Hip-Muscle Activation During the Lunge, Single-Leg Squat, and Step-Up-and-Over Exercises

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**Context:** Functional exercises are often used in strengthening programs after lower extremity injury. Activation levels of the stabilizing hip muscles have not been documented. **Objective:** To document the progression of hip-muscle activation levels during 3 lower extremity functional exercises. **Design:** Cross-sectional. **Setting:** Laboratory. **Participants:** 44 healthy individuals, 22 women and 22 men. **Intervention:** Subjects, in 1 testing session, completed 3 trials each of the lunge (LUN), single-leg squat (SLSQ), and step-up-and-over (SUO) exercise. **Main Outcome Measures:** Root-mean-square muscle amplitude (% reference voluntary muscle contraction) was measured for 5 muscles during the 3 exercises: rectus femoris (RF), dominant and nondominant gluteus medius (GMed_D and GMed_ND), adductor longus (ADD), and gluteus maximus (GMX). **Results:** The RF, GMAX, and GMed_D were activated in a progression from least to greatest during the SUO, LUN, and SLSQ. The progression for the GMed_ND activation was from least to greatest during the SLSQ, SUO, and then LUN. Activation levels of the ADD showed no progression. **Conclusion:** Progressive activation levels were documented for muscles acting on the hip joint during 3 functional lower extremity exercises. The authors recommend using this exercise progression when targeting the hip muscles during lower extremity strengthening. **Keywords:** electromyography, gluteus medius, exercise progression

Activation levels of the muscles surrounding the hip joint have become an area of increasing interest in reference to lower extremity injuries. Muscle weakness, specifically of the hip-abductor muscle group, has been observed in patients with patellofemoral pain syndrome, iliobibial band syndrome, anterior cruciate ligament injuries, and ankle instability. Previous studies have reported activation levels of the gluteus medius during rehabilitation exercises. Less attention, however, has been paid to the activation levels of other muscles that help stabilize the hip joint during functional exercises. To progress a patient back to full activity, it is necessary to understand the complete muscular contribu-
tion during functional exercises, which are often prescribed to strengthen the hip muscles.

Multiple studies have examined activation levels of the gluteal muscles during common lower extremity rehabilitation exercises. Mean electromyographical (EMG) activation levels of the gluteus medius have been reported during isometric hip-abduction and -rotation exercises, but interpreting the activation levels is difficult, because muscle activity was measured in volts and not as a percentage of maximum muscle activity. Few studies have reported mean activation levels of the gluteal muscles as a percentage of maximum muscle activity during selected lower extremity exercises. In general, greater activation levels of the gluteus medius were observed during exercises in which the base of support was minimal, such as the side bridge, unilateral squat, and lateral step-up, than with exercises in which the base of support was greater, such as the bilateral squat and lunge. Exercises that included an active hip-extension contraction were shown to activate the gluteus maximus to a greater extent than exercises without. Although information regarding the gluteal muscles is available during rehabilitation exercises, knowledge of the contributions of the surrounding muscles acting on the hip joint have yet to be identified during lower extremity exercises.

Closed-kinetic-chain, functional multijoint exercises such as lunges and squats are commonly integrated into lower extremity rehabilitation programs. Selective hip-muscle activation, kinematics, force, and gender differences have been examined during related exercises. Muscle activation of the specific prime movers of the hip joint has not been thoroughly reported, however. Therefore, our purpose was to compare the activation levels of the specific hip muscles between 3 functional exercises, the lunge (LUN), single-leg squat (SLSQ), and step-up and over (SUO), in healthy individuals. Specifically, we studied the gluteus maximus (GMX), adductor longus (ADD), rectus femoris (RF), dominant-limb gluteus medius (GMed_D), and nondominant-limb gluteus medius (GMed_ND). Our directional hypothesis was that mean EMG amplitudes for all hip muscles examined would progress from least to greatest during the SUO, the LUN, and the SLSQ.

Methods

Design

Our study employed a cross-sectional design. Subjects reported to 1 testing session in which all dependent measures were recorded. The dependent variable of interest was root-mean-square (RMS) muscle activation represented as a percentage of a reference voluntary muscle contraction (%RVC) for 5 muscles (GMX, ADD, RF, GMed_D, and GMed_ND). The independent variable was exercise with 3 levels (LUN, SLSQ, and SUO).

Participants

The subject population was a convenience sample consisting of 44 healthy individuals, 22 men and 22 women. Subject demographics (age, height, and mass) for the sample are as follows: 23.3 ± 5.1 years, 174.5 ± 9.1 cm, and 74.6 ± 16.5 kg. Subjects were included if they had no history of any major knee or hip injury or
surgery on either lower extremity and were able to perform the 3 functional exercises being evaluated. Subjects who had a history of minor sprains or strains or chronic conditions such as tendinitis were included in the study if these conditions were completely asymptomatic at the time of the study. Leg dominance was determined by asking subjects with which leg they would kick a soccer ball (right = 39, left = 5). All subjects read and signed a consent form that was approved by the university’s institutional review board.

**Instrumentation**

A 16-lead EMG system (Run Technologies, Mission Viejo, CA) was used to record muscle activity. A Myopac transmitter belt unit (Run Technologies, Mission Viejo, CA) was worn by each subject during data collection and was used to transmit raw EMG data at 1339 Hz via a fiber-optic cable to its receiver unit. Unit specifications included an amplifier gain of 2000 and a common-mode rejection ratio of 90 dB. Muscle activation of the GMX, ADD, RF, GMed_D, and GMed_ND was collected for each subject using bipolar Ag-AgCl surface electrodes (Therapeutics Unlimited, Inc, Iowa City, IA) measuring 5 mm in diameter with a center-to-center distance of approximately 20 mm. Electrodes were placed in parallel arrangement over the muscle belly for each muscle. EMG data were sampled at 1339 Hz and synchronized with kinematic data using Motion Monitor Ascension software (Innovative Sports Training Inc, Chicago, IL). Kinematic data were collected at 103 Hz for the purpose of identifying the beginning and end of each activity for EMG analysis. EMG and kinematic data were stored for analysis using Datapac software (Run Technologies). To allow for comparison between subjects, EMG data were normalized to %RVC. Before electrode placement, the skin was prepared by dry-shaving the area, abrading it with sandpaper, and cleansing it with alcohol to reduce impedance. Electrode placement for the GMX, electrodes were placed at half the distance between the greater trochanter of the femur and the spinous process of the second sacral vertebra along an oblique angle at the level of the greater trochanter or slightly above. Electrode placement for the GMed_D and GMed_ND was the proximal one third of the distance between the iliac crest and the greater trochanter of the femur, anterior to the GMX. Electrode placement for the ADD was at the medial thigh, approximately 2 cm from the pubic bone. The RF was used as a representative muscle for hip flexion and as a substitute for the iliopsoas muscle to garner an indirect assessment of hip-flexor activity. The iliopsoas was not assessed because of difficulty in reducing cross-talk with surface electromyography. Electrode placement for the RF was at the center of the anterior surface of the thigh, approximately halfway between the knee and anterior superior iliac spine. To ensure accurate electrode placement, the subjects were instructed to contract each muscle being tested while EMG activity was observed using the oscilloscope.

**Testing Procedures**

On arrival at the laboratory, subjects completed a written consent form and were instructed on the proper technique and procedures for the SLSQ, SUO, and LUN exercises. They were allowed to practice performing the exercises for familiarization purposes. On average, subjects required no more than 2 practice trials for
each exercise. Before testing, each subject performed a 5-minute warm-up on an exercise bike, followed by a static lower extremity flexibility program. Subjects were outfitted with the surface electrodes as described previously and completed a reference voluntary contraction (RVC) test for each muscle. After the RVC trials, each subject performed 3 trials each of the LUN, SLSQ, and SUO. Exercise order was randomized and counterbalanced between subjects. Subjects were given a 30-second rest between trials and a 2-minute break between exercises to prevent fatigue.

**RVC Testing**

Each subject had surface electrodes applied on the 5 muscles as described previously and was asked to perform 3 RVCs for each muscle. Each trial lasted 3 seconds, with a 30-second rest between trials. For the RF, the subject was seated on the edge of a box with a strap around the distal third of the shank (Figure 1). The subject was instructed to lift the foot of the testing leg off the floor and then push out against the strap, attempting to extend the knee. For the GMed_D and GMed_ND, the subject was standing and a strap was placed around both feet. The subject was instructed to push out against the band with the test leg while keeping the knee straight and the toes pointed forward (Figure 2). For the ADD, the subject was standing and was instructed to push the foot of the dominant leg against the nondominant leg while keeping the knee straight and toes pointed forward (Figure 3). For the GMX, the subject was standing, slightly leaning against a box for sup-

![Figure 1](image_url) — Initial subject position for reference voluntary-contraction testing of the rectus femoris.
port. The box was held in place through the use of external weight to keep it from shifting during testing. A strap was placed around the distal third of the subject’s thigh. The subject was asked to bend the knee approximately 90° and push the thigh posteriorly against the strap, attempting to extend the thigh (Figure 4).

Functional Exercises

_SLSQ._ Subjects were instructed to stand on their dominant leg with their hands crossed over their chest. The nondominant leg was held in approximately 45° of knee flexion. Subjects were instructed not to contact the nondominant leg with the dominant stance leg at any time during the activity. The subjects were instructed to squat down as far as they were able without losing their balance and return to single-leg stance. If a subject lost his or her balance or made contact with the nondominant leg, the data were discarded and the trial was repeated.

_LUN._ Subjects were instructed to stand with their feet shoulder width apart. The distance subjects stepped forward during the lunge was normalized to 100% of

**Figure 2** — Initial subject position for reference voluntary-contraction testing of the gluteus medius dominant and nondominant.
their leg length, measured as the distance from the anterior superior iliac spine to the medial malleolus of the tibia. Subjects were instructed to step out to this position using their dominant leg, lunge down to a comfortable distance, return to full knee extension of the lunge leg, and return to the starting position. If a subject did not reach the full lunge distance, the data were discarded and the trial was repeated.

**SUO.** Subjects were instructed to stand with their feet aligned behind an 8-in box. They were instructed to step up onto the 8-in box with their dominant limb and bring their nondominant limb up and over the box onto the platform on the other side. The subjects then stepped off the box with their dominant limb and came to a stance on the platform. If the subject could not step over the box in 1 motion, the data were discarded and the trial was repeated.

**Data Reduction and Statistical Analysis**

EMG data were band-pass filtered from 20 to 500 Hz and RMS smoothed using a 20-millisecond moving time constant. The mean amplitudes were then normal-
ized to a percentage of the RVC. Using SPSS Version 15.1 (SPSS Inc, Chicago, IL), 5 one-way analyses of variances (ANOVA) were conducted to determine whether there was a difference in muscle activation between exercises. Post hoc Bonferroni analyses were used to determine statistical significance with $\alpha$ set a priori at $P \leq .017$ to control for repeated measures.

Results

There was a main effect of exercise for the RF muscle. Post hoc testing revealed greater RMS EMG amplitudes during the SLSQ than the LUN and SUO and for the LUN when compared with the SUO ($P < .001$). There was a main effect of exercise for the GMX and GMed_D. Post hoc testing revealed greater mean RMS EMG amplitudes for both muscles during the SLSQ than with the SUO and LUN ($P < .001$). There was a main effect of exercise for the GMed_ND. Post hoc testing revealed greater mean RMS EMG amplitude during the LUN than the SLSQ ($P = .006$). There were no significant differences for ADD mean RMS EMG amplitudes between the 3 exercises (Table 1).
Based on our results, we accept our hypotheses that the muscle activations for the RF, GMX, and GMed_D would be least to greatest during the SUO, the LUN, and the SLSQ. We reject this hypothesis, however, for the ADD and the GMed_ND. The activation levels of the GMed_ND progressed from least to greatest during the SLSQ, the SUO, and the LUN. Activation of the ADD showed no clear progression or trend between the 3 exercises. This information is important to consider when developing a rehabilitation progression because clinicians commonly order exercise sequences from least to most difficult.

For the RF and the GMX, the exercise progression occurred from least to greatest activation during the SUO, the LUN, and the SLSQ. The observed sequence is intuitively consistent with the difficulty of the exercises and also the amount of flexion and extension that was performed during each exercise. Muscle activation was highest during the SLSQ because the body weight was being supported by the dominant leg while the subject moved into flexion and extension of the hip and knee. In contrast, when subjects performed the LUN and the SUO, the body was supported with both the dominant and the nondominant extremity while they moved into flexion and extension of the hip and knee, therefore requiring less muscle activation.

The magnitude of muscle activation observed in our study for the GMX was less than levels previously reported. Zeller et al\textsuperscript{14} reported GMX activation levels greater than 60% of the maximal voluntary isometric contraction (MVIC) for males and females during the SLSQ, and Ayotte et al\textsuperscript{12} reported GMX activation levels of 57% MVIC during a unilateral minisquat. Slightly lower activation levels were reported by Ekstrom et al\textsuperscript{13} during the LUN (36% MVIC). The GMX activation levels observed in this study were 35% MVIC during the SLSQ and 22% MVIC during the LUN. The differences might be the result of variations in the performance of each exercise between studies. Zeller et al\textsuperscript{14} reported that their

### Table 1  Muscle Activation During Functional Exercises Represented as % RVC

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Single-leg squat</th>
<th>Lunge</th>
<th>Step-up-and-over</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF</td>
<td>26.7 ± 16.1*†</td>
<td>19.1 ± 11.6†</td>
<td>10.8 ± 14.5</td>
</tr>
<tr>
<td>ADD</td>
<td>23.4 ± 29.5</td>
<td>23.6 ± 36.1</td>
<td>27.2 ± 61.1</td>
</tr>
<tr>
<td>GMX</td>
<td>35.2 ± 24.0*†</td>
<td>21.7 ± 14.7</td>
<td>16.5 ± 11.7</td>
</tr>
<tr>
<td>GMed_D</td>
<td>30.1 ± 9.1*†</td>
<td>17.7 ± 8.8</td>
<td>15.2 ± 6.9</td>
</tr>
<tr>
<td>GMed_ND</td>
<td>12.0 ± 7.5</td>
<td>19.0 ± 11.7‡</td>
<td>16.8 ± 10.4</td>
</tr>
</tbody>
</table>

Abbreviations: RVC, reference voluntary isometric muscle contraction; RF, rectus femoris; ADD, adductor longus; GMX, gluteus maximus; GMed_D, dominant-limb gluteus medius; GMed_ND, nondominant-limb gluteus medius.

*Significantly greater than the lunge (P ≤ .017). †Significantly greater than the step-up-and-over (P ≤ .017). ‡Significantly greater than the single-leg squat (P ≤ .017).
subjects squatted into greater degrees of knee flexion during the SLSQ (average depth 90° for men and 95° for women) than what we observed in our study (average depth 60°). This would increase the difficulty of the exercise and might be the reason for higher activation levels of GMX activation in their study. Similarly, Ekstrom et al. collected data over a 5-second hold at maximum knee flexion during the standing LUN compared with no hold in our study. The addition of a sustained contraction would require greater muscle activation to perform the exercise. Although differences in the magnitude of muscle activation reported in the literature vary because of methodological differences, it appears that the LUN is a less demanding exercise than the SLSQ for the GMX muscle. The activation levels for the GMX during the LUN were less than during the SLSQ and therefore suggest that the LUN be implemented in rehabilitation before the SLSQ.

Mean muscle activation for the GMed_D followed a sequence similar to those of the RF and GMX. The highest muscle activation observed for our study was during the SLSQ (30% RVC). GMed muscle activation has been reported as high as 77% MVIC for males and 41% MVIC for females during the SLSQ, 44% MVIC during the unilateral minisquat, and 29% MVIC during the LUN. These are considerably greater than the values reported in this study (30% RVC during the SLSQ and 18% RVC during the LUN). Again, differences between the studies in patient instructions on performing the exercise most likely resulted in the variations in muscle-activation levels. In addition, the testing position in which our reference contractions were collected (standing) differed from the traditional side-lying position reported by other studies. This might have affected the magnitude of the muscle activity required during these contractions, resulting in higher or lower normalizing values. Without knowledge of the raw voltage observed in the other studies, we cannot comment on whether our values were comparable. As with the GMX, however, it appears that the LUN is a less demanding exercise than the SLSQ for the GMed and should be performed before it in rehabilitation.

To our knowledge, our study is the first to report activation levels of the contralateral GMed during functional activities. Traditionally, the GMed has been described as an active abductor and medial rotator of the thigh; however, this is based on biomechanical models that do not take into account the true anatomy of the muscle. Anatomically, the GMed is segmented into 3 parts (anterior, middle, and posterior), each with separate innervations and phasic activity based on fiber orientation. As a whole, the muscle functions to stabilize the hip joint during weight bearing. The anterior and middle portions of the muscle secondarily help initiate active abduction of the femur, which is completed by the tensor of the fascia lata. This segmented activation has been validated through indwelling EMG investigations. The greatest GMed activation was observed during the stance phase of gait, with little to no EMG muscle activation during isolated abduction movements. Because our activities were performed in a weight-bearing position, we chose to measure muscle activation for both the GMed_D and GMed_ND to better understand the contribution of each muscle during functional tasks. During the SLSQ, in which the base of support is shifted solely to the stance limb, the GMed of this limb demonstrated twice the activation level of the noncontact limb. In contrast, muscle-activation levels were equal between sides during the LUN and SUO, in which the base of support is distributed between both limbs.
Activation levels of both the GMed_D and GMed_ND during all exercises were less than 20% RVC, with the exception of the GMed_D during the SLSQ. These findings emphasize the importance of the GMed as a pelvic stabilizer.23

Despite the anatomic and EMG findings that highlight the importance of the GMed during closed-kinetic-chain pelvic stabilization, maximal voluntary isometric muscle testing positions have been primarily referenced only in the open kinetic chain with side-lying hip abduction.26,27 Because of unanticipated problems with the testing device during data collection, we were unable to perform our reference testing of the gluteus medius in an open-kinetic-chain position. We chose to assess activation of the gluteus medius during weight-bearing isometric resisted hip abduction. We noted that activation levels of the gluteus medius on the test leg were greatest while it was acting to stabilize the pelvis during contralateral-limb active abduction as compared with resisted active abduction. These results further support the function of the GMed as integral to pelvic stabilization versus mainly being described as an active abductor. Although we do not know if our testing position produced muscle-activation levels similar to those observed in maximal muscle testing in the side-lying position, previous research has demonstrated greater mean GMed activation during stance while the opposite limb was actively abducting when compared with side-lying active abduction.9 Future studies are needed to determine which testing position would produce the greatest, most reliable representation of maximal muscle output for the GMed. Similarly, it is often difficult to compare GMed activation levels between studies because of differences in methodology; therefore, we have summarized the available literature describing GMed activation levels during rehabilitation exercises in Table 2.

In contrast to the other muscles examined in our study, there were no differences in muscle-activation levels for the ADD between any of the exercises. This might be because of the large degree of variance observed in the activation levels, which all exceeded the mean values (SLSQ ± 29.5, LUN ± 36.1, SUO ± 61.1%RVC). Overall, the ADD was active at approximately 25% of the RVC, which suggests that, during the 3 functional exercises, this muscle might function in a stabilizing role, controlling frontal-plane motion, because it is antagonistic to the GMed. Therefore, the 2 muscles might be working synergistically to control frontal-plane stability of the pelvis during functional tasks.

The greatest overall muscle activation in the current study was 35%RVC and occurred in the GMX during the SLSQ. Andersen and Kearney28 suggest that 40% to 60% of the maximal effort of a muscle must be reached before significant strength gains can be achieved. Based on our findings, these exercises might not be ideal for increasing maximal strength in any of the 5 muscles but might be used to increase submaximal strength or stability when performed as described herein. The application of an external load would likely elevate the muscle-activation levels observed in our study and might be appropriate to facilitate strengthening.

**Limitations**

Because of issues encountered with collecting EMG data simultaneously with the 3-dimensional kinematic data using an electromagnetic system, subject position during RVC testing differed from previously reported positions. The electromagnetic system emitted a sinusoidal wave, which was incorporated into the baseline...
<table>
<thead>
<tr>
<th>Exercise</th>
<th>Ayotte et al(^{12\text{a}})</th>
<th>Bolgla and Uhl(^{9\text{a}})</th>
<th><strong>Current study (%RVC)</strong></th>
<th>Ekstrom et al(^{13\text{a}})</th>
<th>Zeller et al(^{14\text{a}})</th>
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</thead>
<tbody>
<tr>
<td>Step-up-and-over</td>
<td></td>
<td></td>
<td>15 ± 7</td>
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<tr>
<td>NWB standing flexed hip abduction</td>
<td></td>
<td>28 ± 21(^{b})</td>
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<tr>
<td>Prone bridge</td>
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<td>Bridge</td>
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<tr>
<td>Lunge</td>
<td></td>
<td>19 ± 12</td>
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<tr>
<td>Dynamic edge</td>
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</tr>
<tr>
<td>NWB standing hip abduction</td>
<td></td>
<td>33 ± 23(^{b})</td>
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<tr>
<td>Unilateral squat</td>
<td>36 ± 17</td>
<td>30 ± 9</td>
<td>77 ± 64 (M)</td>
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<tr>
<td>Retro step-up</td>
<td>37 ± 18</td>
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<tr>
<td>NWB side-lying hip abduction</td>
<td></td>
<td>42 ± 23(^{b})</td>
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<tr>
<td>WB hip abduction</td>
<td></td>
<td>42 ± 27(^{b})</td>
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<tr>
<td>Quadruped arm/lower extremity lift</td>
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<tr>
<td>Lateral step-up</td>
<td>38 ± 18</td>
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<tr>
<td>Forward step-up</td>
<td>44 ± 17</td>
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<tr>
<td>WB with flexion hip abduction</td>
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<td>46 ± 34(^{b})</td>
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<td>Unilateral bridge</td>
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<td>47 ± 24</td>
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<tr>
<td>Wall squat</td>
<td>52 ± 22</td>
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<tr>
<td>Pelvic drop</td>
<td></td>
<td>57 ± 32(^{b})</td>
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<tr>
<td>Side bridge</td>
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<td>74 ± 30</td>
</tr>
</tbody>
</table>

Abbreviations: MVIC, maximal voluntary isometric muscle contraction; RVC, reference voluntary isometric muscle contraction; NWB, non-weight-bearing; WB, weight bearing.

\(^{a}\) Collected MVIC with patients in a side-lying position. \(^{b}\) Applied an external weight equal to 3% of body weight during exercise testing.
of our EMG data. Because of this, we had to standardize the area in which we collected all data, including RVC testing. This area was not large enough to incorporate a plinth in which to position the subjects in a side-lying or prone position, which has been described as the standard testing position for the muscles incorporated in this study.27 Based on this, muscle-activation levels reported in our study as a %RVC might not be directly comparable to other studies that have examined the same muscle using a standardized method for collecting MVIC. Because we standardized the RVC testing position for all of our testing, however, we feel that it provided an appropriate constant in which comparisons between exercises could be made.

In addition, the distance each subject flexed the knee during a SLSQ was not controlled. We also did not control the speed at which each exercise was performed. We chose not to control these variables because we felt it better represented what would be seen in a clinical setting, where there would be normal intersubject variability. Similarly, we have begun using this method to study patients with whom it is difficult to insist on a specific range of motion during the performance of the exercise.

Conclusions

Overall, the results of our study demonstrate that mean EMG activation levels of muscles acting on the hip joint increase incrementally during the SUO, LUN, and SLSQ. Because the level of muscle activation might not be optimal for maximal strengthening, we recommend incorporating these exercises early during functional rehabilitation programs to help enhance stability and muscle endurance. Based on our findings, exercises should progress from the SUO to the LUN to the SLSQ.

References


