Original Article

Influence of Hip Joint Position on Muscle Activity during Prone Hip Extension with Knee Flexion

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Abstract. [Purpose] This study investigated the selective activation of the gluteus maximus during a prone hip extension with knee flexion exercise, with the hip joint in different positions. [Subjects] The subjects were 21 healthy, male volunteers. [Methods] Activities of the right gluteus maximus, right hamstrings, bilateral lumbar erector spinae, and bilateral lumbar multifidus were measured using surface electromyography during a prone hip extension with knee flexion exercise. Measurements were made with the hip joint in each of 3 positions: (1) a neutral hip joint position, (2) an abduction hip joint position, and (3) an abduction with external rotation hip joint position. [Results] Gluteus maximus activity was significantly higher when the hip was in the abduction with external rotation hip joint position than when it was in the neutral hip joint and abduction hip joint positions. Gluteus maximus activity was also significantly higher in the abduction hip joint position than in the neutral hip joint position. Hamstring activity was significantly lower when the hip was in the abduction with external rotation hip joint position than when it was in the neutral hip joint and abduction hip joint positions. [Conclusion] Abduction and external rotation of the hip during prone hip extension with knee flexion exercise selectively activates the gluteus maximus.
Key words: Prone hip extension with knee flexion, Hip joint position, Electromyography

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INTRODUCTION

Because the gluteus maximus (GM) muscle fibers are aligned perpendicular to the sacroiliac joint, GM contractions compress the sacroiliac joint, and contribute to pelvic stability[1]. GM contraction also contributes to the transmission of force from the lower extremity to the pelvis through the sacroiliac joint during functional activities, such as ambulation[2–4]. Bruno et al.[5] reported that patients with low back pain have a significantly delayed onset of GM activity when performing prone hip extension movements compared to healthy subjects. Hungerford et al.[6] reported that when the contralateral hip is flexed, delayed GM activity and early hamstring (HAM) activity in the supporting leg occur in patients with sacroiliac joint pain. Inappropriate timing of GM activation during gait is believed to be one of the causes of low back pain, resulting from a deficient shock absorption mechanism in the sacroiliac joint[3]. From these

observations, improving the activation pattern of the GM is important for the treatment and prevention of low back and sacroiliac joint pain[7].

A systematic review that investigated exercise therapy for improving muscle activity onset times concluded that training involving selective muscle activation improves muscle activity onset times[8], suggesting that training involving selective GM activation might improve GM activity patterns in people with low back pain. One exercise for suppressing HAM activity and activating GM that is often used clinically is prone hip extension with knee flexion (PHEKF)[9]. Kang et al.[10] and Sakamoto et al.[9] investigated the impact of muscle activity during PHEKF exercise using hip joint abduction and external rotation to discover a method for activating the GM. The impact of a compound movement involving hip joint abduction and external rotation on muscle activity during PHEKF exercise, however, has not been investigated. Therefore, this study investigated the muscle activity of selective GM activation during PHEKF exercise in different hip joint positions.

SUBJECTS AND METHODS

The subjects were 21 healthy, male volunteers (average age, 20.2 ± 0.4 years; average height, 171.1 ± 5.0 cm; average weight, 64.3 ± 10.5 kg). Individuals were excluded if

they had experienced musculoskeletal pain within the past 12 months; had a history of surgery involving the lower limbs, spine, or pelvis; demonstrated hip flexor shortness, as assessed by the Thomas test; or had tensor fasciae latae shortness, as assessed by Ober's test. This study was performed with approval from the Kawasaki University of Medical Welfare Ethics Committee (approval number, 418). We obtained written informed consent from each participant after giving them a complete explanation of the study.

Muscle activities were measured using a surface electromyograph (Vital Recorder 2, Kissei Comtec, Nagano, Japan) with a 1,000-Hz sampling frequency. We measured the right GM, halfway between the greater trochanter and the second sacral vertebra; the right HAM, approximately halfway between the gluteal fold and the popliteal fold[10]; the bilateral lumbar erector spinae at the L1 level, 2–3 cm external to the spinous process; and the bilateral lumbar multifidus (MF) at the L5/S1 level, immediately lateral to the spinous process. Disposable electrodes (Blue Sensor M-00-S, Ambu, Ballerup, Denmark) applied after appropriate skin preparation. Inter-electrode gaps were set to 2.5 cm, and the reference electrode was attached to the second sacral vertebra.

Measurements were made with the hip joint in each of 3 positions: (1) the neutral hip joint position (position N), (2) the abduction hip joint position (position AB), and (3) the abduction with external rotation hip joint position (position ABER). Each participant was positioned prone, with 90° of right knee flexion. In position N, the right hip joint had 0° of abduction and 0° of external rotation. In position AB, the joint had 15° of abduction and 0° of external rotation; and position ABER involved 15° of hip joint abduction and 20° of external rotation. The measurement of the hip joint angle was conducted using a goniometer (Og Giken, Okayama, Japan). The hip joint's abduction angle was determined by the angle formed by the thigh center line and a line perpendicular to a line connecting both posterior superior iliac spines. The angle of external rotation was determined by the angle formed by the lower leg center line and a plumb line passing through the patella. Bars were installed vertically inside and outside the right thigh to avoid changing the abduction angle during the measurements. Each subject was instructed to extend his right hip joint until the patella was raised 5 cm above the bed, while actively maintaining the knee flexion angle, hip abduction angle, and hip external rotation angles; Extension of the hip joint was maintained for 5 s[10]. Before data acquisition, all subjects practiced the PHEKF exercise for 5 min to familiarize themselves with the testing procedure. The subjects performed the PHEKF exercise 3 times in each hip position. The participants were allowed a 2-min rest period between each measurement. The order of measurement of the 3 positions was randomly assigned. All measurements were performed by one tester.

All electromyograph waveforms were processed through a band-pass filtered (20–500 Hz), then full-wave rectified was subsequently performed, and the average amplitudes were determined over the 5 s of hip extension. To reduce the variability for each measured muscle, we averaged 3 measurements of each position as a representative value and

Table 1. Electoromyographic activity of each muscle in each position (%)

	Position N	Position AB	Position ABER	comparison
GM	14.1 (9.4)	22.5 (13.6)	41 (23.6)	N-AB*
				N-ABER*
				AB-ABER*
HAM	9.7 (9.3)	9.2 (11.8)	7.2 (10.4)	N-ABER†
				AB-ABER*
rt ES	20.8 (9.4)	20.1 (12.0)	13.8 (12.5)	N-AB‡
				N-ABER*
				AB-ABER*
rt LM	30.9 (8.0)	33.4 (10.4)	32.5 (9.5)	N-AB*
lt ES	23.3 (11.6)	20.1 (10.6)	21.6 (7.4)	N-AB*
lt LM	28.3 (11.0)	27.9 (9.1)	22.4 (9.8)	N-ABER*
				AB-ABER*
GM/HAM	1.3 (2.2)	2.5 (3.1)	4.9 (4.4)	N-AB*
				N-ABER*
				AB-ABER*

median (interquartile range) *p<0.017, †p<0.025, ‡p<0.05 N: position N, AB: position AB, ABER: position ABER rt: right, lt: left, GM: gluteus maximus, HAM: hamstrings, ES: lumbar erector spinae, LM: lumbar multifidus

normalized the average value using the average amplitude during maximum voluntary contraction (MVC) as %MVC. The MVC of each muscle was measured using a standard manual muscle testing method[11].

The GM/HAM ratio was calculated by dividing the GM activity by the HAM activity to determine whether GM could be selectively activated.

SPSS Ver. 21 software for Windows (IBM, Armonk, NY, USA) was used for all statistical analyses. We confirmed muscle activity tested the normality of the data using the Shapiro-Wilk test. The intrarater reliability of muscle activity for each of the 3 hip joint positions was analyzed using an intraclass correlation coefficients [ICC (1, 3)]. Since the muscle activity data were not normally distributed, non-parametric methods were used. The Friedman repeated measures analysis of variance was used to detect differences in muscle activities among the three positions (N, AB, and ABER). Post hoc analyses using the Wilcoxon signed-rank tests were conducted with a Holm's correction (or adjustment) applied. The level of significance was chosen as $p < 0.05$.

RESULTS

The ICC (1, 3) of muscle activities of each of the 3 hip joint positions were 0.91–0.98, indicating that the intrarater reliabilities were excellent. The electromyography activities (median, interquartile range) of each muscle in each position are shown in Table 1. The GM activity and GM/HAM ratio were highest in the ABER position, followed by positions AB and N. We observed significantly increased GM activity and GM/HAM ratio in position ABER compared to those in the other positions. The GM activity and GM/

HAM ratio were also significantly higher in position AB than in position N. The HAM, right lumbar erector spinae, and left lumbar multifidus showed the lowest EMG activity levels in the ABER position, followed by position AB and position N. The HAM, right lumbar erector spinae, and left lumbar multifidus showed significantly lower activity in position ABER than in the other positions. The bilateral lumbar erector spinae showed significantly lower activity in position AB than in position N, and the right lumbar multifidus showed significantly higher activity in position AB than in position N.

DISCUSSION

In patients with low back and sacroiliac joint pain, GM activity delays and early HAM activity have been reported[5, 6]. These muscular activity patterns cause sacroiliac instability and increase the strain on the soft tissue[3]. This study, therefore, investigated HAM suppression and the selective activation of the GM during the PHEKF exercise, with the hip joint in different positions.

We observed that GM activity was significantly increased in positions AB and ABER compared to in position N. This result is consistent with the report by Kang et al.[10], who studied the effects of PHEKF exercise during hip joint abduction. By performing hip abduction during PHEKF exercise, the direction of muscle pull runs parallel to the fibers of the muscle, leading to increased EMG amplitudes. GM activity was also significantly higher in the ABER position than in position AB. This is likely because, in position ABER, the GM is in a shortened state, making muscle contraction inefficient, possibly necessitating increased GM muscle activity to extend the hip joint.

HAM activity was significantly lower in position ABER than in positions N and AB. The height to which the legs were elevated during the PHEKF exercise was constant, and the GM activity increased in position ABER. HAM is a synergist of hip extension, and the factors noted above may have reduced the HAM work load during hip extension, thus reducing HAM activity. In addition, externally rotating the hip joint and, thereby, reducing the hip extension moment that the HAM exerts, may also have reduced HAM activity.

The right lumbar erector spinae activity was also significantly lower in position ABER than in positions N or AB. The bilateral lumbar erector spinae activity was significantly lower in position AB than in position N. On the other hand, the GM/HAM ratio was significantly higher in position ABER than in positions N or AB and was significantly higher in position AB than in position N. Tateuchi et al.[12] reported a negative correlation between the GM/HAM ratio and the lumbar erector spinae muscle activity during hip extension exercises in the prone position. Similarly, we propose that lumbar erector spinae muscle activity was decreased since the GM/HAM values were high in positions AB and ABER. One conceivable factor causing the increase in the GM/HAM ratio and the decreased in lumbar erector spinae activity during hip extension is that the moment arm of hip extension, involving the GM in hip extension, is

higher than that of the HAM[13, 14]. Therefore, the increased GM activity improved the power production efficiency of hip extension and decreased the compensatory lumbar erector spinae activity during hip extension.

The left lumbar multifidus activity was significantly lower in position ABER than in positions N or AB. Additionally, the right lumbar multifidus activity was significantly higher in position AB than in position N. The multifidus muscle stabilizes the spine; When it acts bilaterally, it has a spine extension function, and when it acts unilaterally, it rotates the spine[15, 16]. Kim et al.[17] reported that when lumbar rotation moment is applied, the multifidus muscle is activated more to overcome the load of rotation. In positions AB and ABER, a rotation moment is generated on the ventral side of the pelvis. Therefore, to counteract this, the right multifidus muscle activity has to increase in position AB and the left multifidus muscle activity is necessarily decreased in position ABER.

This study had several limitations. First, all subjects participating in the study were healthy young men. Second, surface EMG was used to investigate muscle activity, suggesting the possibility of crosstalk from adjacent muscles. Third, we did not consider lumbopelvic motion when measuring the effect of muscle activity in each position during PHEKF. Therefore, we were not able to describe lumbopelvic motion and its relationship with muscle activity. This relationship, during PHEKF exercise in different hip joint positions, should be confirmed in future investigations of patients with low back pain.

In the present study, the GM/HAM ratio was highest in the ABER position, followed by positions AB and N, indicating that abduction and external rotation of the hip joint selectively activates the GM. Furthermore, lumbar erector spinae activity decreased in positions AB and ABER. Excessive activity of the erector spinae, during prone hip extension, has been reported in patients with low back pain[18]. Increased erector spinae activity may cause muscle pain and contribute to a vicious pain-spasm-pain cycle and increased compression of the spine[19]. This suggests the possibility that abduction and external rotation of the hip joint during PHEKF exercise may be beneficial for selective GM strength training in people with low back pain.

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