EMG Analysis of Gluteus Medius Subdivisions during Modified Unilateral Biofeedback Exercises for the Lower Limbs

Hyo-Jin Heo¹, Duk-Hyun An², Won-Gyu Yoo², Jae-Seop Oh²

¹) Department of Rehabilitation Science, The Graduate School, Inje University
²) Department of Physical Therapy, College of Biomedical Science and Engineering, Inje University:
607 Obangdong, Gimhae, Gyeongsangnam-do, 621-749 Republic of Korea. TEL: +82 55-320-3680,
FAX: +82 55-329-1678, E-mail: dhahn670208@gmail.com

Abstract. [Purpose] The purpose of this study was to investigate the activation of subdivisions of the gluteus medius during modified unilateral weight-bearing exercises using a pressure-biofeedback unit in order to suggest the most effective exercise method. [Subjects] We recruited 15 healthy adult females with no pain in the gluteus medius and no other orthopedic problems in the lower limbs. [Methods] The enrolled individuals performed four modified unilateral biofeedback exercises: wall-press with adduction force, WP-ADD; wall-press with abduction force, WP-ABD; wall-squat with adduction force, WS-ADD; and wall-squat with abduction force. [Results] The anterior and middle fibers of the gluteus medius were highly activated during WP-ADD, and the posterior fiber of the gluteus medius was activated during WS-ABD. [Conclusion] These results suggest that weight-bearing exercises for gluteus medius strengthening should be more specific, and chosen based on the characteristics of each subdivision.

Key words: Wall-press, Wall-squat, Weight bearing


INTRODUCTION

The gluteus medius (GM) controls femoral motion, primarily during dynamic lower extremity motion, stabilizing the pelvis in both the frontal and transverse planes¹-³. It is composed of three distinct sections: the anterior, middle and posterior GM fibers⁴-⁵. The actions of these segments differ: the anterior GM fiber is involved in hip abduction and internal rotation and assists flexion; the middle GM fiber is involved only in abduction of the hip; and the posterior fiber is involved in hip abduction and external rotation, and assists extension⁶-⁷. Weakness or injury of the GM is associated with many lower limb pathologies, including patellofemoral pain syndrome, iliotibial band friction syndrome, anterior cruciate ligament injury and lower-back pain¹²-¹⁰; it is also origin of abductor lurch or gluteus medius lurch and Trendelenburg gait¹¹. Compared to males, females are almost twice as likely to sustain a running injury, such as patellofemoral pain syndrome, iliotibial band syndrome or gluteus medius injury¹², ¹³. Previous studies have evaluated the efficacy of GM-strengthening exercises to address these problems. Some exercises are unilateral weight-bearing exercises, such as the unilateral wall squat, mini-squat, various step-up exercises, the pelvic drop and the wall press¹⁴, ¹⁵. Distefano et al.¹⁶ suggested that unilateral weight-bearing exercise requires frontal-plane pelvic stability and that gravitational force creates substantial hip adduction torque during the single-limb stance that must be resisted by GM and other muscles of the hip and pelvis to maintain upright standing. Recently, the wall-press exercise (WP) and the wall-squat exercise (WS) have been used for hip muscle strengthening. These exercises allow patients with an unstable pelvis to recover strength for daily living or sporting activities. Biofeedback has been used to increase the efficacy of exercises¹⁷. The pressure-biofeedback unit is an indirect clinical testing method, and is generally used for stabilization exercises for all parts of the body¹⁸. Cynn et al.¹⁹ conducted hip-abduction exercises using a pressure-biofeedback unit for lumbar stabilization and observed increased muscle activity of the lumbar stabilizer muscles. Several studies have suggested that three subdivisions of GM can be isolated and activated separately¹, ¹⁴, ¹⁹. However, no investigation has been conducted using specific methods to activate each of the three subdivisions. Therefore, the purpose of this study was to identify differences in muscle activities among the three GM subdivisions during hip abduction, and adduction-added WP and WS. In addition, we developed improved exercise methods to allow evaluation of the characteristics of each fiber.

SUBJECTS AND METHODS

In total, we enrolled 15 healthy female volunteers for this study. Individuals were excluded if they had a history of pathological problems, including musculoskeletal or neurological disorders. They were also excluded if they suffered from back or lower limb injury which had required treatment in the past 6 months, the balance impairment in one-legged
standing caused by currently prescribed medication, or any skin problems at the electrode-attachment points. The participants’ mean \((\pm SD)\) age was 23.53 \((\pm 3.15)\) years, their mean height was 162.06 \((\pm 4.78)\) cm, and their mean body mass was 52.60 \((\pm 4.84)\) kg. Surface EMG activities of the three subdivisions of GM were recorded by a MP150WSW (Biopac Systems, Santa Barbara, CA, USA) and pairs of silver-silver chloride disposable electrodes, with a diameter of 3 mm (EL 503, Biopac system). All EMG signals were amplified, bandpass-filtered (20 Hz to 500 Hz), and sampled at 1,000 Hz using Acqknowledge software, version 3.9.1. The root mean square values of the raw data were calculated for 250 samples, with the amplitude normalized to maximal voluntary isometric contraction (MVIC). A pressure-biofeedback unit (Stabilizer, Hixson, USA) was used to measure the force of each exercise. The maximum isometric force was measured during pelvic rotation, being the maximum force the subjects could sustain for 5 s. Before placing the electrodes, the skin was shaved and rubbed with alcohol to reduce its electrical impedance. The locations of the electrodes for the GM subdivision fibers were as follows. The anterior GM electrode was placed at 50% of the distance between the anterior superior iliac spine (ASIS) and the greater trochanter. The middle GM electrode was placed at 50% of the distance between the greater trochanter and the iliac crest. The posterior GM electrode was placed at 33% of the distance between the posterior ilium and the greater trochanter. A reference electrode was placed at the anterior superior iliac spine\(^{14}\). EMG data were normalized to MVIC to determine the differences in muscle activation during the hip-abduction exercise. The highest muscle activation value for each subdivision of GM during hip contraction was recorded, and data obtained from each weight-bearing exercise trial were expressed as a percentage of this value (%MVIC). The four unilateral weight-bearing exercises were performed using the pressure-biofeedback unit. For the wall-press exercise with abduction force (WP-ABD), the subjects were asked to stand next to a wall with the left limb furthest from the wall and assume a single-leg stance position by flexing their right hip 60° and their right knee at 90°, angles which were verified using goniometric measures. The pressure-biofeedback unit was held on the subject’s right limb around the medial aspect of the thigh next to the wall. The wall-squat exercise with abduction force (WS-ABD) was performed by the subjects standing with their backs resting against the wall, with their left hip flexed at 60°, and their right leg maintained parallel to their right side. The pressure-biofeedback unit was held against the right leg in the lateral direction for 5 s. The wall-squat exercise with adduction force (WS-ADD) was performed in the same manner as WS-ADD, but the press direction was reversed. The biofeedback unit was pressed between the knees for 5 s to prevent excessive internal rotation. All participants were allowed to lightly touch the wall with their hands in order to maintain their balance and used a marking mirror due to prevent pelvic rotation. Each trial was recorded for 5 s, during which time the subjects performed three repetitions of each exercise, with a 30 s rest period between trials and a 1-min rest period between exercises to reduce the possibility of fatigue. Statistical analysis was performed using SPSS, version 17.0 (SPSS Inc., Chicago). One-way repeated measures ANOVA was initially performed to determine significant differences in the activities of each subdivision during the exercises. Bonferroni’s correction was performed post hoc to assess differences among GM muscle subdivisions and exercises. A value of \(p < 0.05\) was deemed to indicate statistical significance.

### RESULTS

Activations of each GM subdivision during the exercises are described Table 1. The subjects’ mean maximum isometric force was 20.24 mmHg. The WP-ADD exercise showed the highest activation \((42.11 \pm 20.63\% \text{MVIC})\) in the anterior fiber. The WS-ADD exercise showed the highest activation in both the middle \((32.96 \pm 10.86\% \text{MVIC})\) and posterior \((43.81 \pm 19.42\% \text{MVIC})\) fibers.

### DISCUSSION

In this study, we investigated effective exercise methods for the three GM subdivisions, under the hypothesis that each subdivision has different characteristics, by performing EMG analysis of the activation of each subdivision during WP-ABD, WP-ADD, WS-ADD, and WS-ADD exercises. The anterior GM fiber was activated to a greater extent during adduction force added unilaterally during weight bearing. The highest activation of the posterior fiber was during unilateral weight bearing with an abduction force, as in the wall-squat or wall-press exercises. O’Sullivan et al.\(^{14}\)

<table>
<thead>
<tr>
<th>Fibers</th>
<th>WP-ADD</th>
<th>WP-ABD</th>
<th>WS-ADD</th>
<th>WS-ADD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>42.11±20.63</td>
<td>19.36±13.32</td>
<td>15.66±10.50</td>
<td>28.72±14.70</td>
</tr>
<tr>
<td>Middle</td>
<td>31.32±17.38</td>
<td>26.84±13.20</td>
<td>20.69±9.56</td>
<td>32.95±10.86</td>
</tr>
<tr>
<td>Posterior</td>
<td>22.43±10.10</td>
<td>32.99±10.84</td>
<td>27.97±19.78</td>
<td>43.81±19.42</td>
</tr>
</tbody>
</table>

reported that overall GM activation was greatest during the wall-press exercise, and the posterior fiber showed the highest activation during the pelvic-drop exercise, the wall-press exercise, and the wall-squat exercise in healthy subjects. Their results were recorded without addition of adduction force in all exercises. We conducted the wall-squat exercise and the wall-press exercise with adduction and abduction forces. Our wall-press with abduction force exercise results were similar to those of O’Sullivan et al. Earl compared the anterior and middle GM fibers among three variations of the isometric single-leg stance. His results indicate that the anterior fiber exhibits the highest activation in internal rotation exercise. Our results were similar when adduction was performed with force added. Only the activation of the anterior GM fiber increased as the load increased. O’Dwyer et al. compared the activation of the proposed functional subdivisions of GM during isometric contraction of the hip performed by normal subjects and determined the isometric hip contraction that caused the greatest GM activation. Their results indicate that the anterior fiber was activated the most by all exercises. They also emphasized that use of a single electrode to assess GM function may be inappropriate, due to differences in muscle activation levels between the GM subdivisions. A number of studies have investigated both the whole GM and its muscle fiber subdivisions. We also investigated the GM subdivisions, as suggested by previous anatomical studies. Our present results suggest that the GM subdivisions were activated in isolation and not simultaneously. However, gluteal muscles may work together synergistically when people with patellofemoral pain perform hip exercises, dependent on the load placed on the body, rather than in isolation. Cowan et al. demonstrated delayed activation of both anterior and posterior GM fibers in subjects with patellofemoral pain. Their findings suggest that the anterior and posterior fibers are activated in the same manner and not in isolation. However, these results were derived from subjects with numerous musculoskeletal disorders. Therefore, this provides further evidence that rehabilitation programs aimed at increasing the strength and activation of hip muscles, such as the GM, are effective at reducing pain and disability and improving lower limb kinematics and athletic performance. The results of the present study suggest that the proper exercise method for GM-strengthening exercises for the anterior fiber is WP-ABD, and that for the posterior is WS-ABD. Furthermore, it is important that future studies evaluate the activation of GM subdivisions in numerous lower limb disorders. This study had several limitations. The sample size (n = 15) was small, and consisted only of young, healthy asymptomatic female subjects. Use of surface electrodes always involves the risk that cross-talk from nearby muscles, or even adjacent muscle subdivisions, could affect the results. Here we examined the activation of only GM, and not other hip muscles involved in movement and stability. Concurrent recording of the activation of these other muscles would provide a more comprehensive analysis.

ACKNOWLEDGEMENTS

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