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SYSTEMATIC REVIEW

A literature review of studies evaluating gluteus maximus and gluteus medius activation during rehabilitation exercises

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ABSTRACT

Recently, clinicians have focused much attention on the importance of hip strength for the rehabilitation of not only patients with low back pain but also lower extremity pathology. Properly designing a rehabilitation program for the gluteal muscles requires careful consideration of biomechanical principles, such as length of the external moment arm, gravity, and subject positioning. Understanding the anatomy and function of these muscles also is essential. Electromyography (EMG) provides a useful means to determine muscle activation levels during specific exercises. Descriptions of specific exercises, as they relate to the gluteal muscles, are described. The specific performance of these exercises, the reliability of such EMG measures, and descriptive figures are also detailed. Of utmost importance to practicing clinicians is the interpretation of such data and how it can be best used in exercise prescription when formulating a treatment plan.

INTRODUCTION

Strengthening of any muscle group requires careful planning and a systematic progression from less challenging to more challenging exercises. The demand of a particular exercise can be influenced by the plane of movement, effects of gravity, speed of motion, base of support, and type of muscle contraction. Clinicians should consider these factors when designing and implementing strengthening exercises for the gluteals. An appreciation of this muscle group's anatomy and function also deserves attention.

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Gluteal anatomy and function

The gluteus maximus (GMax) is the largest muscle of the hip accounting for 16% of the total cross-sectional area (Winter, 2005). It has several anatomical landmarks, including the ilium, sacrum/coccyx, and sacrotuberous ligament as an origin (Kendall, McCreary, and Provance, 1993). Eighty percent of the GMax inserts into the iliotibial band; the remainder inserts in the distal portion of the femur's gluteal tuberosity.

The GMax is a powerful hip extensor and lateral rotator (Delp, Hess, Hungerford, and Jones, 1999). It is often used to accelerate the body upward and forward from a position of hip flexion ranging from 45° to 60° (e.g., sprinting, squatting, and climbing a steep hill). In addition, the GMax is active during a plant and cut maneuver to the opposite side (Neumann, 2010).

The gluteus medius (GMed) is broad and fan shaped, attaching to the superior ilium and inserting on the lateral aspect of greater trochanter (Pfirrmann et al, 2001). Anatomically, the GMed is divided into three parts: 1) anterior; 2) middle; and 3) posterior, each with separate branches from the superior gluteal nerve.

As a whole, the GMed stabilizes the femur and pelvis during weight-bearing activities with the greatest GMed activation observed during the stance phase of gait (Gottschalk, Kourosh, and Leveau, 1989; Lyons et al, 1983). Functionally, it generates an exceptional amount of force given its size (Ward, Winters, and Blemker, 2010).

The GMed accounts for 60% of the total hip abductor muscle cross-sectional area (Clark and Haynor, 1987). The three anatomical parts' phasic activity is based on fiber orientation (Gottschalk, Kourosh, and Leveau, 1989). The anterior and middle portions of the GMed help initiate hip abduction. The anterior portion singly abducts, medially rotates, assists with hip flexion, and is active when the base of support is minimal (e.g., bridges, unilateral squat, lateral step-up) (Boudreau et al, 2009). It has been demonstrated that there is an eightfold increase in medial rotation leverage at 90° of flexion (Delp, Hess, Hungerford, and Jones 1999). The posterior portion of the muscle extends, abducts, and laterally rotates the hip.

Hip/gluteal weakness and pathology

Hip dysfunction (e.g., weakness and limited range of motion) is one factor that has been associated with low back and various lower extremity pathologies. A moderate relationship currently exists between hip dysfunction and low back pathology (Reiman, Bolgla, and Lorenz, 2009), whereas a much stronger relationship has been identified between hip dysfunction and knee pathology (Powers, 2010; Reiman, Bolgla, and Lorenz, 2009).

Hip abduction and lateral rotation weakness has been associated with patellofemoral pain syndrome (PFPS). Ireland, Willson, Ballantyne, and Davis (2003) revealed that females with PFPS demonstrated 26% less hip abductor and 36% less hip lateral rotation strength than controls. Others have identified similar trends (Bolgla, Malone, Umberger, and Uhl 2008; Piva, Goodnite, and Childs, 2005; Robinson and Nee, 2007; Willson and Davis, 2009).

Powers (2003) has theorized that hip abductor and lateral rotator weakness can lead to knee valgus, hip adduction, and hip internal rotation, a position that can place undue stress on lower extremity joints. Ferber, Kendall, and Farr (2011) found that correcting the hip strength deficits improves lower extremity pain in runners.

Emerging data support the important role of the GMax and GMed during athletic endeavors, and a variety of strengthening exercises have been described. The purpose of this manuscript is to provide a review of the current literature regarding GMax and GMed activation during rehabilitative exercises. It is our intent that clinicians use this information to facilitate a systematic approach for the development and implementation of GMax and GMed strengthening programs.

METHODS

A literature search was performed for experimental studies, randomized controlled trials, systematic reviews, narrative reviews, and meta-analyses using the Medline (1966 to 05/2010), CINAHL (1982 to 05/2010), and Sports Discus (1975 to 05/2010) databases. Search terms included hip; strengthening; exercise; therapy; gluteus maximus; gluteus medius; gluteal muscles; exertion; testing; electromyography (EMG); electromyographic analyses; maximum voluntary isometric contraction (MVIC); and training, in all possible combinations. Sources also were located by scanning reference lists from all relevant articles.

Information from the various sources was compared among authors for relevance of inclusion. Primary inclusion criteria were studies investigating EMG activity for either the GMax or GMed. Articles were excluded if EMG analyses were not performed for these two muscles. Additional exclusion criteria for articles investigating EMG analyses were used to minimize heterogeneity between studies. Additional exclusion criteria included 1) studies/exercises that measured EMG activity while adding additional weight or resistance; 2) studies/exercises that measured EMG activity while using machines/equipment to modify the activity; 3) studies/exercises that measured EMG activity only during the eccentric phase of an exercise; 4) studies/exercises that did not normalize EMG activity to a MVIC; 5) studies/exercises that examined gender differences (separate calculations for males for males and females); and 6) studies/exercises that lacked detailed information to discern proper inclusion/exclusion criteria.

RESULTS

Six studies for the GMax (Ayotte, Stetts, Keenan, and Greenway 2007; Blanpied, 1997; Distefano, Blackburn, Marshall, and Padua 2009; Ekstrom, Donatelli, and Carp 2007; Ekstrom, Osborn, and Hauer 2008; Farrokhi et al, 2008) and four studies for the GMed (Ayotte, Stetts, Keenan, and Greenway 2007; Bolgla and Uhl, 2005; Distefano, Blackburn, Marshall, and Padua 2009; Ekstrom, Donatelli, and Carp 2007) met the inclusion criteria. To make meaningful comparisons of EMG activation levels between studies, we categorized activation into previously described levels (low-level muscle activation at 0–20% MVIC; moderate-level activation at 21–40% MVIC; high-level activation 41–60% activation, and very high-level activation at greater than 60%) (Escamilla et al, 2010).

Appendix I lists the exercises included, EMG activity, and measurement reliability (when available). Appendix II provides a detailed description of each study. To make meaningful comparisons of EMG activity between studies, we summarized EMG data for the GMax (Figure 1) and GMed (Figure 2) during exercise from the lowest to highest activation level. For exercises examined in a single study, we reported their individual mean and standard deviation. For exercises examined in more than one study, we reported the pooled mean and its 90% confidence interval (CI).

Gluteus maximus activation

Low-level activation (0–20% MVIC)

Three exercises met the criteria for inclusion in the category of low-level activation (Figure 1). These exercises included 1) Prone bridge/plank (9% ± 7% MVIC); 2) Lunge with backward trunk lean (19% ± 12% MVIC); and 3) Bridging on Swiss ball (20% ± 14% MVIC).

Moderate-level activation (21–40% MVIC)

Seven exercises met the criteria for inclusion in the category of moderate-level activation (Figure 1). The exercises in this category included 1) Side-lying hip abduction (21% ± 16% MVIC); 2) Lunge with forward trunk lean (22% ± 12% MVIC); 3) Bridging on stable surface (25% ± 14% MVIC); 4) Clam with 30° hip flexion (34% ± 27% MVIC); 5) Lunge-neutral trunk position (36% MVIC; 90% CI [32, 40]);

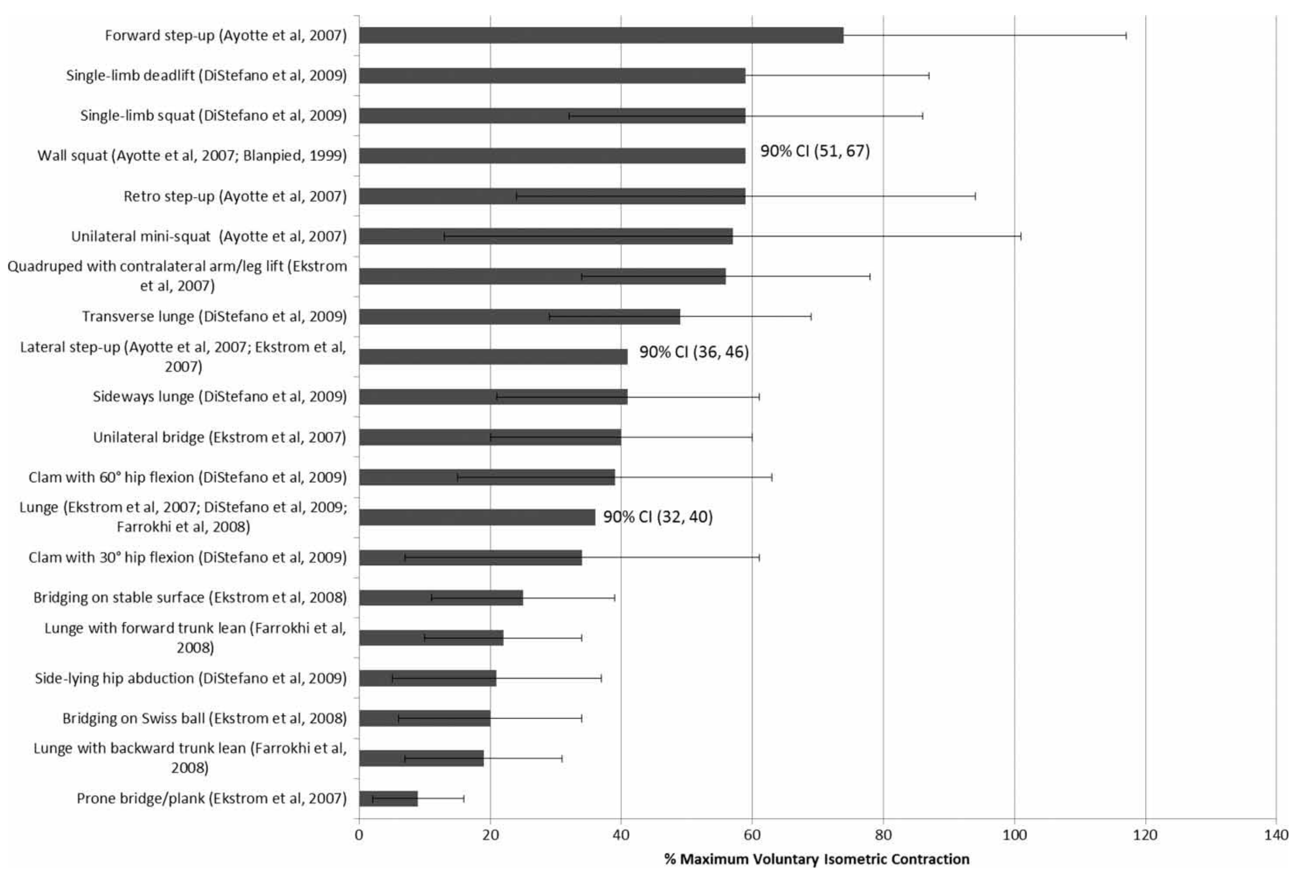

FIGURE 1 Gluteus maximus percent maximum voluntary isometric contraction ranking of exercises.

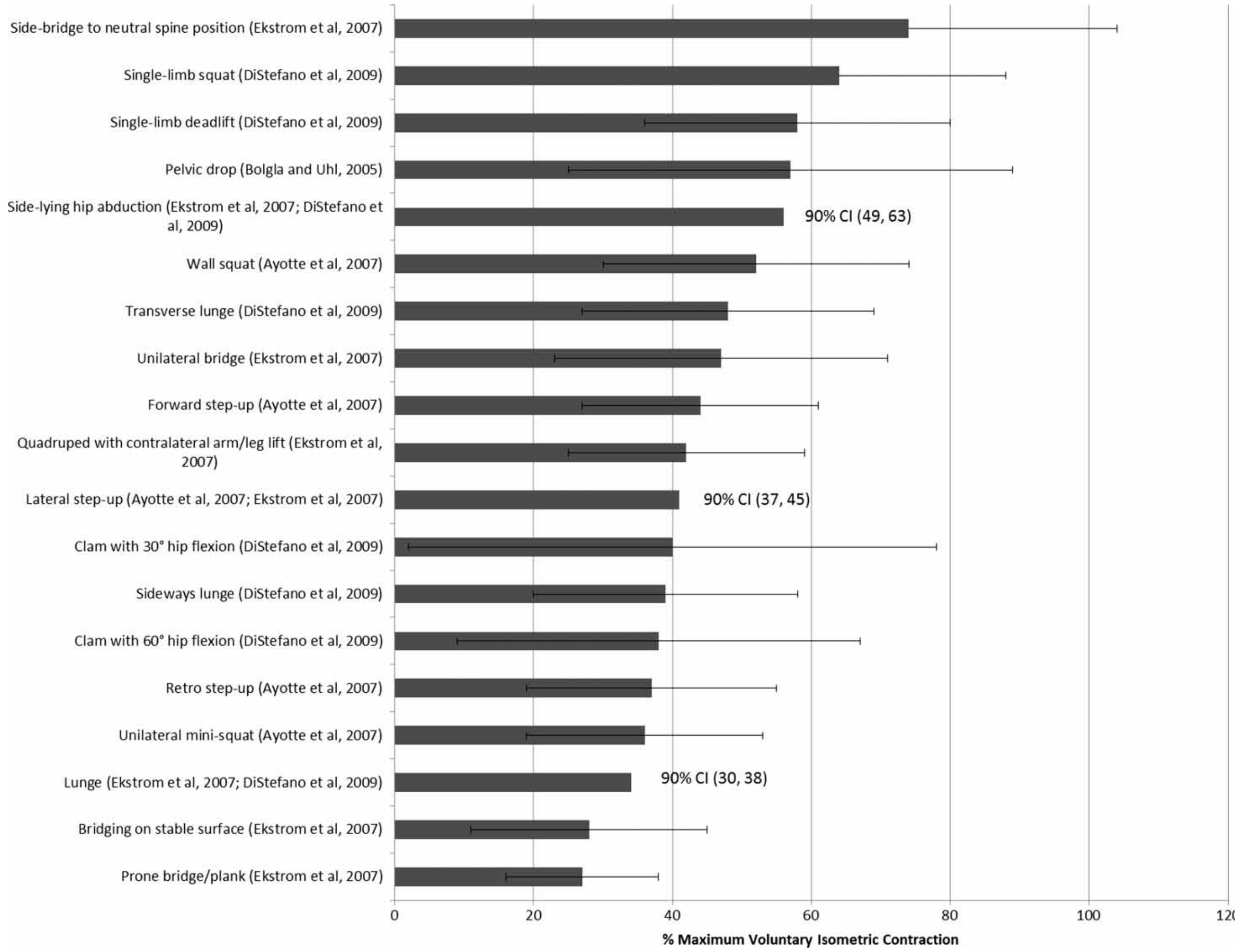

FIGURE 2 Gluteus medius percent maximum voluntary isometric contraction ranking of exercises.

6) Clam with 60° hip flexion (39% ± 24% MVIC); and 7) Unilateral bridge (40% ± 20% MVIC).

High-level activation (41–60% MVIC)

Nine exercises met the criteria for inclusion in the category of high-level activation (Figure 1). These exercises were 1) Sideways lunge (41% ± 20% MVIC); 2) Lateral step-up (41% MVIC; 90% CI [36, 46]); 3) Transverse lunge (49% ± 20% MVIC); 4) Quadruped with contralateral arm/leg lift (56% ± 22% MVIC); 5) Unilateral mini-squat (57% ± 44% MVIC); 6) Retro step-up (59% ± 35% MVIC); 7) Wall squat (59% MVIC; 90% CI [51, 67]); 8) Single-limb squat (59% ± 27% MVIC); and 9) Single-limb deadlift (59% ± 28% MVIC).

Very high-level activation (>60% MVIC)

One exercise met the criteria for inclusion in the very high-level activation (Figure 1). This exercise was Forward step-up (74% ± 43% MVIC).

Gluteus medius activation

Low-level activation (0–20% MVIC)

None of the included studies had any exercises that met the criteria for inclusion in the category of low-level activation.

Moderate-level activation (21–40% MVIC)

Eight exercises met the criteria for inclusion in the category of moderate-level activation (Figure 2). These exercises were 1) Prone bridge plank (27% ± 11% MVIC); 2) Bridging on stable surface (28% ± 17% MVIC); 3) Lunge-neutral trunk position (34% MVIC; 90% CI [30, 38]); 4) Unilateral mini-squat (36% ± 17% MVIC); 5) Retro step-up (37% ± 18% MVIC); 6) Clam with 60° hip flexion (38% ± 29% MVIC); 7) Sideways lunge (39% ± 19& MVIC); and 8) Clam with 30° hip flexion (40% ± 38% MVIC).

High-level activation (41–60% MVIC)

Nine exercises met the criteria for inclusion in the category of high-level activation (Figure 2). The exercises were 1) Lateral step-up (41% MVIC; 90% CI [37, 45]); 2) Quadruped with contralateral arm and leg lift (42% ± 17% MVIC); 3) Forward step-up (44% ± 17% MVIC); 4) Unilateral bridge (47% ± 24% MVIC); 5) Transverse lunge (48% ± 21% MVIC); 6) Wall squat (52% ± 22% MVIC); 7) Side-lying hip abduction (56% MVIC; 90% CI [49, 63]); 8) Pelvic drop (57% ± 32% MVIC); and 9) Single-limb deadlift (58% ± 22% MVIC).

Very high-level activation (>60% MVIC)

Two exercises met criteria for inclusion into the category of very-high level activation (Figure 2). These exercises were 1) Single-limb squat (64% ± 24% MVIC); and 2) Side-bridge to neutral spine position (74% ± 30% MVIC).

DISCUSSION

Therapeutic exercise is one of the most important interventions that clinicians prescribe for the treatment of low back and lower extremity pathology. Researchers (Ayotte, Stetts, Keenan, and Greenway, 2007; Bolgla and Uhl, 2005; Boudreau et al, 2009; Distefano, Blackburn, Marshall, and Padua, 2009; Krause et al, 2009) have used surface EMG to quantify hip muscle activity during various activities and exercises. They have theorized that exercises requiring greater EMG activity will result in strength gains. Clinicians can use this information because strength gains of the active muscle(s) are expected when EMG activity is greater than 40% MVIC (Ayotte, Stetts, Keenan, and Greenway, 2007; Escamilla et al, 2010). The following sections provide an explanation for the muscle activation levels, as delineated in Figures 1 and 2, for the GMax and GMed.

Gluteus maximus activation

Our review identified three low-level exercises, seven moderate-level exercises, nine high-level exercises, and one very high-level exercise for GMax activation. The prone bridge/plank differed from the other exercises in the low-level activation due to its static nature to maintain a neutral hip and spine position during this exercise. The low activation (9% MVIC) most likely reflected the GMax's role as a hip and spine stabilizer.

Data for the five lunges suggested that trunk position and movement direction can influence GMax activity. Farrokhi et al (2008) reported 22% MVIC GMax activation when subjects performed a forward lunge with the trunk flexed forward relative to the hip and pelvis. Compared to the trunk extended lunge, the trunk flexed forward lunge was more demanding because it placed the body's center of mass more forward relative to the hip joint's axis of rotation. This position change essentially increased the external moment arm that resulted in an increased external hip flexion torque. Therefore, subjects generated greater GMax activity to counteract the higher hip flexion torque.

Our review included three variations of a bridging exercise that specifically targeted the GMax's role as a dynamic hip extensor. Subjects performed the unilateral and traditional bridges in a hook-lying position, which effectively shortened the hamstrings to target GMax activity. The unilateral bridge (40% MVIC) had greater activation than the traditional bridge (25% MVIC) because the GMax controlled multiple planes of hip and pelvis movement when performing the unilateral bridge. It is interesting that subjects generated less GMax activity (19% MVIC) during the bridge on Swiss ball. This exercise differed from the unilateral and traditional bridge because subjects performed it with the knees extended. This position most likely allowed for hamstring activation that assisted with hip extension during the bridge on Swiss ball.

Besides the various lunge and unilateral bridge exercises, the side-lying hip abduction and clam exercises all generated moderate GMax activity. Although typically prescribed as exercises to strengthen the GMed, they also can provide additional benefit for the GMax. The side-lying hip abduction (21% MVIC) generated less GMax activation than the clam with 30° (34% MVIC) and 60° (39% MVIC) of hip flexion. This relatively lower activation during side-lying abduction likely reflected the GMax's role as a secondary hip abductor. The clam exercises differed from side-lying hip abduction because both incorporated dynamic hip lateral rotation, another important GMax action. As discussed in the GMed section, both clam exercises generated GMed activation levels similar to the GMax. Therefore, clinicians should consider prescribing clam exercises if the goal is to equally target the GMax and GMed.

The high-level activation tier of GMax muscle activation included mostly standing exercises. The sideways lunge and lateral step-up both had lower GMax activation levels (41% MVIC) than the transverse lunge (49% MVIC). The sideways lunge differed because subjects performed this maneuver in the frontal plane, whereas the transverse lunge incorporated movement in both the frontal and horizontal planes. These patterns imposed greater demands on the GMax to help maintain the pelvis in a level position (as a hip abductor) and minimize knee valgus collapse (as a hip lateral rotator). Therefore, clinicians should consider trunk position relative to the base of support as well as movement direction when developing and implementing a progressive strengthening program.

The quadruped with contralateral arm and leg lift required 56% MVIC of GMax activity and highlighted the GMax's role as both a hip stabilizer and hip extensor. Subjects were further challenged because the GMax had to control multiple planes of movement via the contralateral arm and leg lift. While clinicians prescribe this exercise as part of a progressive spinal stability program, patients with marked hip weakness also may benefit from this exercise.

The remaining single-leg squats (single-limb deadlift, single-limb squat, wall squat, retro step-up, unilateral mini-squat) generated relatively higher GMax activity (57–59% MVIC) than the lateral step-up because they incorporated a greater excursion of the body's center of mass away from the base of support and movements in multiple planes. The front step-up had the highest level of GMax activity (74% MVIC), which most likely reflected an even greater amount of body excursion to and from the base of the support.

Gluteus medius activation

Our review identified eight moderate-level exercises, nine high-level exercises, and two very high-level exercises for GMed activation. The prone bridge/plank again demonstrated the lowest level of GMed activation (27% MVIC). Similar to the GMax, the static nature to maintain a neutral hip and spine position likely reflected the GMed's role as a hip and spine stabilizer.

Bridging on a stable surface (28% MVIC), lunge in neutral trunk position (34% MVIC), unilateral mini-squat (36% MVIC), and retro step-up (37% MVIC) generated moderate-level GMed activation. Subjects performed these exercises primarily in the sagittal plane that required the GMed to maintain a level pelvis. These findings suggest an important stabilizing effect afforded by the GMed and the use of the above listed exercises early in the rehabilitation process to strengthen the GMed.

Other exercises in the moderate-level tier included the clam exercises at 30° (40% MVIC) and 60° (38% MVIC) of hip flexion as well as the sideways lunge (39% MVIC). GMed activity generated during both clam exercises was similar to that of the GMax (34% and 39% MVIC at 30° and 60° of hip flexion, respectively) during these exercises. It was noteworthy that the clam exercises incorporated a combination of hip abduction and lateral rotation. Although the GMed is primarily responsible for hip abduction, its posterior fibers also assist with hip lateral rotation.

GMed activity during the lunges ranged from 34% to 48% MVIC. Subjects performed the forward lunge in the sagittal plane, which would explain its relatively lower amount of activity (34% MVIC). However, GMed activation increased when performing lunges in the frontal (39% MVIC for the sideways lunge) and horizontal (48% MVIC during the transverse lunge) planes. These exercises were more dynamic than the front lunge and most likely required greater GMed activity to maintain a level pelvis position (as a hip abductor) and minimize knee valgus collapse (as a hip lateral rotator). It is interesting that subjects generated similar GMax activity during the sideways (41% MVIC) and transverse (49% MVIC) lunges as the GMed. These findings further highlighted the synergistic role that the GMax and GMed play during these exercises. In summary, clinicians should ensure that a patient with GMed weakness can correctly perform a forward lunge before prescribing the sideways and transverse lunges.

The quadruped with contralateral arm and leg lift (42% MVIC) and unilateral bridge (47% MVIC) required high GMed activation. The increased challenge of controlling multiple planes of movement most likely accounted for the relatively higher GMed activity during these exercises. The clinician should consider these exercises as a logical progression from the clam exercises.

Except for the full single-leg squat, the wall squat required the next highest GMed activity (52% MVIC). This exercise differed from the unilateral mini-squat, retro step-up, lateral step-up, and forward step-up because subjects began the squat by positioning the trunk against the wall and the stance limb 15.2 cm away from the wall. This position effectively placed the body's center of mass posterior to the base of support. Movement of the pelvis away from the base of support would require greater activity of all muscles around the hip, including the GMed, to stabilize the pelvis (Ayotte, Stetts, Keenan, and Greenway, 2007). These findings highlighted movement of the body's center of mass away from the base of support as a logical exercise progression.

Side-lying hip abduction generated GMed activation equal to 56% MVIC, which most likely reflected this muscle's role as a primary hip abductor. While this exercise was in the high-level activation tier, other standing exercises demonstrated similar

GMed muscle activation levels (52–58% MVIC). The standing exercises highlighted the GMed's importance in providing multi-planar stabilization for the trunk/pelvis. These findings were clinically relevant because subjects who cannot perform GMed weight bearing exercises may get similar benefit by performing the side-lying exercise (Bolgla and Uhl 2005).

The pelvic drop and single-limb deadlift exercises (57% and 58% MVIC, respectively) had the highest relative activation in this exercise tier. The pelvic drop exercise specifically targeted the GMed's ability to control pelvis-on-femur adduction and abduction, which incorporated a combination of eccentric and concentric muscle actions. The single-limb dead lift task differed in that the GMed worked in an isometric manner. Subjects performed this exercise by flexing the hip enough to touch the long finger of one hand on the ground. Like posterior displacement of the body's center of mass relative to the base of support, anterior displacement from the stance limb would require greater overall hip muscle activity. In summary, these exercises would provide similar strengthening effects as the others described above and would provide clinicians another way for targeting the GMed.

The very high-level tier of GMed activation included the single-limb squat and the side-bridge to neutral spine position. Although the single-limb squat is similar in some respects to exercises previously described, subjects who performed the lunge, unilateral mini-squat, and step-up exercises did so with the trunk in a more vertical alignment over the stance limb. This position differed from the single-leg squat described by DiStefano, Blackburn, Marshall, and Padua (2009), who reported greater GMed activity (64% MVIC) during a full single-leg squat. Subjects in their study squatted low enough to touch the long finger of one hand on the ground. This larger excursion of the body's center of mass toward the ground would explain the relatively higher GMed activity needed to stabilize the pelvis and knee.

The side-bridge to neutral spine position exhibited the highest GMed muscle activation (74% MVIC) of all the exercises included in our review. Typically, the lateral side-bridge exercise has represented a more demanding spinal stabilization exercise targeting the lateral abdominal muscles (Ekstrom, Donatelli, and Carp, 2007; Ekstrom, Osborn, and Hauer, 2008). However, findings from this review further highlight the stabilizing role of the GMed. The clinician should carefully consider the prescription of this and other high- to very-high level tier exercises later in the rehabilitation process.

CONCLUSION

The purpose of this review was to analyze studies that have evaluated activation of the GMax and GMed during rehabilitation exercises. Our findings showed how changes in the trunk position, movement direction, and base of support can affect EMG activity. EMG activity for these muscles ranged from 9% to 74% MVIC. It is noteworthy that strength gains are expected for activation levels equal to or greater than 40% MVIC (Ayotte, Stetts, Keenan, and Greenway, 2007; Escamilla et al, 2010). However, clinicians can still use the lower-level activation exercises to facilitate neuromuscular activation (Ayotte, Stetts, Keenan, and Greenway, 2007) and progress patients with marked GMax and GMed weakness to more demanding tasks. Finally, the clinician should note that subjects who performed exercises included in this review were healthy. It remains elusive if similar findings would result in patients with pathology.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article.

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Appendix I. EMG (%MVIC) for Gluteal Strengthening Exercises.

Exercise	Description	EMG (% MVIC)(SD)	Reliability (ICC)	Reference
SUPINE				
Bridging on Stable Surface	 Subject in supine with bilateral knees bent 90^0. Subject lifts bilateral hips to nuetral hip position.	GMed 1. 28(17) GMax 1. 25(14) 2. 27(13)	2. 0.93	1. Ekstrom et al. 2007 2. Ekstrom et al. 2008
Unilateral Bridge	 Subject in supine with bilateral knees bent 90^0. Subject lifts left leg and extends it at the knee. Subject then lifts bilateral hips to neutral hip position with rigt leg only.	GMed 1. 47(24) GMax 1. 40(20)		1. Ekstrom et al. 2007
Bridging on Swiss Ball	 Supine with bilateral legs extended and feet on Swiss ball. Subject lifts bilateral hips to neutral position.	GMax 1. 20(14)		1. Ekstrom et al. 2008
PRONE				
Prone Bridge/Plank	 Subject props on bilateral forearms and bilateral toes. Subject maintains neutral position along entire spine.	GMed 1. 27(11) GMax 1. 9(7)		1. Ekstrom et al. 2007
Quadruped with contralateral arm and leg lift	 Subject in quadruped position. Subject lifts right arm and left leg at the same time to level horizontal position.	GMed 1. 42(17) GMax 1. 56(22)		1. Ekstrom R, et al. 2007 2. Ekstrom et al. 2008
SIDE-LYING				
Side-lying Hip Abduction	 Subject lies on side with the bottom leg bent to maintain body from rotating. Top leg is abducted approximately 25^0 degrees, held for 2-3 seconds and adducted to starting position.	GMed 1. 39(17) 2. 81(42) GMax 2. 21(16)	2. 0.98 for GMed and 0.94 for GMax	1. Ekstrom et al. 2007 2. DiStephano et al. 2009
Side-Bridge to Neutral Spine Position	 Subject lying on right side with right forearm resting on table, top (left) leg crossed over bottom leg (right). Subject lifts bilateral hips to neutral position.	GMed 1. 74(30)	1. 0.60 to 0.75	1. Ekstrom et al. 2007
Clam with 30^0 hip flexion	 Subject lies supine with hips flexed 30^0 and knees flexed 90^0. They abduct top leg while keeping feet together. Subject should avoid trunk rotation in transverse plane and only abduct as far as possible without this compensation.	GMed 1. 40(38) GMax 1. 34(27)	1. 0.98 for GMed and 0.95 for GMax	1. DiStefano et al. 2009

Clam with 60^0	Subject performs exercise as above except with knees bent to 60^0.	GMed 1. 38(29)	1. 0.97 for GMed	1. DiStefano et al. 2009
hip flexion		GMax 1. 39(34)	and 0.98 for GMax	
STANDING				
Pelvic Drop	 Subjects stand on the right lower extremity on a 15-cm step; bilateral knees in a fully extended position. Subject slowly lowers the left side of pelvis toward the floor to adduct the right hip; subjects then return the pelvis to a level position	GMed 1. 57(32)	1. 0.95	1. Bolgla & Uhl 2005
Lunge	 Subject starts in bilateral stance and steps forward the distance onto left leg, keeping knee behind front of foot and to a depth of 90^0 hip and knee flexion.	GMed 1. 29(12) 2. 42(21) GMax 1. 36(17) 2. 44(23) 3. 18.5(11)	2. 0.91 for both GMed and GMax	1. Ekstrom et al. 2007 2. DiStefano et al. 2009 3. Farrokhi et al. 2008
Lunge with Forward Trunk Lean	 Subject steps forward to a depth of hip and knee of 90^0 flexion with left leg and leans forward with trunk and bilateral upper extremities, keeping knee over toes.	GMax 1. 22.3(12)		1. Farrokhi et al. 2008
Lunge with Backward Trunk Lean	 Subject steps forward to a depth of hip and knee of 90^0 flexion with left leg and leans backward with trunk and bilateral lower extremities.	GMax 1. 19.3(11.8)		1. Farrokhi et al. 2008
Sideways Lunge	 Subject steps straight laterally from stance leg while keeping trunk upright. Subject lunges to a depth of hip and knee flexon of 90^0, while still keeping knee over toes.	GMed 1. 39(19) GMax 1. 41(20)	1. 0.91 for GMed and 0.85 for GMax	1. DiStefano et a. 2009
Transverse Lunge	 Subjects rotated 135° on their nondominant limb towards their dominant side. Subjects twisted and lunged forward in this direction. Subject lunges to a depth of hip and knee flexon of 90^0, while still keeping knee over toes.	GMed 1. 48(21) GMax 1. 49(20)	1. 0.93 for GMed and 0.95 for GMax	1. DiStefano et al. 2009

Unilateral Mini-Squat	 Subject stands on single leg and lowers body by flexing at the hip, knee and ankle, keeping trunk upright and pelvis level. Subject lowered their body with light touch along the wall (not holding onto wall).	GMed 1. 36(17) GMax 1. 57(44)		1. Ayotte et al. 2007
Single-limb squat exercise	 Subjects stands on single leg with knee and hip flexed approximately 30⁰. Subject then slowly lowers themselves until they touch contralateral middle finger to the outside of the dominant foot, not reaching with shoulder. Subjects then returned to the starting position and instructed to avoid their knee going over their toes.	GMed 1. 64(24) GMax 1. 59(27)	1. 0.95 for GMed and 0.93 for GMax	1. DiStefano et al. 2009
Forward Step-up	 Subject stands just behind stool. Subject then places right foot onto step and raises their body using right leg to lift body up onto step.	GMed 1. 44(17) GMax 1. 74(43)		1. Ayotte et al. 2007
Single Limb Deadlift	 Subjects balanced on their D limb, with their knee and hip flexed approximately 30° and their hands on their hips. Subjects slowly flexed their hip and trunk and touched their contralateral middle finger to the ground beside their support foot, and returned to the starting position. Subjects were instructed to keep their knee flexed 30° when reaching for the desired level, to enable primarily trunk and hip flexion, and to keep their knees over their toes	GMed 1. 58(25) GMax 1. 59(28)	1. 0.95 for both GMed and GMax	1. DiStefano et al. 2009

GMed=gluteus medius; GMax=gluteus maximus; EMG = Electromyography; ICC = Intraclass correlation; WB = Weight-bearing; D=Dominant lower extremity; ND=Non-dominant lower extremity; % MVIC = Percent maximal voluntary isometric contraction.

Appendix II. Details of evaluated studies.

Study	Exercise Included in Review	Subjects
Ayotte et al. 2007	**Gluteus Maximus** • Unilateral mini-squat	Twenty-three physically active Department of Defense beneficiaries (16 males, 7 females; mean ± SD age, 31.2 ± 5.8 years; mean ± SD height, 173.1 ± 10.1 cm; mean ± SD body mass, 77.0 ± 13.9 kg) volunteered for this study. **Inclusion** -Age range, 18–65 years -Bilateral lower extremity range of motion within normal limits -Bilateral lower extremity strength with manual muscle testing 5/5 -Able to perform single-limb balance with eyes open for 30 seconds -Department of Defense beneficiary **Exclusion** -History of surgery for spine or lower extremities -History of disease affecting the spine or lower extremities, such as diabetes, peripheral neuropathy, stroke, arthritis, or fibromyalgia -Unresolved lower extremity pathology or current pain in the spine or lower extremities -Taking any medications

Continued

Appendix II. Details of evaluated studies. *Continued*

Study	Exercise Included in Review	Subjects
Blanpied 1999	**Gluteus Maximus** • Wall squat	Twenty asymptomatic women (age = 31.3 ± 6.9 years, height = 160.9 ± 4.1 cm, mass = 58.1 ± 8.7 kg) subjects. **Inclusion/exclusion criteria**: No pathology, subjects over 170 cm tall were excluded due to equipment size limitations.
Bolgla & Uhl, 2005	**Gluteus Medius** • Pelvic drop	Sixteen healthy subjects (8 men, 8 women; mean ± SD age, 27 ± 5 years; mean ± SD height, 1.7 ± 0.2 m; mean ± SD body mass, 76 ± 15 kg) volunteers. **Inclusion/exclusion criteria**: No lower extremity dysfunction and could safely perform a single-leg stance on each lower extremity. Subjects were excluded if they had a history of significant lower extremity injury or surgery in the preceding year.
DiStefano et al, 2009	**Gluteus Maximus** • Side-lying hip abduction • Clam with 30° hip flexion • Clam with 60° hip flexion • Lunge • Sideways lunge • Transverse lunge **Gluteus Medius** • Side-lying hip abduction • Clam with 30° hip flexion • Clam with 60° hip flexion • Lunge • Sideways lunge • Transverse lunge	Twenty-one healthy subjects (9 males, 12 females; mean ± SD age, 22 ± 3 years; height, 171 ± 11 cm; mass, 70.4 ± 15.3 kg) volunteered to participate in this study. **Inclusion/exclusion criteria**: Subjects were recreationally active individuals who participated in physical activity for at least 60 minutes, 3 days per week.
Ekstrom, Donatelli & Carp, 2007	**Gluteus Maximus** • Prone plank • Unilateral bridge • Quadruped with contralateral arm and leg lift • Lunge • Lateral step-up **Gluteus Medius** • Side-lying hip abduction • Prone plank • Unilateral bridge • Bridging on stable surface • Quadruped with contralateral arm and leg lift • Side-bridge to neutral spine position • Lunge	Thirty healthy subjects (19 males and 11 females; mean ± SD age 27 ± 8 years; height,176 ± 8 cm; body mass, 74 ± 11 kg), participated in the study. **Inclusion/exclusion criteria**: Subjects were accepted for the study if they were in good health, with no current or previous lower extremity or back problems. They were excluded if they had low back or lower extremity pain, or any recent surgery.
Ekstrom, Osborn, & Hauer, 2008	**Gluteus Maximus** • Bridge on stable surface • Bridging on Swiss ball	In group 1 there were 30 subjects (23 females, 7 males; mean ± SD height, 170 ± 6 cm; body mass, 64 ± 9 kg; age, 24 ± 4 years). Group 2 consisted of 29 subjects (12 females, 17 males; mean ± SD height, 175 ± 8 cm; body mass, 73 ± 10 kg; age, 27 ± 8 years). In group 3 there were 30 subjects (20 females, 10 males; mean ± SD height, 171 ± 7 cm; body mass, 68 ± 9 kg; age, 26 ± 7 years). **Inclusion/exclusion criteria**: Subjects were accepted for the study if they were in good health, with no current back or lower extremity problems. Subjects were excluded if they had any previous back surgery.
Farrokhi et al, 2008	**Gluteus Maximus** • Lunge • Lunge with forward trunk lean • Lunge with backward trunk lean	Ten healthy adults (5 males and 5 females) without a history of lower extremity pain or pathology participated in this study (mean ± SD age, 26.7± 3.2 years). **Inclusion/exclusion criteria**: Subjects were excluded from participation if they reported having any of the following: (1) previous history of knee surgery, (2) history of traumatic patellar dislocation, or (3) neurological involvement that would influence performing the required exercises. The average ± SD height and mass of the subjects were 1.73 ± 0.07 m and 62.5 ± 9.8 kg, respectively.