during the assessment. The angle of the trunk and the exercise methods were different for each subject during the exercise, and a wall squat was performed to control these variables. At the time of the squat, the subjects were instructed to gaze at the front, and the velocity at the rate preferred by the subjects was used. Hamstring muscle stretching was applied using the hold and relax method to investigate the effect of the flexibility of the hamstring muscle on EMG recordings and the Q:H ratio. After stretching, a sequence of pre-stretch test was performed again, and the ASLR and PSLR tests were also reconducted to determine if there was any change in the joint angle; thereafter, a wall squat was performed with the application of EMG electrodes. The EMG results before and after stretching were compared.

Intervention

Fixed time intervals are required to do hold-relax stretches for the standardized stretching method. The experimenter passively pulled the hamstrings until the subject first reported a mild stretch sensation and held the position for 7 seconds. Next, the subject isometrically contracted the hamstrings maximally for 7 seconds by trying to push his/her leg back against the resistance of the experimenter. After the contraction, the subject relaxed for 5 seconds. The experimenter then passively pulled the muscle until a mild stretch sensation was reported. The stretch was held for another 7 seconds. This sequence was repeated 5 times on each subject.

Scott reported that hold-relax stretches produced significantly increased hamstring flexibility that lasted 6 minutes after the stretching protocol ended [20].

Electromyography

The maximum muscle activity of the quadriceps and hamstring muscles was measured using the Telemyo 2400 G2 Telemetry electromyography system (2011; Noraxon Inc., Scottsdale, AZ, USA). Data was measured using a sampling rate of 1,000 Hz and a band-pass filter of 10-450 Hz. The root mean square of the signal was calculated and were normalized to the EMG data maximum voluntary contraction.

The maximum isometric contraction value of each muscle was normalized by converting the average signal value of the peak value for 5 seconds except for the first and last second, leaving the middle 3 seconds to be used to calculate the % maximum voluntary isometric contraction, which was

performed three times. The surface electrodes were attached to the dominant muscle and parallel to the muscle fibers by the same experimenter. To attach the electrodes properly, foreign substances were removed by wiping the attachment site with alcohol. The electrode attachment sites of the EMG devices were determined by referring to previous studies [21,22].

Statistical method

All statistical analyses were performed using IBM SPSS Statistics ver. 21.0 software (IBM Co., Armonk, NY, USA). After the normality test, the pre-intervention/post-intervention change in the PSLR and ASLR test and EMG results and the results within both groups were analyzed using the paired t-test. Additionally, to compare the effects between the two groups, an independent t-test was used. The statistical significance level was set at $p < 0.05$.

Results

General characteristics of the subjects

This study was performed on 14 healthy adults 7 female

Table 1. General characteristics of the subjects (N=14)

Variable	Over 80° (n=7)	Under 80° (n=7)	Total
Sex (male/female)	2/5	5/2	7/7
Age (y)	23.78 (2.29)	24.28 (2.98)	23.28 (1.38)
Height (cm)	168.42 (8.39)	163.57 (2.63)	173.28 (1.38)
Weight (kg)	59.10 (10.32)	52.92 (3.58)	65.28 (11.35)

Values are presented as number only or mean (SD).

and 7 male. The mean age was 23.78 ± 2.29 years; the mean height was 168.42 ± 8.39 cm; and the mean body weight was 59.10 ± 10.32 kg (Table 1).

Comparison of the SLR test changes before and after hamstring muscle stretching

The ASLR and PSLR test changes before and after stretching in all subjects were compared using the paired t-test and independent t-test (Table 2). The ASLR and PSLR test changes after hamstring muscle stretching were significantly different ($p < 0.05$). The number of the patients in the over 80-degree group was 7, and that of the patients in the under 80-degree group was 7 based on the SLR test results.

Comparison of the quadriceps muscle activity before and after stretching

Fourteen subjects were evaluated for the muscle activity of the vastus lateralis oblique, vastus medialis oblique, and rectus femoris muscles, which are parts of the quadriceps muscle, before and after stretching. The maximum muscle activities of the three muscles were compared using the intra-group paired t-test and the inter-group independent sample t-test (Table 3). The muscle activity of the vastus lateralis oblique muscle increased in both groups; however, there was no difference between the groups. The muscle activity of the vastus medialis oblique muscle decreased in both groups. Finally, the muscle activity of the rectus femoris muscle only decreased at over 80°. But In under 80° was increased.

Table 2. Comparison of the ASLR test findings before and after hamstring muscle stretching

(N=14)

Variable	Over 80° (n=7)	Under 80° (n=7)	t (p)
ASLR			
Before	81.71 (6.64)	57.28 (9.52)	5.566 (<0.001)
After	88.71 (8.80)	70.33 (8.74)	3.920 (0.002)
Difference	6.99 (6.62)	13.04 (5.73)	-1.827 (0.930)
t (p)	-2.798 (0.031)	-6.024 (<0.001)	
PSLR			
Before	92.57 (13.81)	64.85 (8.71)	4.489 (0.001)
After	98.90 (16.49)	80.27 (9.00)	2.581 (0.024)
Difference	6.33 (5.24)	12.71 (5.67)	-2.976 (0.012)
t (p)	-3.196 (0.019)	-6.411 (0.001)	

Values are presented as mean (SD) (° angle).

ASLR: active straight leg raise, PSLR: passive straight leg raise.

Table 3. Comparison of the quadriceps muscle activity before and after stretching (N=14)

Variable	Over 80° (n=7)	Under 80° (n=7)	t (p)
VLO			
Before	50.85 (17.53)	45.94 (17.11)	0.531 (0.609)
After	52.11 (23.64)	46.08 (15.99)	0.559 (0.587)
Difference	-1.25 (10.48)	0.14 (7.965)	0.224 (0.827)
t (p)	-0.317 (0.762)	-0.047 (0.964)	
VMO			
Before	55.67 (19.71)	60.68 (25.79)	-0.409 (0.690)
After	54.70 (14.51)	55.00 (18.63)	-0.034 (0.974)
Difference	0.97 (12.80)	-5.69 (14.78)	-0.556 (0.590)
t (p)	0.201 (0.848)	0.817 (0.445)	
RF			
Before	38.18 (20.04)	31.47 (17.16)	0.673 (0.514)
After	37.17 (18.38)	32.68 (13.80)	0.516 (0.615)
Difference	1.01 (4.38)	1.21 (5.45)	-0.460 (0.654)
t (p)	0.231 (0.825)	-0.589 (0.577)	

Values are presented as mean (SD) (%maximum voluntary contraction).

VLO: vastus lateralis oblique, VMO: vastus medialis oblique, RF: rectus femoris.

Table 4. Comparison of the hamstring muscle activity before and after stretching (N=14)

Variable	Over 80° (n=7)	Under 80° (n=7)	t (p)
BF			
Before	8.51 (2.44)	6.33 (4.57)	1.109 (0.289)
After	8.43 (2.57)	6.63 (4.79)	0.873 (0.400)
Difference	0.80 (1.46)	0.30 (1.53)	-0.475 (0.643)
t (p)	0.144 (0.890)	-0.519 (0.622)	
STD			
Before	7.40 (2.97)	7.09 (2.72)	0.982 (0.407)
After	6.11 (1.72)	6.68 (2.88)	-0.447 (0.663)
Difference	1.29 (2.08)	0.21 (2.26)	-0.989 (0.342)
t (p)	1.644 (0.151)	1.021 (0.347)	

Values are presented as mean (SD) (%maximum voluntary contraction).

BF: biceps femoris, STD: semitendinosus.

Table 5. Comparison of the muscle activity ratios of the quadriceps and hamstring muscles before and after hamstring muscle stretching (N=14)

Variable	Quadriceps:Hamstring (%)	t (p)
Before	1:0.16 (0.48)	1.820 (0.092)
After	1:0.15 (0.48)	

Values are presented as mean (SD).

Comparison of the hamstring muscle activity before and after stretching

The muscle activity of the biceps femoris and semitendinosus muscles, which are a part of the hamstring muscle, before and after stretching, was measured in all 14 subjects.

The maximum muscle activities of these two muscles were compared using the intra-group paired t-test and the inter-group independent t-test (Table 4). The muscle activity of the biceps femoris muscle decreased after stretching in the over 80° group and increased in the under 80° group. The muscle activity of the semitendinosus muscle after stretching also decreased. There was no difference between the two muscle groups.

Comparison of the muscle activity ratios of the quadriceps and hamstring muscles before and after stretching

The maximum muscle activity of the quadriceps and hamstring muscles before and after stretching was measured (Table 5). When the value for the quadriceps muscle was set

Table 6. Quadriceps and hamstring muscle activity ratio before and after stretching between groups (N=14)

Variable	Quadriceps:Hamstring (%)	t (p)
Over 80°		
Before	1:0.17 (0.05)	1.550 (0.172)
After	1:0.16 (0.04)	
Under 80°		
Before	1:0.15 (0.04)	0.984 (0.363)
After	1:0.14 (0.05)	

Values are presented as mean (SD).

to 1 and the value for the hamstring muscle was compared using the paired t-test, the Q:H ratio showed a minimal difference before and after stretching. Q:H ratio=(sum of average hamstring/sum of average quadriceps)

Quadriceps and hamstring muscle activity ratio before and after stretching between groups

The Q:H ratio before and after stretching between groups showed that the hamstring muscle ratio decreased after stretching in both groups; however, there was only a minimal difference between the two ratios (Table 6).

Discussion

According to the study by Tang *et al.* [14], increased stress in the patellofemoral joints was found to be strongly associated with the occurrence of PFPS. Particularly, reduced hamstring length caused lateral patellofemoral and total patellofemoral joint stress, which significantly increased during squatting [15]. This suggests that hamstring muscle shortening is directly related to PFPS and patellofemoral degeneration in weight-bearing exercises, such as squatting exercises. Previous studies have addressed the problems of physiological mechanics in shortened hamstring muscles; their findings are supported by those of studies in which it is advisable to increase the hamstring muscle length to prevent and manage patellofemoral joint pathologies. Previous studies have also emphasized the importance of the Q:H ratio especially for all activities to stabilize the knees. The Q:H ratio is important in preventing and protecting against knee stress and achieving knee stabilization.

In this study, we compared the muscle activity of the lower limb according to the degree of hamstring muscle shortening before and after stretching and identified the Q:H ratio according to the increased hamstring muscle length to suggest a more effective treatment method in the squat exercise.

The squat exercise method used in the study was the wall squat method to minimize the side effects caused by a faulty posture. However, the degree of muscle activity was not large, and the muscle activity of the quadriceps and hamstring muscles used in the wall squat had no significant difference. Based on the results of the present study, it was confirmed that the change in muscle length affects muscle activity as in previous studies; however, stretching alone cannot physically affect the muscle itself. Therefore, it can be seen that training through time and resistance can lead to an effective Q:H ratio change. The duration of the stretch lasted 6 minutes, which could have affected the results of this study. Therefore, the future study would be better to be completed in 6 minutes through controlled time management.

Also, depending on the degree of wall support, muscle activity could have been affected depending on using partial wall support and full wall support [23]. Although the study involved the use of a consistent squat posture, the degree of wall support could not be regulated. In conclusion, it may be appropriate to approach the Q:H ratio according to the concept of isotonic strength by Adegoke *et al.* [13]. In addition, the wall squat, which was performed to evaluate the stability of the subjects, and the standardized squat were inadequate in determining the Q:H ratio. In the future, it may be more effective to perform an anteroposterior posture in which the torque of the hamstring muscle connected with the hip joint is assessed to obtain the Q:H ratio.

In conclusion, in this study, we attempted to analyze the muscle activity ratio of the lower limb according to changes in the SLR test angle with hamstring muscle shortening using squat exercises. The following conclusions were obtained from this study with 14 healthy individuals.

First, there was a clear difference between the results of hamstring muscle stretching and non-hamstring muscle stretching ($p < 0.05$). After hamstring muscle stretching, both the ASLR and PSLR test results of the subjects increased.

Second, there were insignificant differences between the quadriceps and hamstring muscle activities during squatting after stretching.

Third, the Q:H ratio before and after stretching between groups was not significantly different. Both groups showed a decreased hamstring muscle ratio after stretching compared to before stretching.

It was difficult to make a direct comparison of normalized muscle activity between patients with PFPS and healthy individuals in this study. Since the number of subjects was

small and not proportionated between the two groups, this could have had an effect on the results of study.

Also, since the time interval between the application of the hamstring muscle stretching and squatting among the subjects was not constant, it may have affected the lower limb muscle activity according to the degree of muscle fatigue.

Future long-term studies on more subjects and systematic comparative studies with an experimental design that can minimize muscle fatigue are required.

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Conflict of Interest

The authors declared no potential conflicts of interest with respect to the authorship and/or publication of this article.

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