Adductor Longus Activation During Common Hip Exercises

Article *in* Journal of Sport Rehabilitation · May 2014

DOI: 10.1123/JSR.2012-0046 · Source: PubMed

3 authors, including:

Kevin Laudner
Illinois State University

Michael Torry
Illinois State University

Journal of Sport Rehabilitation, 2014, 23, 79-87
http://dx.doi.org/10.1123/JSR.2012-0046

JOURNAL OF
SPORT REHABILITATION
www.JSR-Journal.com
ORIGINAL RESEARCH REPORT

Adductor Longus Activation During Common Hip Exercises

Robert J. Delmore, Kevin G. Laudner, and Michael R. Torry

Context: Hip-adductor strains are among the most common lower-extremity injuries sustained in athletics. Treatment of these injuries involves a variety of exercises used to target the hip adductors. ***Objective:*** To identify the varying activation levels of the adductor longus during common hip-adductor exercises. ***Design:*** Descriptive study. ***Setting:*** Laboratory. ***Participants:*** 24 physically active, college-age students. ***Intervention:*** None. ***Main Measurement Outcomes:*** Peak and average electromyographic (EMG) activity of the adductor longus muscle during the following 6 hip-adductor rehabilitation exercises: side-lying hip adduction, ball squeezes, rotational squats, sumo squats, standing hip adduction on a Swiss ball, and side lunges. ***Results:*** The side-lying hip-adduction exercise produced more peak and average activation than any other exercise ($P < .001$). Ball squeezes produced more peak and average activation than rotational squats, sumo squats, and standing adduction on a Swiss ball ($P < .001$). Ball squeezes had more average activation than side lunges ($P = .001$). All other variables for peak activation during the exercises were not statistically significant ($P > .08$). These results allowed the authors to provide an overall ranking system (highest to lowest muscle activation): side-lying hip adduction, ball squeezes, side lunges, standing adduction on a Swiss ball, rotational squats, and sumo squats. ***Conclusion:*** The study provides a ranking system on the activation levels of the adductor longus muscle for 6 common hip-adductor rehabilitation exercises, with the side-lying hip-adduction and ball-squeeze exercises displaying the highest overall activation.

Keywords: therapeutic, rehabilitation, adductor strains

Adductor strains are among the most common lower-extremity injuries seen in athletics.[1–3] A common mechanism of this injury is when the adductors attempt to decelerate an extending, abducting leg by using an eccentric contraction to adduct and flex the hip.[4] With the forceful eccentric contraction, the adductors may not be strong enough to withstand the force, and injury can occur. The injury may also occur during a forceful concentric contraction of the muscle. Lower-extremity athletes such as ice hockey and soccer players are naturally more prone to this pathology due to the importance of the hip adductors in lower-extremity performance.[4]

Research has reported that 10% of all ice hockey injuries sustained are hip-adductor strains.[1] Other research has found that 43% of all muscle strains over the course of a hockey season are diagnosed as hip-adductor strains.[2] Another investigation looking solely at adductor/abdominal-strain incidence in all U.S. National Hockey League teams over 6 competitive seasons reported that out of 7050 ice hockey players, 617 adductor/abdominal strains were reported, with adductor strains being the most common compared with abdominal strains.[3]

The authors are with the School of Kinesiology and Recreation, Illinois State University, Normal, IL.

Soccer athletes also frequently sustain hip-adductor muscle injuries, with 12% to 18% of all soccer-related injuries being diagnosed as adductor strains.[5,6] Sixty percent of these injuries are due to overuse, while the other 40% are caused by acute trauma.[5] Experience level has also been shown to increase the incidence of adductor strains in soccer, with athletes in higher experience levels reporting more adductor strains.[6] In the adductor muscle group, the adductor longus has been shown to be most susceptible to injury when the leg is transitioning from hip extension to hip flexion during a soccer kick.[7] This is a common action not only in soccer but also in any sport requiring forceful hip flexion and extension. Hockey players perform a similar motion while skating, making the mechanism of hip-adductor injury common in both soccer and hockey.

The adductor longus muscle has been found to be the most frequently injured of the adductor group, with 62% of adductor injuries occurring to the musculotendinous junction of the adductor longus.[8] With adductor strains being such a common injury among different athletes, understanding how the adductor longus muscle specifically functions during different exercises becomes a key component in the prevention and treatment of such injuries. With the occurrence of hip-adductor strains being 17 times more likely when hip-adductor strength is 80% or less than the strength of the abductors,[9] this makes adductor strength a vital component in the prevention of this pathology. Past studies have used an array of adductor exercises while looking at adductor-injury-prevention programs, as well as for postinjury rehabilitation protocol.[10,11] At the heart of these techniques are activities that specifically target adductor strength and stabilization. While these methods have been suggested to help treat adductor pathologies, the amount of specific muscle activation during individual exercises has yet to be examined. Therefore, the purpose of this study was to identify the amount of activation of the adductor longus muscle during common hip-adductor-strengthening and -stabilization exercises. By obtaining these data, clinicians may be able to choose specific exercises to reach desired activation levels of the hip adductors, thereby assisting in the prevention and rehabilitation of such injuries.

Methods

Participants

Twenty-four male participants (age 21.5 ± 2.0 y, height 180.5 ± 6.3 cm, mass 86.9 ± 10.8 kg) volunteered to participate in this study. Exclusion criteria included previous history of lower-extremity injury within the past 6 months and any previous history of hip surgery. Participants were required to be active for a minimum of 3 times per week, for at least 30 minutes per session. Each participant was informed of the experimental risks of the study and signed an informed-consent form as approved by the university review board before data collection.

Instrumentation

Muscle-activity data were obtained using surface electromyography (EMG; Bagnoli EMG system, Delsys Inc, Boston, MA). Signals were amplified from a test electrode (Delsys DE-2.1 differential EMG sensor, Delsys Inc, Boston, MA) and a disposable pregelled adhesive ground electrode with a circular contact diameter of 5 cm. EMG data were collected at a frequency of 2000 Hz per channel. Each EMG signal exhibited a bandwidth of 3 dB at 10 to 500 Hz. The lower cutoff filter was a first-order, high-pass design. The upper cutoff filter was a fourth-order Butterworth low-pass design. The differential amplifier had a fixed gain of 1000, an input impedance of >10 Ω, and a common rejection ratio of 130 dB. Surface EMG has been proven to be reliable in past studies that examined the use of the technology with other hip muscles such as the quadriceps, hamstrings, and gluteus medius.[12,13] All EMG data were processed using ProEMG software (Prophysics AG, Zurich, Switzerland) integrated with a Vicon Nexus system (Vicon Inc, Los Angeles, CA).

Procedures

Each participant's dominant leg (the leg preferred to kick a ball) was used for testing. Electrodes were applied to the skin of the test leg after the areas were shaved, abraded, and cleansed with 70% isopropyl alcohol. The test electrode was applied to the adductor longus at the center of the muscle belly parallel to the muscle fibers. The adductor longus belly was found midway between the origin at the pubic tubercle and the insertion at the medial linea aspera of the femur.[14] To ensure electrode placement, the test leg was passively abducted and the adductor longus muscle belly was palpated just distal to the muscle's tendon, traced from the pubic tubercle on the medial side of the leg. The participant was then asked to actively adduct the leg against resistance to confirm that motor-unit activation was recorded by appropriate placement of the electrode. A ground electrode was placed on the anteromedial tibia of the test leg.

Once prepared, the participants first performed a 5-second maximal voluntary isometric contraction (MVIC) of the adductor longus to gain a baseline measurement. MVICs were taken with the participant side-lying on the test side, with the contralateral leg flexed so that the foot rested on the table in front of the participant. The test leg was kept straight and was lying flat against the table. The researcher then provided manual resistance against the leg as the participant attempted to adduct toward the ceiling (Figure 1). The test leg was kept flat on the table during each MVIC to ensure an isometric contraction. The participant was asked to provide a maximal effort for 5 seconds for a total of 5 trials.

The participants performed each of the following 6 hip-adductor exercises: side-lying hip adduction, ball squeezes, rotational squats, sumo squats, standing hip adduction on a Swiss ball, and side lunges. The exercises were chosen based on previous research[10,15] and our 12 years of therapeutic exercise experience. Stabilization exercises were defined as exercises that incorporated adductor longus activation to maintain an exercise pattern or stance. Strength exercises were defined as exercises that incorporated adductor longus activation to sustain activation against resistance. All exercises were completed at the pace of a metronome set at 1 beat/s to maintain compliance with the variable of time. The researcher also provided a verbal cadence to the beat of the metronome to ensure that the participant maintained the correct rhythm during the exercise. The verbal cadence consisted of the researcher counting out the seconds during each repetition of the exercise. The researcher providing the verbal cadence was also in charge of striking the force platform at the beginning and end of each repetition. The force-platform data in conjunction with the muscle-activation data allowed us to separate each repetition and look at it individually to avoid processing for the short rest period between repetitions. Participants were shown each exercise and allowed to practice it before data collection began to familiarize themselves with the movements. Practice of each exercise did not exceed 5 repetitions. The order of the exercises was randomized across participants, and all exercises were performed for 5 repetitions, with each repetition lasting 5 seconds (2.5 s for the concentric contraction and 2.5 s for the eccentric contraction).

The side-lying hip-adduction exercise was performed in the side-lying position with the test side on a standard treatment table. The nontest hip and knee were flexed to 90° and rotated so that the foot was flat on the table in front of the test leg. The test leg was kept straight throughout the exercise. A 5-lb (~2.3-kg) ankle weight was placed around the ankle of the test leg to provide resistance (Figure 2). The ankle weight was used to help simulate the resistance used in the other exercises, as well as test the exercise as it is commonly performed. The placement of the ankle weight was 79 cm from the test-side anterosuperior iliac spine down the test-side tibia. This length was standardized to ensure that the lever arm during the exercise would be the same for all participants. The participant was asked to slowly adduct the test leg (lift the leg off the table) and then slowly lower it back down to the starting position.

Ball squeezes were performed supine with the participant's knees flexed to 45° and a 45-cm Swiss ball (TheraBand, Akron, OH) held between the medial

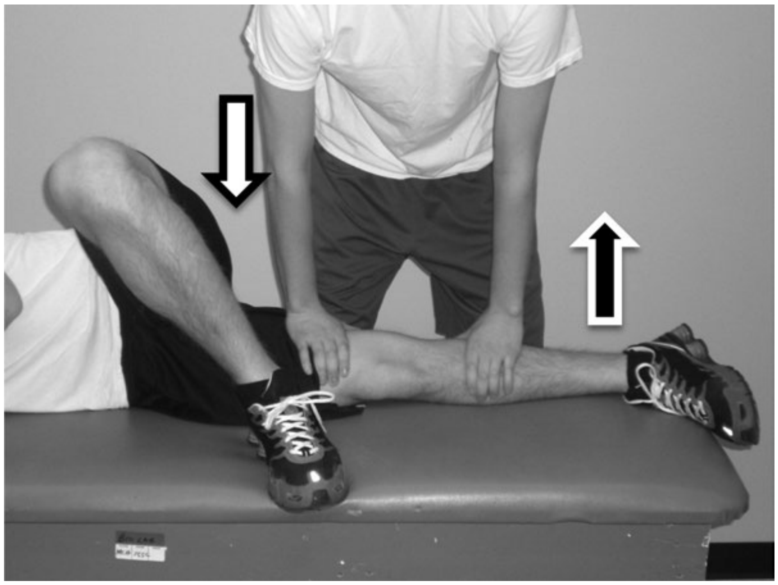

Figure 1 — Position for maximal voluntary isometric contraction. White arrow indicates direction of force of the researcher; black arrow indicates direction of force of the participant.

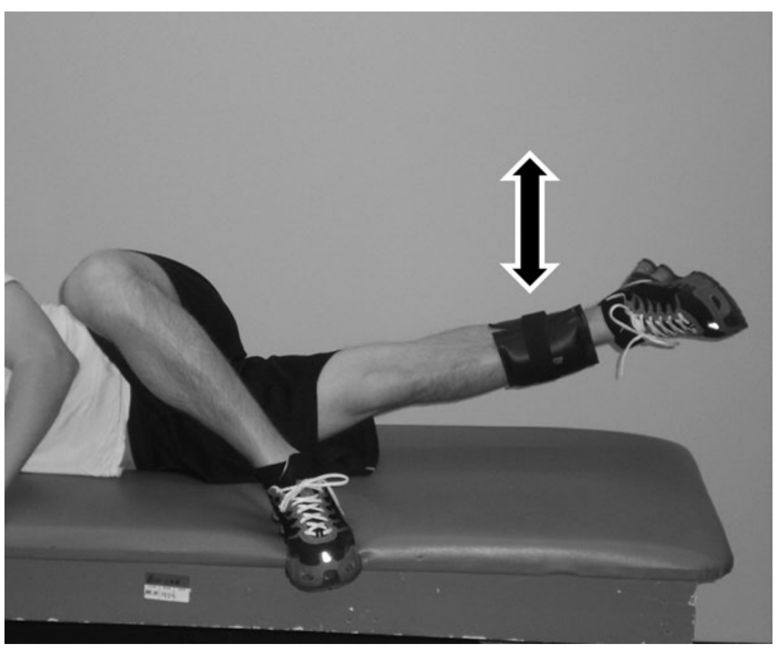

Figure 2 — Side-lying hip adduction. Black arrow indicates direction of force of the participant.

aspects of both knees (Figure 3). The participant was asked to adduct his hips, thereby squeezing the ball, and then return to the starting position. The participant was instructed to squeeze the ball at submaximal intensity, enough to indent the ball slightly.

Rotational squats were performed by having the participant stand with his feet shoulder width apart and knees slightly flexed. A circular resistance band (Thera-Band, red: medium resistance, 28 in) was placed around both knees, just proximal to the joint (Figure 4). The

Figure 3 — Ball squeeze.

Figure 4 — Rotational squat. Black arrow indicates direction of force of the participant.

participant was asked to rotate his trunk approximately 80° to 90° while externally rotating the hip 80° to 90° away from the midline of the body, so the test foot was pointing at a 90° angle from the nontest foot. While turning, the participant was asked to simultaneously squat by flexing at the knees and then extend to return to the start position with both feet facing forward.

Sumo squats began with the feet shoulder width apart and rotated away from the midline of the body at approximately a 45° angle. In this position, the participant was then asked to flex at the hips and knees into a squatting position (to approximately 90°) and then return to the starting position by extending both legs (Figure 5).

Standing hip adduction on a Swiss ball began with the test knee flexed and resting on a 75-cm Swiss ball (TheraBand, Akron, OH). The participant was then asked to move the test leg away from the midline of the body by rolling the Swiss ball out and then bring the test leg back toward the midline of the body to the starting position (Figure 6).

Side lunges were performed by having the participant step to the side while facing forward, allowing both knees to flex to 90° and keeping the back straight (Figure 7). The step was double the length of the distance between the feet when they are shoulder width apart. The participants alternated stepping to the right and then to the left to keep close proximity to the EMG equipment.

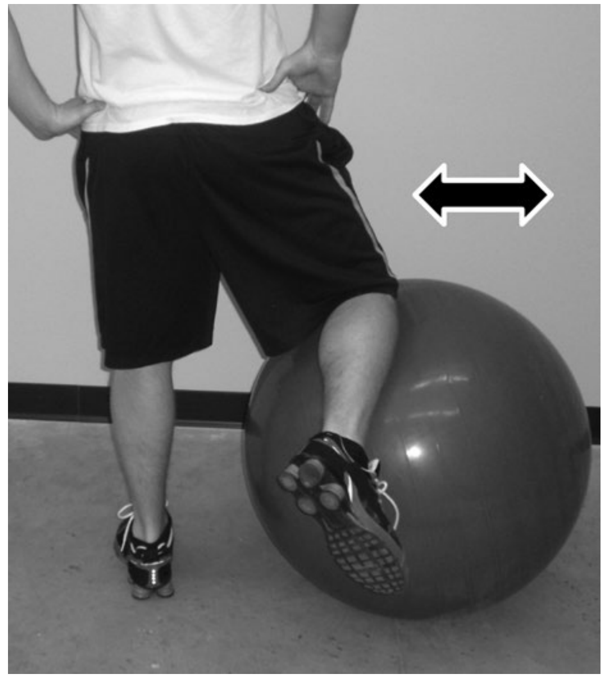

Figure 6 — Standing hip adduction on a Swiss ball. Black arrow indicates direction of force of the participant.

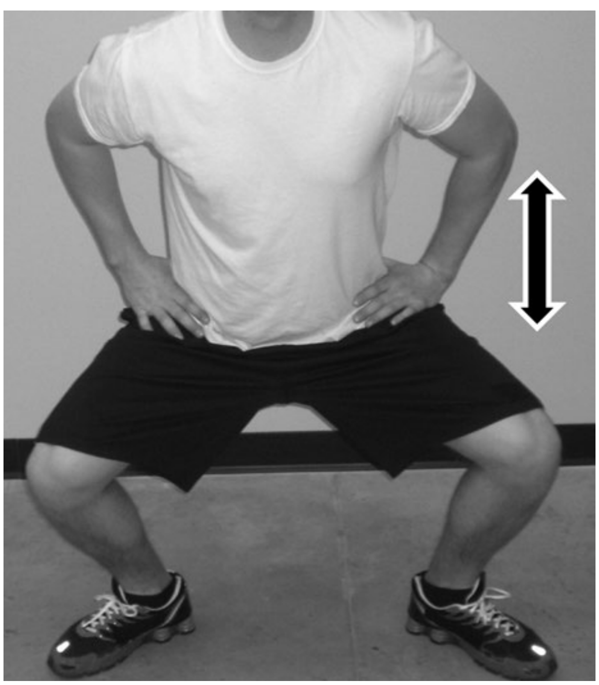

Figure 5 — Sumo squat. Black arrow indicates direction of force of the participant.

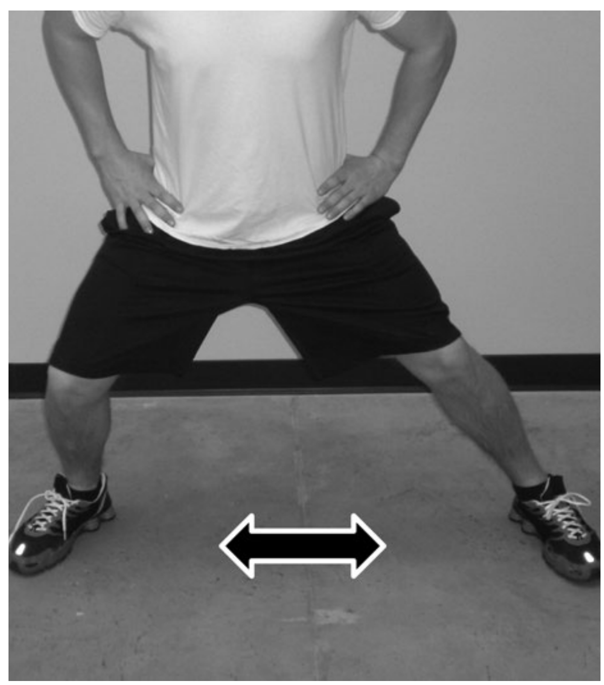

Figure 7 — Side lunge. Black arrow indicates direction of force of the participant.

Statistical Methods

The MVIC raw signal was full-wave rectified and processed using a root-mean-square of 100 milliseconds. For the MVICs, the average of the highest peak activation of 3 of 5 trials was used for trial data normalization. Trial data were processed for peak and average activation. After the raw signal was rectified and smoothed, it was divided by the respective MVIC value to yield percentage activation values. Peak %MVIC activation trials were processed by taking the highest value in each repetition of each exercise. Average %MVIC activation trials were processed by averaging all the activity for each repetition for each exercise.

Using PASW version 18 (PASW Inc, Chicago, IL), a 1-way repeated-measures analyses of variance (ANOVA) was conducted to compare average and peak EMG-signal amplitude between the exercises. A Bonferroni correction was used to protect against type I error caused by multiple tests ($P < .05/6$, or $P < .008$). To ensure that EMG values were consistent within each exercise and during the MVICs, reliability analyses were also conducted using intraclass correlation coefficients ($ICC_{3,1}$). The rank of the exercises was determined by rank of highest peak and average amplitude and then viewed as an overall rank. When a discrepancy existed between exercises in regard to the order of peak rank and average rank, the sum of the peak and average rank was determined and used to determine the placement of the exercise within the ranking system.

Results

The side-lying hip-adduction exercise produced more peak %MVIC activation than ball squeezes (24.1%, $P = .001$), side lunges (33.4%, $P = .001$), standing adduction on a Swiss ball (42.8%, $P = .001$), rotational squats (44.3%, $P = .001$), and sumo squats (46.4%, $P = .001$). Ball squeezes produced more peak %MVIC activation than standing adduction on a Swiss ball (18.7%, $P = .001$), rotational squats (20.2%, $P = .001$), and sumo squats (22.3%, $P = .001$). All other variables for peak %MVIC activation during the exercises were not statistically significant ($P > .08$).

Side-lying hip adduction produced more average %MVIC activation than ball squeezes (8.1%, $P = .001$), side lunges (13.9%, $P = .001$), rotational squats (15.3%, $P = .001$), standing adduction on a Swiss ball (16.0%, $P = .001$), and sumo squats (16.4%, $P = .001$). Ball squeezes produced more average %MVIC activation than side lunges (5.8%, $P = .001$), rotational squats (7.2%, $P = .001$), standing adduction on a Swiss ball (7.9%, $P = .001$), and sumo squats (8.3%, $P = .001$). The percentages in the parentheses represent the difference in percentage activation between exercises. All other variables for average %MVIC activation during the exercises were not statistically significant ($P > .42$). Peak and average %MVIC activation of adductor longus across all exercises are displayed in Table 1.

Reliability analysis revealed $ICC_{3,1}$ values of .98 to .99 when assessing all 5 repetitions of each exercise. When we assessed reliability between the 3 MVIC repetitions, the ICC value was found to be .93. These values are displayed in Table 2 and suggest there was strong reliability within subjects throughout each exercise and the MVIC trials. The means and standard deviations for all normalized peak and average amplitude data can be viewed in Table 1. Based on these data each exercise was ranked from highest to lowest muscle activity of the adductor longus (Table 3).

Table 1 Peak and Average EMG Amplitudes (as %MVIC) of Adductor Longus Across 6 Exercises

Exercise	% peak amplitude MVIC (SD)	% average amplitude MVIC (SD)
Side-lying hip adduction	60.1 (16.2)*	22.4 (5.5)†
Ball squeezes	36.0 (18.0)+	14.3 (6.0)‡
Rotational squats	15.8 (10.7)	7.1 (4.3)
Sumo squats	13.7 (7.6)	6.0 (3.0)
Standing hip adduction on Swiss ball	17.3 (9.7)	6.4 (3.1)
Side lunges	26.7 (13.1)	8.5 (3.9)

Abbreviations: EMG, electromyography; MVIC, maximum voluntary isometric contraction. Significance was set at $P = .001$, with a symbol indicating significance.

*Side-lying hip adduction produced more peak activation than ball squeezes, rotational squats, sumo squats, standing adduction on Swiss ball, and side lunges.

+Ball squeezes produced more peak activation than rotational squats, sumo squats, and standing adduction on Swiss ball.

†Side-lying hip adduction produced more average activation than ball squeezes, rotational squats, sumo squats, standing adduction on Swiss ball, and side lunges.

‡Ball squeezes produced more average activation than rotational squats, sumo squats, standing adduction on Swiss ball, and side lunges.

Table 2 Within-Subject Reliability for Each Exercise and MVICs

Exercise	ICC
Maximum voluntary isometric contraction	.93
Side-lying hip adduction	.98
Ball squeezes	.98
Rotational squats	.99
Sumo squats	.99
Standing hip adduction on Swiss ball	.99
Side lunges	.98

Table 3 Rank Order for Adductor Longus Muscle Activation

Overall rank	Exercise	%PA	%AA
1	Side-lying hip ADD	1	1
2	Ball squeezes	2	2
3	Side lunges	3	3
4	Standing hip ADD on Swiss ball	4	5
5	Rotational squats	5	4
6	Sumo squats	6	6

Abbreviations: ADD, adduction; %PA, percent peak amplitude of maximum voluntary isometric contraction; %AA, percent average amplitude of maximum voluntary isometric contraction.

Discussion

Various athletes, such as hockey and soccer players, commonly sustain injuries to the hip-adductor muscles.[7,16–19] It is critical to understand what exercises produce the largest amount of activation. Our study is the first to show significant differences between common hip-adductor exercises and to specifically rank these therapeutic exercises based on mean and peak %MVIC activation of the adductor longus. More specifically, our results show that the side-lying hip-adduction exercise produced more activity than any other adduction exercise, followed by the isometric ball-squeeze exercise.

The side-lying hip-adduction exercise was found to generate the highest activation levels, for both peak and average %MVIC activation, when compared with all other exercises. In the side-lying position the pelvis is stabilized from laterally tilting by the table. Therefore, the adductor longus may have been better isolated, without any contribution from supplementary hip muscles, compared with the other exercises. Our findings suggest that this side-lying method not only is beneficial for therapeutic exercises but could also be considered when testing the strength of the adductor longus during evaluations and during MVICs used for EMG studies. Our results support previous literature by Kendall et al,[20] who recommended the side-lying position for strength testing of the hip adductors.

Delahunt et al[15] examined the optimal position for the supine adductor squeeze test, a common test to evaluate the strength of the hip adductors. Their results indicated that 45° of knee flexion (while supine) is the best position of the patient to generate maximum muscle activation of the adductor muscles. In the current study, although the side-lying position produced more mean and peak %MVIC activation than the ball squeeze, the ball squeeze ranked the second highest among the 6 exercises and produced significantly higher average and peak %MVIC activation than the rotational squats, sumo squats, and standing adduction on a Swiss ball, as well as more average %MVIC activation than the side lunges. With ball squeezes ranking second in terms of activation, it supports the position found in the results of the Delahunt et al[15] study that it is effective in generating adductor activation but might not be optimal when compared with the side-lying position used in our study.

The current study supports the findings of Delahunt et al,[15] but differences in the methods make them difficult to compare. Unlike our study, Delahunt et al investigated the activity levels of the hip-adductor muscles at maximum strength, compared with our submaximal strength measures, and only investigated variations of the ball-squeeze exercise, compared with our multiple exercises. Other hip adductors such as the adductor magnus, adductor brevis, gracilis, and pectineus were also focused on in Delahunt et al's results, as opposed to only looking at the adductor longus. This difference could make for an interpretation of higher activation of the adductors as a whole when compared with adductor longus activation in isolation found in the current study. It should also be noted that the activation levels in current study may have occurred due to some internal rotation of the hip during the exercise, which the adductor longus is responsible for producing. Regardless, our results provide clinically useful information when determining which exercises should be used in the rehabilitation of various pathologies associated with adductor longus weakness.

Side lunges ranked third in the continuum. Tyler et al[10] used this exercise in the warm-up portion of their rehabilitation protocol for adductor strains, which our results would support due to moderate activation levels. However, sumo squats were also used during the warm-up of the Tyler et al[10] study but ranked last according to our data. Although our results do not suggest that sumo squats are unnecessary, they do support the idea that other exercises, which appear to produce higher amounts of both average and peak %MVIC activation of the adductor longus, may be more beneficial for a warm-up before adductor-related rehabilitation.

Standing hip adduction on a Swiss ball and rotational squats ranked fourth and fifth, respectively, in the ranking system. However, unlike the other 4 exercises, these ranks were not consistent between peak and average

%MVIC activation. These results may be due to other muscles' being recruited during both exercises. Standing hip adduction on a Swiss ball was determined to be a higher overall rank by summing the peak and average amplitude of both exercises to determine the placement of the exercise within the ranking system.

When examining the overall ranking of the exercises based on activation levels, some speculation can be made about why each exercise produced the activation that it did. It appears that as the exercises became more complex and began to use joints other than the iliofemoral joint, less activation of the adductor longus muscle occurred. This is plausible because as more joints are recruited for an exercise, so are more muscles to make those joints mobile. Increased muscle recruitment from subsequent muscles may consequently allow the adductor longus muscle to activate less but still complete the desired exercise. Gravity independence and knee flexion during the exercises may have also played a role in lower activation levels in more complex exercises. As the knee flexes, other muscles are recruited to complete the motion, allowing the adductor longus to activate less. Although more complex motions should also be incorporated into various hip-rehabilitation programs due to their functionality, the side-lying and ball-squeeze exercises should be considered when more of an emphasis is desired for isolation of the adductor longus.

As with any study, there are several limitations of our study worth noting. One was the use of surface EMG to detect muscle-activation levels. While surface EMG has been proven to be reliable[12,13] when examining the hip musculature, its validity is often questioned. Noise can occur, with other electronics in the vicinity of the system resulting in inaccurate signal noise.[21] In an attempt to minimize this variable, electronics not required for data collection were not allowed near the equipment during collection. However, since there is no way to distinguish whether a high amplitude was true activation or signal noise after filtering was applied, all maximum amplitudes had to be considered muscle activation. Another limit of surface EMG is the accuracy of electrode placement. While standardized procedures were used to ensure correct placement of the electrode to the adductor longus, cross talk may have occurred. The electrode still may have picked up activity from other medial thigh muscles such as adductor magnus, adductor brevis, or gracilis muscles.[14,22,23] Another limitation of our study was the use of the same amount of resistance (ankle weight and resistance band) for all participants. Our participants were asymptomatic, physically active, college-age men, and based on our clinical experience we felt that the amount of resistance used (5-lb ankle weight and medium-resistance band) represented a typical load for this population. To promote consistency of the side-lying hip-adduction exercise, we placed the ankle weight at the same distance from the anterosuperior iliac spine down the tibia for all participants to standardize the moment arm. However, differences in strength between participants obviously exist and should be considered when interpreting our results. Finally, we only used asymptomatic participants, which may make our results difficult to compare with the activation levels of an injured population. Injured participants may exhibit a change in muscle activation due to the muscle's recent damage. Our data could provide normative baselines for future research to make comparisons between healthy and symptomatic individuals.

Conclusion

The side-lying exercise produced significantly more activity than any other exercise, while the ball squeeze produced more activity than the rotational squats, sumo squats, standing adduction on a Swiss ball, and the side lunges. However, it should be emphasized that although we ranked the 6 exercises based on the amount of peak and average %MVIC activation, the only exercises with statistically larger amounts of activation levels were for side-lying hip adduction and ball squeeze. The other 4 exercises may be considered interchangeable based on the closeness of their activation levels determined in this study. The side-lying hip-adduction exercise produced the most activation of the muscle, followed by ball squeezes, side lunges, standing hip adduction on a Swiss ball, rotational squats, and sumo squats. These results may be beneficial not only in the prevention and rehabilitation of various pathologies associated with adductor longus weakness but also in manual muscle testing during clinical evaluations. Future research should examine activation levels when comparing male and female subject, injured populations, and across various resistance levels for the exercises.

References

1. Lorentzon R, Wedren H, Pietila T. Incidence, nature, and causes of ice hockey injuries: a three-year prospective study of a Swedish elite ice hockey team. *Am J Sports Med*. 1988;16(4):392–396. PubMed doi:10.1177/036354658801600415
2. Molsa J, Airaksinen O, Nasman O, Torstila I. Ice hockey injuries in Finland: a prospective epidemiologic study. *Am J Sports Med*. 1997;25(4):495–499. PubMed doi:10.1177/036354659702500412
3. Emery CA, Meeuwisse WH, Powell JW. Groin and abdominal strain injuries in the National Hockey League. *Clin J Sport Med*. 1999;9(3):151–156. PubMed doi:10.1097/00042752-199907000-00006
4. Sim FH, Chao EY. Injury potential in modern ice hockey. *Am J Sports Med*. 1978;6(6):378–384. PubMed doi:10.1177/036354657800600612
5. Engstrom B, Forssblad M, Johansson C, Tornkvist H. Does a major knee injury definitely sideline an elite soccer player? *Am J Sports Med*. 1990;18(1):101–105. PubMed doi:10.1177/036354659001800118
6. Nielsen AB, Yde J. Epidemiology and traumatology of injuries in soccer. *Am J Sports Med*. 1989;17(6):803–807. PubMed doi:10.1177/036354658901700614

7. Charnock BL, Lewis CL, Garrett WE, Jr, Queen RM. Adductor longus mechanics during the maximal effort soccer kick. *Sports Biomech*. 2009;8(3):223–234. PubMed doi:10.1080/14763140903229500
8. Renstrom P, Peterson L. Groin injuries in athletes. *Br J Sports Med*. 1980;14(1):30–36. PubMed doi:10.1136/bjsm.14.1.30
9. Tyler TF, Nicholas SJ, Campbell RJ, McHugh MP. The association of hip strength and flexibility with the incidence of adductor muscle strains in professional ice hockey players. *Am J Sports Med*. 2001;29(2):124–128. PubMed
10. Tyler TF, Nicholas SJ, Campbell RJ, Donellan S, McHugh MP. The effectiveness of a preseason exercise program to prevent adductor muscle strains in professional ice hockey players. *Am J Sports Med*. 2002;30(5):680–683. PubMed
11. Bennell KL, Hunt MA, Wrigley TV, Hunter DJ, Hinman RS. The effects of hip muscle strengthening on knee load, pain, and function in people with knee osteoarthritis: a protocol for a randomised, single-blind controlled trial. *BMC Musculoskelet Disord*. 2007;8:121. PubMed doi:10.1186/1471-2474-8-121
12. Bolgla LA, Uhl TL. Reliability of electromyographic normalization methods for evaluating the hip musculature. *J Electromyogr Kinesiol*. 2007;17(1):102–111. PubMed doi:10.1016/j.jelekin.2005.11.007
13. Fauth ML, Petushek EJ, Feldmann CR, et al. Reliability of surface electromyography during maximal voluntary isometric contractions, jump landings, and cutting. *J Strength Cond Res*. 2010;24(4):1131–1137. PubMed doi:10.1519/JSC.0b013e3181cc2353
14. Jenkins DB. *Hollinshead's Functional Anatomy of the Limbs and Back*. 9th ed. St. Louis, MO: Saunders Elsevier; 2009.
15. Delahunt E, Kennelly C, McEntee BL, Coughlan GF, Green BS. The thigh adductor squeeze test: 45° of hip flexion as the optimal test position for eliciting adductor muscle activity and maximum pressure values. *Man Ther*. 2011;16(5):476–480. PubMed http://dx.doi.org/10.1016/j.math.2011.02.014
16. Katis A, Kellis E. Three-dimensional kinematics and ground reaction forces during the instep and outstep soccer kicks in pubertal players. *J Sports Sci*. 2010;28(11):1233–1241. PubMed doi:10.1080/02640414.2010.504781
17. Lees A, Asai T, Andersen TB, Nunome H, Sterzing T. The biomechanics of kicking in soccer: a review. *J Sports Sci*. 2010;28(8):805–817. PubMed doi:10.1080/02640414.2010.481305
18. Humble RN, Gastwirth BW. The biomechanics of forward power skating. *Clin Podiatr Med Surg*. 1988;5(2):363–376. PubMed
19. Brophy RH, Backus SI, Pansy BS, Lyman S, Williams RJ. Lower extremity muscle activation and alignment during the soccer instep and side-foot kicks. *J Orthop Sports Phys Ther*. 2007;37(5):260–268. PubMed doi:10.2519/jospt.2007.2255
20. Kendall FP, McCreary EK, Provance PG, Rodgers MM, Romani WA. *Muscles: Testing and Function with Posture and Pain*. 5th ed. Baltimore, MD: Lippincott Williams and Wilkins; 2005.
21. Konrad P. *The ABC of EMG.* ; 2005:60.
22. Prentice WE. *Arnheim's Principles of Athletic Training: A Competency-Based Approach*. 12th ed. New York, NY: McGraw-Hill; 2006.
23. Magee DJ. *Orthopedic Physical Assessment*. 5th ed. St. Louis, MO: Saunders Elsevier; 2008.