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Electromyographic Analysis of Hip Abductor Exercises Performed by a Sample of Total Hip Arthroplasty Patients

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Abstract: Weakness of the hip abductors after total hip arthroplasty may result in pain and/or functional limitation. Non-weight-bearing (NWB) exercises are often performed to target the hip abductors; however, muscle activation of NWB exercises has not been compared to weight-bearing (WB) exercises. Our purpose was to evaluate gluteus medius activation during 2 WB and 2 NWB hip abductor strengthening exercises. Fifteen patients at least 6 weeks post unilateral total hip arthroplasty volunteered for the study. Electromyographic amplitude for each exercise was normalized to each patient's maximal voluntary isometric contraction. There were no significant differences in gluteus medius electromyographic amplitudes between the 4 exercises (P = .15). Based on our results, NWB exercises provided no clear benefit in terms of gluteus medius activation when compared to potentially more functional WB exercises in the early postoperative period.
Key words: EMG, THA, closed kinetic chain, open kinetic chain.

Between 1990 and 2002, the number of primary total hip arthroplasty (THA) procedures performed annually in the United States increased from 119000 to 193000 [1]. In 1990, patients between the ages of 45 and 64 years accounted for 28% of the population being treated with primary THA [1], which equates to approximately 33000 procedures per year. By 2002, the percentage had increased to 40% [1], or roughly 77000 procedures per year, thus illustrating the growing utilization of primary THA in younger and potentially more active patients.

Because more young patients are electing to undergo THA, a greater emphasis is being placed on an earlier return of function after surgery, leading to the development of minimally invasive surgical techniques and accelerated or rapid recovery protocols [2,3]. In our clinical experience, we have observed that 35% of younger THA patients enrolled in a rapid recovery protocol required additional postoperative follow-up visits for pain and/or functional limitation secondary to hip abductor weakness (unpublished data). Other groups of authors that have studied postoperative lower extremity strength, gait, and functional outcomes after THA have suggested that comprehensive rehabilitation protocols that specifically address hip abductor weakness need to be developed [4-10].

The hip abductors play an obvious role in maintaining neutral pelvic alignment during gait and other activities of daily living [11-14]. Because

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of the slow disease progression associated with osteoarthritis, weakness of this muscle group is common in patients with osteoarthritis [15] and has also been demonstrated to persist after THA [8,9,16,17]. Strength of the hip abductors improves to only 50% of normal 6 months after THA, which leaves the hip relatively unguarded during this time [16]. Perrin et al [16] further suggested that prolonged use of assistive ambulatory devices may improve results in younger, more active patients.

The success of rapid recovery protocols, both in the eyes of the patient and the surgeon, has been predicated on the patient's ability to progress to full weight bearing without the use of a cane or crutches as quickly and as safely as possible. In fact, studies evaluating minimally invasive surgical techniques and rapid recovery protocols often use the time to discontinued cane use as a direct measure of clinical success [2,18]. A concerted effort to reduce the duration of postoperative use of assistive devices without formally addressing strength deficits may create a less than optimal situation for the patient. Hip abductor weakness will alter forces experienced by the hip joint leading to joint instability [17], which may be amplified in the early postoperative period by unassisted weight bearing.

Despite the hip abductors' role during gait and activities of daily living, limited research exists in the rehabilitation literature to support which exercises progressively challenge the hip abductors. Non-weight-bearing (NWB) exercises are often performed to specifically target this muscle group; however, weight-bearing (WB) exercises may provide more functional benefit because this type of exercise often activates a greater number of muscle groups while also providing the opportunity for proprioceptive benefit [19-21]. To our knowledge, only one study has compared hip abductor muscle activation during NWB exercises to activation during potentially more functional WB exercises. Bolgla and Uhl [22] previously evaluated 6 hip abductor exercises in a population of healthy adults with mean age of 27 years to determine an order of exercise progression. They reported that WB exercises demonstrated significantly greater electromyographic (EMG) amplitudes than NWB exercises, with the exception of NWB side-lying hip abduction [22]. A limitation of this study was the inability to generalize these results to a postoperative patient population. To more accurately define THA rehabilitation models, hip abductor activation must be assessed within a population of THA patients. Therefore, the purposes of this study were to evaluate gluteus medius EMG activation during 4 commonly used hip abductor exercises in a sample of THA patients to determine if an inherent order of exercise progression exists and to determine if differences in activation exist between NWB and WB exercises. We hypothesized that our results would mimic those of Bolgla and Uhl, with WB exercises demonstrating greater EMG amplitudes than NWB exercises.

Methods

Patients

Fifteen patients (9 men, 6 women; mean age, 57.4 ± 10.2 years; mean body mass index, 31.8 ± 6.7 kg/m^2) that were at least 6 weeks status post unilateral primary THA (mean follow-up of 15.5 weeks; range, 7-32 weeks) volunteered for this study. Patients who had undergone primary THA via a posterior approach with a posterior capsule and piriformis repair performed by a single surgeon were recruited during routine postoperative follow-ups. Patient diagnoses included osteoarthritis (10 patients), avascular necrosis (2 patients), hip dysplasia (2 patients), and displaced femoral neck fracture (1 patient). Patients were allowed to participate in this study if they had no complications from surgery that would prevent them from completing the exercise protocol. Patients were also excluded from this study if they had a latex allergy, an injury currently affecting their gait, or a disorder affecting their balance. All patients provided informed consent before participation in this institutional review board–approved protocol.

Setup Procedures

Before testing, patients rode a stationary bike at a self-selected speed for 5 minutes to warm up followed by gentle calf, hamstring, and quadriceps stretching consisting of three 15-second repetitions. We then familiarized each patient with the exercises they would perform during testing. Patients generally required 5 to 10 practice repetitions for each task. After the familiarization session, the patients rested 10 minutes to reduce the possible effects of fatigue. During this rest period, we instrumented each patient for data collection.

We prepared the patient's skin for surface EMG in a standard manner [23]. Bipolar Ag/AgCl surface electrodes (Ambu, Glen Burnie, Md) were placed on the skin over the proximal third of the distance between the iliac crest and greater trochanter in line with the gluteus medius and anterior to the gluteus maximus. This placement was used to limit crosstalk from surrounding muscles [24]. Proper location was visually confirmed by examining the electrical signal on an oscilloscope by having the patient actively abduct their hip. Cover Roll (BSN-Jobst, Charlotte, NC) was applied over the electrodes to prevent any movement during testing, and a ground electrode was positioned over a bony prominence such as the acromion process or patella. We applied 2-dimensional electrogoniometers (Biometrics Ltd, Ladysmith, Va) using double-sided tape over the lateral aspect of the right and left hips for the purpose of delineating repetitions during exercise. We visually confirmed electrogoniometer activity in response to hip movement before testing. Cover Roll was also used to prevent movement of the electrogoniometers during testing.

After instrumentation, the patients performed 3 maximal voluntary isometric contractions (MVICs) of the gluteus medius to normalize the raw EMG data. We assisted the patients into a side-lying position on their uninvolved side with their involved extremity positioned in slight abduction by placing pillows between the patients' legs [25]. In this position, resistance to movement was applied with a stabilization strap located over the lateral femoral condyle [22]. Patients received strong verbal encouragement as they performed three 5-second MVICs and rested 1 minute between each effort. To exclude ambient noise during exercise testing, a 5-second quiet trial was collected while the patients stood still with their body weight distributed equally between both feet with their hands resting at their sides.

Exercise Procedures

We asked patients to perform 10 repetitions of each exercise keeping in pace with a metronome (Seiko, Mahwah, NJ) set at 50 beat/min [21] with verbal cues of "raise, lower, rest" at each successive tone. Using trigonometry, we determined that the distance the foot had to be displaced to create 30° of hip abduction was 50% of each patient's leg length. For the purpose of this investigation, leg length was defined as 46% of the patient's height, as determined by previous anthropometric studies [26]. Patients rested 3 minutes between exercises to reduce the affects of fatigue, and the order of exercises was randomized using a random number table to eliminate ordering bias.

Non-Weight-Bearing Standing Abduction. For this exercise, a cuff weight representing 1% of the patients' body weight-height was applied to the ankle of the involved extremity, which was determined using an equation developed by Fredericson et al [27]. Cuff weights used during the standing exercises ranged from 0.45 to 2.27 kg for this group of patients. Patients began the exercise with their feet together and with their hands resting on a bathroom scale placed on the edge of an adjustable treatment table. Patients were instructed to place as little pressure on the scale as possible in an effort to limit upper extremity compensation during the exercise. We also placed a mirror in front of the patients on the opposite side of the table to provide visual feedback to help them keep their pelvis level and minimize trunk lean during the exercise (Fig. 1). Patients were instructed to abduct their leg until the lateral aspect of the involved foot touched a plastic block and return to the start position.

Weight-Bearing Standing Abduction. This exercise was done exactly the same as the NWB exercise but with the cuff weight placed on the ankle of the uninvolved leg. Although the uninvolved leg moved through the 30° arc of abduction, we monitored the EMG activity of the involved leg while acting as the support limb during movement of the contralateral limb.

Side-Lying Abduction. A cuff mass equal to 0.5% of the patients' body weight and height was placed around the ankle of the involved limb. We reduced resistance in an attempt to maintain

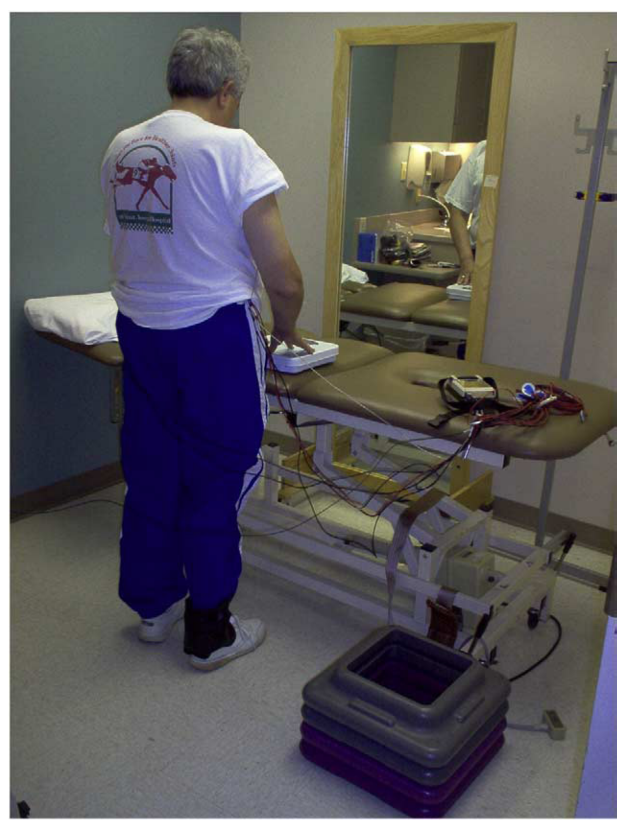

Fig. 1. A patient performing the weight-bearing standing hip abduction exercise.

Fig. 2. A patient performing the side-lying hip abduction exercise.

consistent peak external torque between each exercise by accounting for the length of the lever. The length of the lever was defined as the horizontal distance that the load was displaced (ie, the distance perpendicular to the force of gravity). In a side-lying position, the maximum length of the lever was equivalent to each patient's leg length. In the standing exercises, the horizontal distance was 50% of leg length because this was the distance necessary to create 30° of hip abduction, as previously described. Therefore, to maintain consistent peak external torque, the resistance placed at the ankle during the side-lying exercise was 50% of the resistance used in the standing exercises. Cuff weights used during this exercise ranged from 0.23 to 1.14 kg for this group of patients.

We positioned patients on their uninvolved side with enough pillows between their knees to have their leg rest at 0° of hip abduction. Patients were instructed to keep their hips, knees, back, and neck in a straight line while laying their head on a pillow and looking straight ahead. Patients actively abducted their leg 50% of their leg length and returned to the starting position. A wooden dowel fixed to a clamp was used to demarcate this arc of motion (Fig. 2).

Resisted Side-Stepping Exercise. We applied Thera-band elastic resistance (Hygenic Corporation, Akron, Ohio) proximal to the patient's ankles with neoprene straps. The resistance level (color of elastic band) was determined as the color necessary to create similar peak external torque (1% body weight-height) as the other standing exercises, with the band displaced 50% of each patient's leg length [28]. Patients began the exercise by standing with their feet 30.5 cm apart with the resistance band taut but without tension (Fig. 3). Patients side-stepped to the involved side a distance equal to 50% of their leg length and then brought their uninvolved leg toward the involved leg to return the band to its original length. Colored tape marks were placed on the floor to mark proper foot placement. Like the other exercises, a metronome and verbal cues were used to dictate the rate of movement. Patients completed one set of 10 repetitions toward and away from the involved leg.

Electromyographic Analysis

A 16-channel Myopac EMG system was used (Run Technologies, Mission Viejo, Calif) to record muscle activity. Patients wore a Myopac transmitter belt unit that transmitted all raw EMG data at 1000Hz via a fiber optic cable to its receiver unit. Unit specifications for the Myopac included a common mode rejection ratio of 90 dB, an amplifier gain of 2000 for the surface EMG electrodes, and amplifier gain of 1000 for the electrogoniometer. Raw EMG data were band-pass–filtered at 20 to 500 Hz using Datapac Software (Run Technologies), stored on a personal computer and analyzed using Datapac software.

Fig. 3. A patient performing the resisted side-stepping exercise.

Electrogoniometer signals were linear smoothed over a moving 15-millisecond window and used to demarcate hip motion for each repetition. For all exercises, the electrogoniometers showed an upward and downward deflection during movement, followed by a relatively flattened line during the rest periods. We identified EMG signals associated with movement and excluded those signals generated during the rest periods for the purposes of statistical analysis. For each exercise, we then calculated the root-mean-square (RMS) amplitude for each repetition and expressed these amounts as a percentage of the MVIC (%MVIC). A trial was considered unusable if the patient was not able to correctly perform the entire motion with proper bodily alignment or at the correct speed of movement. Normalized data from the useable repetitions for each exercise were then averaged and used for statistical analysis [22].

Statistical Analysis

We did not perform an a priori power analysis because we had no previous data to use for analysis, and no similar data have been previously published with THA patients. However, we did perform a midterm power analysis after data had been collected on 8 patients that demonstrated that a minimum sample size of 12 patients would be adequately powered (90%) to locate a difference in mean rank of 0.88 between the side-lying and resisted side-stepping exercises assuming the standard deviation would remain near the 1.05 value measured at that time.

Because of the relatively small sample size, a nonparametric Friedman test was used to determine differences in hip abductor amplitudes between exercise conditions. Statistical analysis was performed using SPSS Version 15.0 (SPSS Inc, Chicago, Ill). Level of significance was set at $P < .05$. If significant differences were found, Wilcoxon-signed rank tests were used to determine the location of significant differences. In addition, pairwise Cohen's d calculations were performed to determine the relative effect size of any differences in activation between the exercises [29,30]. Cohen defined effect sizes as small, $d = 0.2$; medium, $d = 0.5$; and large, $d = 0.8$ [29].

Results

Of the 15 patients, 2 were excluded from statistical analysis. One patient was unable to correctly perform the side-lying exercise, and the data for the other 3 exercises were omitted from the Friedman test. A technical malfunction rendered the data from a second patient unusable. The remaining 13 patients had mean modified Harris Hip Scores [31] of 89.8 at the time of testing. There were no differences ($P = .15$) in hip abductor activation between the 4 exercises, and mean EMG RMS values ranged from 57.80 to 67.05 %MVIC (Table 1). Of the patients, 6 demonstrated the greatest EMG RMS value during a WB exercise, whereas 7 patients demonstrated the greatest EMG RMS value during a NWB exercise. Pairwise effect sizes between exercises were all small, ranging from 0.001 to 0.23, indicating that between-exercise mean differences may have limited clinical significance.

Table 1. Electromyographic Root-Mean-Square Amplitude (Mean ± SD) Representing Activation of the Gluteus Medius Muscle During 4 Exercises, Expressed as a Percentage of Activation During a MVIC (%MVIC)

Exercise	%MVIC	Mean Rank
Side-lying abduction	67.05 ± 34.37	3.15
Resisted side stepping	62.55 ± 44.71	2.46
Weight-bearing standing abduction	67.01 ± 56.36	2.38
NWB standing abduction	57.80 ± 44.96	2.00

No significant differences were noted between the exercises ($P = .15$).

Discussion

The purpose of this study was to evaluate gluteus medius EMG activation during 4 commonly used hip abductor exercises in a sample of THA patients. This EMG analysis was performed to determine if an inherent order of exercise progression exists and to determine if differences in activation exist between NWB and WB exercises. The hip abductors play a vital role in maintaining neutral pelvic alignment during gait and are also active when performing lateral movements and navigating stairs [11-14]. In 2 studies of gait after THA, Madsen et al [6] and Foucher et al [4] both suggested that comprehensive rehabilitation protocols incorporating hip abductor strengthening need to be developed. Weakness of this muscle group has been identified even 2 years after THA, and exercise protocols involving hip abductor strengthening have been demonstrated to improve lower extremity strength, walking distance, and patient-reported functional outcome scores [5,7-10].

We observed no differences in gluteus medius activation between the 4 exercises when controlling the peak external resistance, thus demonstrating that there is no clear order of exercise progression. The lack of difference between the exercises suggests that they may be used interchangeably. When constructing postoperative rehabilitation protocols, surgeons and therapists should consider the potential advantages and disadvantages of each exercise, as well as other patient-specific considerations. For example, to reduce the risk of a fall in a patient with a vestibular or balance disorder, the standing NWB or WB hip abduction exercises may be more appropriate because these exercises allow the patient to use a stable surface, such as a countertop, to provide upper extremity support. In addition, patients who cannot stand safely can challenge the hip abductors in a manner similar to WB exercises by performing side-lying abduction.

It is also interesting to note that no differences in activation were measured between NWB and WB exercises. Historically, postoperative rehabilitation protocols, regardless of joint, have consisted of a progression from submaximal isometric exercises to single-joint open-kinetic-chain exercises and then to closed-kinetic-chain exercises [32]. For the lower extremity, open-kinetic-chain exercises are defined as those in which the foot is free to move in space, whereas closed-kinetic-chain exercises are performed with the foot stabilized or fixed, such as during weight bearing [20]. Weight-bearing exercises have been suggested to provide more functional benefit, both in terms of the pattern of muscle recruitment and proprioceptive stimulation [19-21]. Despite these potential functional benefits, this type of exercise has been suggested to overstress the joint and surrounding musculature [32]. However, the results of the current investigation suggest that in terms of activation of the gluteus medius muscle, there was no difference between NWB and WB exercises.

One patient was unable to perform the NWB side-lying hip abduction exercise, although we attempted to normalize the amount of peak external torque by reducing the amount of resistance added to the limb. The lever arm was twice as long during this exercise than during the other 3 exercises that we studied. With this in mind, clinicians should be cognizant of the effect of the increased lever arm during this exercise on the torque required of the hip abductors. When first initiating hip abductor strengthening, exercises are often performed without placing any external resistance on the limb; however, it should be noted that the weight of the limb alone results in greater external peak torque during side-lying hip abduction than during other hip abductor exercises.

This study was not without limitation. Electromyographic amplitudes were expressed as a percentage of each patient's MVIC. The amount of preoperative deconditioning, amount of time between surgery and EMG testing, and variable rates of rehabilitation can affect EMG amplitudes. Patients in this study participated 7 to 32 weeks after surgery. If we assume that patients tested longer after surgery would have greater strength than patients that had surgery more recently, we would expect to see affected level of activation. Stronger patients would require lower levels of activation in relation to their maximal voluntary contraction to perform the exercises when compared to stronger patients. But again, we did not compare one patient to another but attempted to determine if, on a given day, one or more exercises demonstrated consistently greater activation than the others. Therefore, differences in activation between patients would not artificially influence our results. In addition, 3 patients demonstrated amplitudes greater than 100% when performing one or more of the exercises, casting doubt as to whether the patients' isometric contractions were truly maximal. Statistically, increased variability in the magnitude of the EMG results did not artificially result in a lack of significant findings, as the nonparametric test used was based on a rank ordering of the 4 exercises and not on the absolute magnitude of the EMG amplitude. However, we were then unable to discuss any differences in EMG amplitude in these exercises in our sample of THA patients with those reported in a previous study of healthy young adults. In addition, despite our best efforts to have patients maintain vertical torso alignment during testing, some patients may have incorporated small amounts of lateral trunk lean to reduce the demands of these exercises on the hip abductors. Trunk lean and/or compensation with other muscle groups may have contributed to the comparable levels of activation demonstrated by the 4 exercises.

In conclusion, activation of the gluteus medius muscle did not differ between the 2 WB and NWB exercises. Future studies in this area will be necessary to determine if comprehensive rehabilitation protocols including hip abductor strengthening exercises improve postoperative function in THA patients. Previous protocols have initiated postoperative abductor strengthening as early as 3 weeks after THA without complication [5,10]; however, future studies with larger samples of diverse patient ages and activity levels will be needed to determine if formal postoperative therapy is appropriate for all THA patients. In addition, future study will also be necessary to determine if WB exercises truly provide more functional or proprioceptive benefit than NWB exercises as has been previously suggested.

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