Muscle Activation of the Gluteus Maximus and Hamstrings During Prone Hip Extension With Knee Flexion in Three Hip Abduction Positions

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ABSTRACT

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The direction of fiber alignment within a muscle is known to influence the effectiveness of muscle contraction. However, most of the commonly used clinical gluteus maximus (GM) exercises do not consider the direction of fiber alignment within the muscle. Therefore, the purpose of this study was to investigate the influence of hip abduction position on the amplitude and onset time of the GM and hamstrings (HAM) during prone hip extension with knee flexion (PHEKF) exercise. Surface electromyography (EMG) signals were recorded from the GM and HAM during PHEKF exercise in three hip abduction positions: 0°, 15°, and 30°. Thirty healthy subjects (age: 22.8 ± 2.9 yrs, body mass: 66.9 ± 10.8 ㎏, height: 170.3 ± 4.1 ㎝) voluntarily participated in this study. EMG amplitude was transformed into the root-mean-square

(RMS) and expressed as a percentage of the maximal voluntary isometric contraction (MVIC) for each muscle. The relative onset difference between activation of the GM and HAM was calculated by subtracting the HAM onset from the GM onset (in ms). Repeated measures analysis of variance (ANOVA) with Bonferroni post hoc tests was used to compare muscle activation between the three hip abduction positions. The level of statistical significance was set at $p < 0.05$.

The results show that GM amplitude was greatest in the 30° hip abduction position, followed by 15° and then 0° hip abduction during PHEKF exercise (mean ± SD: 29 ± 11% MVIC, 23 ± 9% MVIC, and 20 ± 8% MVIC, respectively). On the other hand, the HAM amplitude was greatest at 0° hip abduction, followed by 15° and then 30° (mean ± SD: 17 ± 15% MVIC, 15 ± 15% MVIC, and 14 ± 14% MVIC, respectively). Additionally, the relative onset difference between the GM and HAM was positive at 0° hip abduction, meaning that GM firing was delayed relative to that of the HAM (mean ± SD, 0.17 ± 0.17 ms). In contrast to the 15 and 30° hip abduction positions, the relative onset difference was negative, which means the GM onset occurred earlier than the HAM (mean ± SD: -0.02 ± 0.11 ms and -0.21 ± 0.20 ms, respectively).

These findings indicate that the 30° hip abduction position maximizes GM amplitude and minimizes HAM amplitude. The EMG onset of the GM was significantly earlier relative to the HAM at 15° and 30° hip abduction. Therefore, performing PHEKF exercise in the 30° hip abduction position may be recommended as an effective way to selectively activate the GM and to reduce the delay in GM firing in

asymptomatic individuals. This finding provides preliminary evidence that amplitude and onset time during PHEKF can be modified by the extent of hip abduction.

Key Words: Amplitude, Electromyography, Gluteus maximus, Hamstrings, Hip abduction, Onset time, Prone hip extension with knee flexion.

Introduction

The group of muscles in the gluteal region consists of the gluteus maximus, medius, and minimus. The gluteus maximus (GM) is the largest and most superficial muscle in the area. It is a broad, thick, fleshy mass of a quadrilateral shape and its fibers are directed obliquely downward and laterally (Frank and Netter 1987; McAndrew et al. 2006). The muscle primarily acts as a powerful extensor of the hip; it also functions as an extensor of the trunk. The upper fibers of the GM extend and abduct the hip joint, and the lower fibers assist in external rotation of the hip. Because the GM muscle fibers are aligned perpendicular to the sacroiliac (SI) joint, GM contraction produces compression of the SI joint, and also contributes to the force transmission mechanism from the lower extremity to the pelvis through the SI joint during functional activities such as ambulation (Hossain and Nokes 2005; Lieberman et al. 2006; Lyons et al. 1983; Mooney et al. 2001).

Inappropriate timing of GM activation during gait is thought to be one of the causes of low back pain (LBP), resulting in a deficiency in the shock absorption mechanism at the sacroiliac joint. Earlier onset of hamstrings (HAM) activation has been noted in patients with LBP as compensation for delayed firing of the GM (Hossain and Nokes 2005; Hungerford et al. 2005). In addition, weakness and imbalanced strength in the GM are associated with lower extremity injuries, including patellofemoral pain syndrome, anterior cruciate ligament sprains, and chronic ankle instability (Cichanowski et al. 2007; Hewett et al. 2006; Friel et al. 2006; Powers 2003; Yang et al. 2011). Weakness of the GM also leads to slouched posture, makes walking extremely difficult, and necessitates substitution by synergists (Kisner and Colby 2005). Therefore, neuromuscular reeducation and/or specific GM strengthening exercises are clinically necessary in rehabilitation for low back pain and lower extremity injuries.

Many studies have demonstrated various methods to reduce delayed firing of the GM. During prone hip extension exercise, lower abdominal hollowing and the abdominal drawing-in maneuver (ADIM) using a pressure biofeedback unit reduced the delay of GM firing relative to that of the HAM (Chance-Larsen et al. 2010; Oh et al. 2006). In addition, gluteal verbal cues during prone hip extension resulted in nearly simultaneous EMG onset of the HAM and GM, which means delayed HAM onset and advanced GM onset based on the no-cues condition (Lewis and Sahrmann 2009).

Several GM strengthening exercises are used in physical therapy and many studies have been conducted to determine the best mode of strengthening the GM. Wilson (2004) advocated the full squat as the most active method, and Distefano (2009) reported that the single-limb squat leads to maximum activity of the GM, among other types of exercise that are commonly performed in a gym setting. Because all of those exercises are difficult for patients who have lower extremity joint or stability problems, bridging and prone hip extension exercises are commonly used in rehabilitation to strengthen the GM muscle (Wilson et al. 2004; Cappozzo et al. 1985; Distefano et al. 2009). In particular, for isolated GM activation, patients are asked to lift their hip while maintaining 90° knee flexion; this position is called prone hip extension with knee flexion (PHEKF). Because this position leads to an active insufficiency of the HAM muscle, the PHEKF exercise is an easily employed position for patients to optimize GM activation. It is also commonly used as a muscle strength test or strengthening exercise for the GM in clinical practice (Sakamoto et al. 2009).

Fiber arrangement within the muscles and joint positions are contributing factors in muscle contraction (Soderberg 1983). When the line of action of the muscle matches the line of fiber of the muscle, the effect of muscle contraction is augmented (Smidt and Rogers 1982); however, many exercises do not consider the downward and outward fiber arrangement within the GM muscle and no study has considered the effect of hip abduction position in relation to muscle fiber arrangement during GM exercises. Therefore, the purpose of this study was to investigate the EMG amplitude and relative onset difference of the GM and HAM during PHEKF exercise in three hip abduction positions (0°, 15°, and 30° hip abduction). We hypothesized that the EMG amplitude of the GM would increase and the EMG onset of the GM would be advanced relative to that of the HAM in the 30° hip abduction position.

Method

1. Subjects

Thirty healthy subjects (18 men, 12 women) were recruited from the Department of Physical Therapy at Yonsei University in Korea (Table 1). The exclusion criteria included (1) a history of lumbar, sacroiliac or lower limb injury within the past year, (2) past or present neurological, musculoskeletal, and cardiopulmonary diseases, (3) hip flexor shortness by the Thomas test (Vogt and Banzer 1997), (4) tensor fasciae latae shortness by Ober's test (Magee 2008), (5) adductor muscle shortness by the Adduction Contracture Test (Magee 2008), (6) hip pain with active straight-leg raises or passive hip flexion with adduction and medial rotation (Lewis and Sahrmann 2009), and (7) lumbar or hip pain when performing PHEKF. Prior to participation in the experimental data collection, the principal investigator explained the entire procedure to the subjects. This study was approved by the Yonsei University Wonju Campus Human Studies Committee and all participants gave written informed consent.

Table 1. General characteristics of the subjects (N=30)

Parameter	Mean ± SD
Age (yr)	22.8 ± 2.9
Body mass (㎏)	66.9 ± 10.8
Height (㎝)	170.3 ± 4.1

2. Experimental Apparatus

EMG data were collected from the dominant leg using a Noraxon Telemyo 2400T system (Noraxon, Inc., Scottsdale, AZ, USA) with a pair of Ag–AgCl surface electrodes 2 ㎝ in diameter. Prior to electrode placement, the electrode sites were shaved and cleaned with rubbing alcohol to prepare the skin. The EMG electrode for the GM was placed halfway between the greater trochanter and second sacral vertebra in the middle of the muscle and at an oblique angle. The electrode for the HAM was placed parallel to the muscle fibers on the posterior aspect of the thigh, approximately halfway between the gluteal fold and the popliteal fold (Cram et al. 1998). The reference electrode was attached to right anterior superior iliac spine (ASIS).

Raw EMG signals were band–pass filtered between 20 and 450 ㎐, sampled at 1000 ㎐, and converted using MyoResearch Master Edition 1.06 XP software (Noraxon, Inc., Scottsdale, AZ, USA). Raw data were processed into root-mean-square (RMS) values and were converted to ASCII files for analysis. For normalization, the mean RMS of three trials of 5-second maximal voluntary isometric contraction (MVIC) was calculated for each muscle. MVIC data were obtained in the manual muscle testing positions recommended by Kendall (Kendall et al. 2005). The data for each trial were expressed as a percentage of the calculated mean RMS of the %MVIC, and the mean %MVIC of three trials was used for statistical analysis.

The baseline EMG was calculated by averaging the EMG activity for 5-second interval in a resting position. The onset of EMG activity of each muscle was determined when the EMG amplitude exceeded two standard deviations of the baseline level for a minimum of 50 ms (Choi et al. 2011; Guimarães 2010; Hodges and Bui 1996). The relative onset difference between the GM and HAM was calculated by the following equation:

relative onset difference = GM onset - HAM onset (in ms)

Therefore, a positive value indicates that the HAM fired before the GM. When the GM fires earlier than the HAM, the relative onset difference becomes a negative value (Chance-Larsen et al. 2010).

3. Experimental Procedure

Each participant was positioned prone on a therapeutic table with their feet shoulder-width apart and arms at their sides; the head was allowed to extend slightly to maintain normal breathing. The two boards shown in Figure 1 served as guidelines for hip abduction at the 0°, 15°, and 30° positions, and its center point was placed under the participant's ASIS. The hip abduction angle was considered the line between the ASIS and mid-point of the patella based on the starting position. For the PHEKF exercise, at the starting position, the subject was asked to bend his or her knee to 90° and relax by resting their leg on a vertically positioned wooden device (Sakamoto et al. 2009). Two vertical wooden guides were aligned with the lower extremity to limit substitutions by knee flexion or hip rotation of the examined leg (Figure 2). Then the participant was given a verbal cue to lift their dominant leg toward the ceiling until the patella was lifted 5 ㎝ off of the supporting surface, and then asked to maintain the extended hip for 5 seconds (Dankaerts et al. 2004). When the examiner observed a deviation from the vertical wooden guides, the data were discarded. Before data acquisition, all subjects practiced the PHEKF exercise for 5 minutes to familiarize themselves with the testing procedure. The subjects performed the PHEKF exercise three times for each hip abduction position with a 30 s inter-trial period. The order of the abduction positions was created using a computer-based randomization program and a 2-minute rest period was given between the trials.

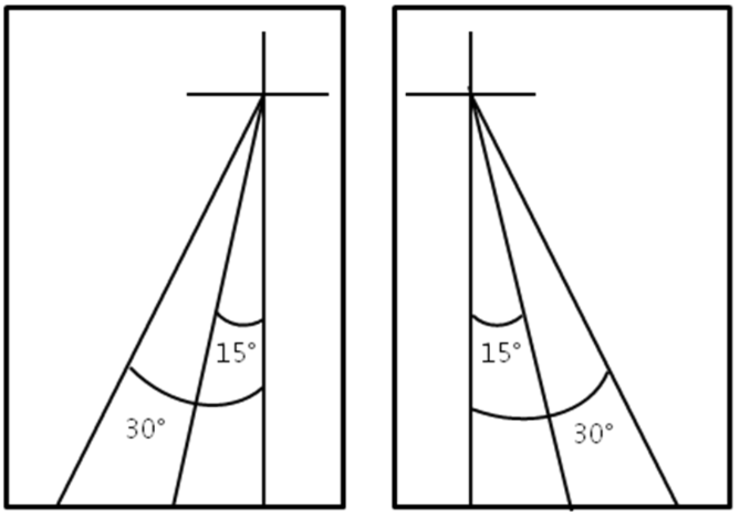

Figure 1. Two boards marked at 0°, 15°, and 30°.

Figure 2. Experimental setting for PHEKF exercise.

4. Statistical Analysis

All dependent variables are presented as the mean ± standard deviation (SD). Repeated measures analysis of variance (ANOVA) was used to compare the EMG amplitude and relative onset differences among the three hip abduction positions. The level of statistical significance was set at 0.05.

Significant differences between three hip abduction positions were determined using the Bonferroni correction (or adjustment); performing pairwise comparisons applying the significance level $\alpha = \alpha$ / the number of pairwise comparisons (0.05 / 3). The Statistical Package for the Social Sciences for Windows version 18.0 (SPSS, Inc., Chicago, IL, USA) was used for all statistical analyses.

Results

1. EMG Amplitude

The GM and HAM amplitudes during PHEKF exercise were significantly different among the three hip abduction positions ($p < 0.001$) (Table 2). Our post hoc comparison revealed that the GM amplitude at 0° hip abduction was significantly lower than at 15° hip abduction ($p_{adj} < 0.001$). The EMG amplitude of the GM at 15° hip abduction was significantly lower than at 30° hip abduction ($p_{adj} < 0.001$). The GM amplitude in the 0° hip abduction position was significantly lower than in the 30° hip abduction position ($p_{adj} < 0.001$) (Figure 3).

On the other hand, the HAM amplitude at 0° hip abduction was significantly greater than at 15° hip abduction ($p_{adj} = 0.008$). There was no significant difference in the EMG amplitudes in the HAM between the 15° and 30° hip abduction positions during PHEKF ($p_{adj} = 0.049$). Finally, a comparison of the results between the 0° and 30° hip abduction positions showed that the HAM amplitude at 0° hip abduction was significantly greater than that in the 30° hip abduction ($p_{adj} < 0.001$) (Figure 4).

Table 2. EMG amplitude of the GM and HAM

	Hip abduction positions				
Muscle	0 °	15°	30°	*F*	*p*
GM [a]	20.16 ± 8.57 [c]	23.35 ± 9.90	29.56 ± 11.48	13.33	< 0.001
HAM [b]	17.92 ± 15.83	15.76 ± 15.03	14.36 ± 14.30	15.86	< 0.001

[a] Gluteus maximus.
[b] Hamstrings.
[c] Mean ± standard deviation (%MVIC).

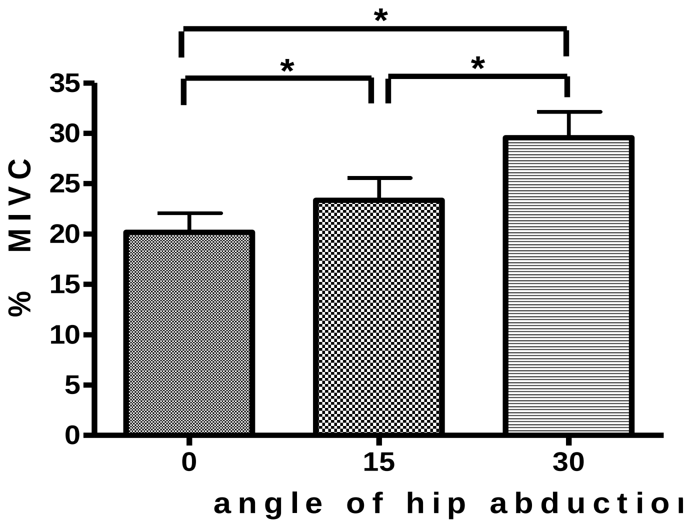

Figure 3. EMG amplitude of the gluteus maximus in three hip abduction positions. The means and SDs are show as bars and hatches. $^{*}p_{\mathbf{adj}} < 0.05/3$.

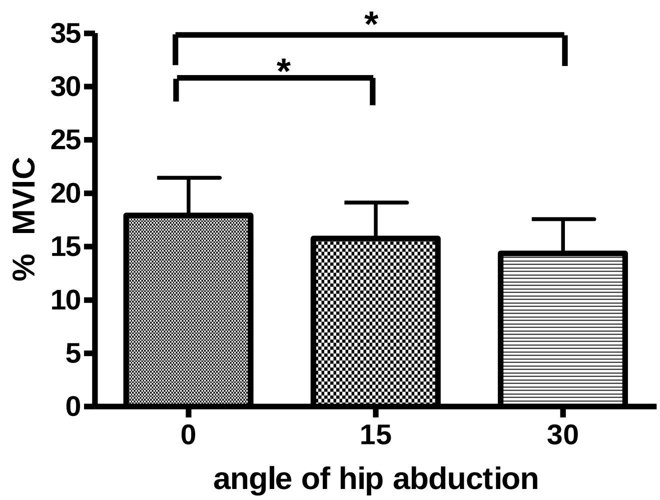

Figure 4. EMG amplitude of the hamstrings in three hip abduction positions. The means and SDs are shown as bars and hatches. $^{*}\ p_{\mathbf{adj}} < 0.05/3$.

2. EMG Onset

There was a significant difference among the three hip abduction positions ($p < 0.001$) (Table 3). In the 0° hip abduction position, the relative onset difference between the GM and HAM was positive (mean ± SD, 0.17 ± 0.17 ms), which implies a delayed GM onset relative to the HAM. In contrast, at the 15 and 30° hip abduction positions, the relative onset difference was negative (mean ± SD: -0.02 ± 0.11 ms and -0.21 ± 0.20 ms, respectively), meaning that the GM fires earlier than the HAM.

Post hoc comparisons revealed significant differences between each of the hip abduction positions (Figure 5). The relative onset difference in the 0° hip abduction position was significantly greater than that in the 15° hip abduction position ($p_{adj} < 0.001$). In addition, the relative onset difference in the 15° hip abduction position was significantly greater than in the 30° hip abduction position ($p_{adj} = 0.001$). Finally, a comparison between the 0° and 30° hip abduction positions showed an onset difference in the 0° hip abduction position that was significantly greater than in the 30° hip abduction position ($p_{adj} < 0.001$).

Table 3. The relative onset difference between GM and HAM

	Hip abduction positions				
	0 °	15°	30°	*F*	*p*
GM-HAM[a]	0.18 ± 0.17[b]	-0.03 ± 0.11	-0.22 ± 0.21	13.57	< 0.001

[a]The relative onset difference between GM and HAM = GM onset - HAM onset.
[b]Mean ± standard deviation (%MVIC).

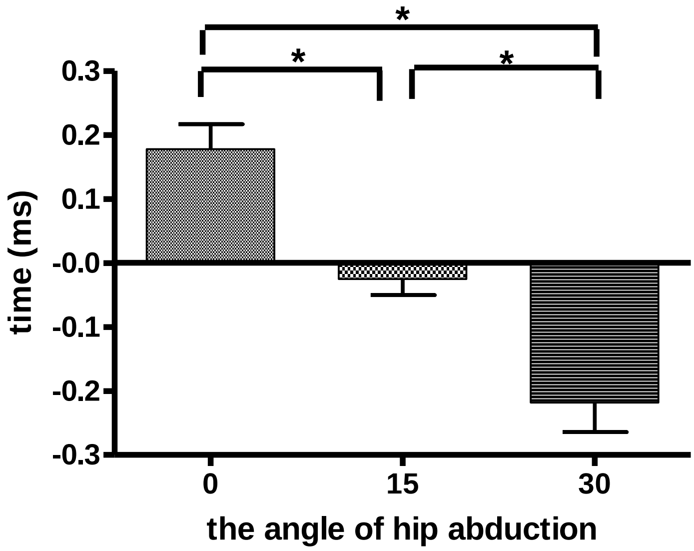

Figure 5. The relative onset difference between the gluteus maximus and hamstrings in three hip abduction positions.

Relative onset difference = GM onset - HAM onset.

Means and SDs are shown as bars and hatches. * $p_{adj} < 0.05/3$.

Discussion

Exercises for reeducation and strengthening of the GM are important in rehabilitation intervention for lower back pain or lower extremity injuries; however, most of the commonly used clinical GM exercises do not consider the direction of fiber alignment within the muscle. Because the GM muscle fibers are oriented downward and outward, performing hip extension in abducted hip position may help match the line of action of the muscle to the line of the fibers. Therefore, the purpose of this study was to investigate the influence of hip abduction on EMG amplitude and the relative onset difference between the GM and HAM.

In this study, subjects performed PHEKF exercise in three different hip abduction positions (0°, 15°, and 30°). The results of this study showed that the EMG amplitude of the GM was greatest with 30° hip abduction, followed by 15°, and then 0° during PHEKF exercise. On the other hand, the amplitude of the HAM was greatest in the 0° hip abduction position, followed by 15°, and then 30°. In brief, when the angle of hip abduction is greater, the GM amplitude increases and the HAM amplitude decreases. Possible mechanisms to explain these findings are discussed below.

First, the location of muscle attachment and joint position are critical in effective motion production since they are the determining factors in the generation of torque or a turning moment at the joint (Soderberg 1983). The fiber arrangement within muscles is classified as fusiform, pennate, and bipennate. Fusiform muscles are composed of fibers that run parallel to the longitudinal axis of the muscle (Landers et al.

2001). A fusiform muscle generates direct tension from contraction by contributing to the total muscle tension produced. On the other hand, pennate muscle fibers lie at an angle to the longitudinal axis of the muscle. This angular insertion of these fibers results in the generation of less tension in the direction of muscle pull (Landers et al. 2001).

Because the GM muscle is considered a fusiform muscle, the muscle fibers should lie in the same direction as the line of pull of the muscle in order to optimize muscle activation (Soderberg 1983; Smidt and Rogers 1982). The GM arises from the posterior gluteal line of the ilium and the posterior surface of the sacrum and coccyx, and is directed downward and outward into the iliotibial tract and the gluteal tuberosity of the femur (Frank and Netter 1987). By performing hip abduction during PHEKF exercise, the direction of muscle pull runs parallel to the fiber of the muscle, leading to increased EMG amplitude.

Second, the length of the lever arm is critical to optimizing muscle activation. An increase in lever arm length causes an increase in the mechanical advantage and strength of the related muscle. EMG research has demonstrated that as the lever arm length increases, the activity of the related muscle increases. Otis et al. (1994) found as the lever arm length increased while glenohumeral joint abducts from 0° to 90°, the EMG activity of the deltoid and supraspinatus muscles also increased. In addition, Wise (2004) recommended that for a progressive shoulder rehabilitation exercise program, the initial activities should involve motion in short lever arm to minimize demand on the glenohumeral musculature, with progression to longer lever arm (Otis et al. 1994; Wise et al. 2004). In this study, the EMG activity of the GM increased when the angle of hip abduction was greater. We conclude that performing PHEKF with hip abduction may increase lever arm length, leading to increased EMG amplitude of the GM.

Third, a synergistic muscle produces movement or stabilization around a joint, such as with the HAM and GM in hip extension. Synergistic muscles work together and influence each other through movement patterns (Chance-Larsen et al. 2010; Janda 2010). Under the assumption that the movement occurs in the same range of motion, an increased EMG amplitude of one muscle can create efficiencies in the movement, thereby decreasing the workload of another muscle (Devlin 2000; Jonkers et al. 2003). In this study, Because the range of hip extension in our experiment was maintained constant in three hip abduction positions, we can speculate that the decreased activity of the HAM in abducted position may have had something to do with the increased activity of the GM during PHEKF exercise. These results suggest that performing hip abduction during hip extension could be a good strategy to selectively increase GM activation.

Another finding of this study was that the relative onset difference between GM and HAM at the 15 and 30° hip abduction positions was negative, meaning that the GM was firing in advance of the HAM. This change in relative EMG onset could be explained by the function of the GM muscle. The GM acts as a powerful extensor of the hip, a strong lateral rotator, and a forcible abductor of the thigh (Frank and Netter 1987). In this experiment, subjects abducted their hip prior to performing PHEKF exercise and performed the exercise while maintaining hip abduction. This led to activation of the GM as a hip abductor, and increased its responsiveness to the load applied during the exercise relative to the 0° hip abduction position. When compared to relative onset differences with 15° and 30° hip abduction, the relative onset difference with 30° hip abduction was smaller than with 15° hip abduction, which means GM firing relative to the HAM occurred earlier with 30° hip abduction. This result implies that the 30° hip abduction position needed greater responsiveness from the GM to maintain the hip abduction position, and showed earlier firing compared to the 15° hip abduction position. Therefore, we think that performing PHEKF in 30° hip abduction position may be an effective method to alter GM onset and may be beneficial for preventing motor control dysfunction of the hip extensors.

Multiple previous studies have examined muscle activation patterns during prone hip extension (PHE), but the existence of a normal activation pattern during PHE remains controversial. Bruno and Bagust (2006) and Lehman et al. (2004) found no consistent pattern, whereas Vogt and Banzer (1997), Janda (2010), and Sakamoto et al. (2009) reported a consistent muscle activation pattern in PHE. Nevertheless, the authors of these studies agree that the GM was consistently the last activated muscle during PHE in both healthy subjects and patients with lower back pain (Bruno and Bagust 2006; Chance-Larsen et al. 2010; Lehman et al. 2004; Lewis and Sahrmann 2009; Sakamoto et al. 2009; Vogt and Banzer 1997).

As we mentioned, many previous studies have examined the muscle activation patterns in PHE, but only one study has investigated recruitment patterns during PHEKF (Sakamoto et al. 2009). That study showed that the movement was initiated by the HAM, followed by the erector spinae (ES), and then the GM. The study results were similar to ours in that the GM was the last muscle to be activated at 0 ° hip abduction during PHEKF. This implies that even during PHEKF exercise that leads to active insufficiency of the HAM muscles, the activation onset of the GM occurs after the activation of the HAM at 0 ° hip abduction position.

We acknowledge several limitations to our study. First, the results of this study are representative of a young, healthy population. Therefore, the changes related to performing hip abduction during PHEKF exercise need to be confirmed in a patient population and muscle imbalance group. Second, in this study, abdominal muscle contraction was not controlled during performance. Previous studies have reported that abdominal muscle contraction, such as the abdominal drawing-in maneuver (ADIM), facilitates transverse abdominis and lumbar stability and it is an essential component for maintaining lumbar and pelvic stability during leg movements (Herrington and Davies 2005; Hodges 1999; Oh et al. 2007). Third, surface EMG was used to monitor EMG amplitude, raising the possibility of cross-talk from adjacent muscles. Fourth, because kinematic data were not collected in our study, the muscle recruitment patterns were not fully described based on a movement's starting point.

Our results imply that performing hip abduction during PHEKF exercise has the potential to increase the EMG amplitude of the GM and to alter the timing of activation of the GM relative to the HAM. Therefore, we suggest performing PHEKF with hip abduction as an effective method to selectively activate the GM and reduce the delay of GM firing. However, this suggestion needs validation through future research, and it should also be confirmed that this change could be maintained and transferred to functional movements such as walking.

Conclusion

The purposes of this study were to quantify the EMG amplitude of the GM and HAM muscles and to measure the relative onset differences between the GM and HAM in three hip abduction positions during PHEKF exercise. We found that the GM amplitude was the greatest and HAM amplitude was the lowest at the 30° hip abduction position during PHEKF exercise. In addition, with 30° hip abduction, the GM onset time was significantly earlier than the HAM onset.

Therefore, performing PHEKF exercise in 30° hip abduction is recommended as an effective method to facilitate EMG amplitude of the GM and to reduce the delay of GM firing relative to HAM. We suggest that performing PHEKF exercise in 30° hip abduction is useful in a treatment protocol designed to increase the contribution of the hip extensors and to improve motor control hip extension by advancing the EMG on-set of the GM.

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국문 요약

무릎 굴곡자세에서 고관절 신전시 고관절 외전각도에 따른 슬괵근과 대둔근의 근활성 비교

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강 선 영

근 수축은 근 섬유가 부착되어 있는 방향과 일치되는 방향으로 발생될 경우 효과적으로 일어난다. 이에 본 연구는 후방, 가쪽으로 부착되어 있는 대둔근의 근 섬유 부착 위치를 고려하여, 0도, 15도, 그리고 30도 고관절 외전자세에서 고관절 신전운동을 하는 동안 슬괵근과 대둔근의 근활성도와 상대적 근 수축 개시시간을 알아보고자 하였다.

연구대상자들은 병리적인 혹은 신경학적인 문제가 없는 건강한 성인 30명을 선정하였으며, 표면 근전도 장비를 이용하여 대둔근과 슬괵근의 근 활성도와 상대적 근 수축 개시시간을 측정 하였다. 상대적 근 수축 개시시간은 대둔근과 슬괵근의 개시시간의 차로 계산하였으며, 가지 고관절 외전 각도에 따른 유의한 차이를 알아보기 위하여 유의수준

은 0.05로 반복측정 분산분석을 실시하였다.

연구결과는 다음과 같다. 1) 고관절 신전 운동 시, 대둔근의 근활성도는 30도, 15도, 0도 고관절 외전 각도 순으로 크게 나타났으며, 슬괵근의 근활성도는 0도, 15도, 30도 순으로 크게 나타났다($p < 0.05$). 2) 대둔근과 슬괵근의 상대적 근 수축 개시시간은 0도 일 때 양수가 나왔고, 이는 슬괵근의 근 수축 개시시간이 대둔근보다 더 빠름을 의미한다. 또한 15도와 30도 고관절 외전 각도일 때의 상대적 근 수축 개시시간은 음수가 나왔으며, 이와 같은 결과는 대둔근의 근 수축 개시시간이 슬괵근보다 유의하게 빠름을 의미한다($p < 0.05$).

그러므로 고관절 30도 외전 자세에서 고관절 신전 운동은 대둔근의 근 활성도를 증가시키는 효과적인 근력 향상 운동 방법으로 제안 될 수 있으며 또한 대둔근의 근 수축 개시 시간을 빨라지게 하는 운동조절 능력 향상 방법으로도 제안될 수 있다. 이와 같은 연구 결과를 바탕으로, 이후 연구에서는 고관절 외전의 효과가 보행과 같은 기능적인 생활에 도움이 될 수 있는지 연구할 필요가 있다고 사료된다.

핵심 되는 말: 고관절 신전 운동, 고관절 외전, 근 수축 개시 시간, 근전도, 근활성도, 대둔근, 슬괵근.