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Research Article

Incorporating Neuromuscular Reeducation Techniques During Postoperative Rehabilitation Improves Functional Performance After Total Hip Arthroplasty: A Preliminary Study

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ABSTRACT

Introduction: Total hip arthroplasty is a common procedure in end-stage hip osteoarthritis. Yet, following hip arthroplasty, deficits in functional performance, possibly due to movement compensations, persist. The purposes of this study are to provide conceptual basis for improving functional performance following hip arthroplasty by addressing movement compensation, present a unique rehabilitation protocol developed from this conceptual framework, and present findings from a preliminary investigation.
Methods: This study was a prospective**,** randomized, controlled preliminary trial with concealed allocation and intention-to-treat analysis. Twenty participants undergoing primary, posterior approach THA were randomized into a neuromuscular reeducation and a control group. The neuromuscular reeducation group completed an 8-week, outpatient rehabilitation program after total hip arthroplasty utilizing neuromuscular reeducation techniques to promote pelvic stability and strength to improve movement quality. The control group was supervised by the study therapist weekly for 8 weeks after surgery but did not attend outpatient rehabilitation. Outcomes, assessed before and after surgery, included stair climb test, gait speed, 6-minute walk test, assessments of postural control and pelvic stability, muscle strength, and self-reported function.
Results: Following the intervention, the neuromuscular reeducation group demonstrated statistically and clinically significant improvements in the stair climb test, 4-meter walk, 6-minute walk, postural control, and in some patient-reported outcomes. Further, there were trends toward improvement in pelvic stability during functional tasks and muscle strength, but these improvements were not statistically significant.
Conclusions: Findings of this preliminary investigation support the use of neuromuscular reeducation techniques to improve functional performance after total hip arthroplasty, yet more information may be needed to determine efficacy. Therefore, this preliminary work has set the stage for future investigations to explore whether neuromuscular reeducation training after total hip arthroplasty should be considered in clinical practice.

Introduction

Total hip arthroplasty (THA) is a common orthopedic surgery with a 174% projected increase in utilization to more than 500,000 THAs per year by 2030 [1-3]. Patients often report pain reduction following surgery; however, functional recovery remains compromised [4]. Postoperative muscle weakness may explain these functional performance deficits; however, movement quality may also play a role.

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In particular, asymmetrical limb loading during standing and sit-to-stand movements, abnormal gait mechanics, and poor mechanics while climbing stairs are often observed after THA suggesting that current approaches to rehabilitation to recover functional performance after surgery may not yield adequate results [5-8]. Previous research suggests that some modes of rehabilitation, such as strength training, are efficacious for improving functional performance after THA and thus, is commonly included in postoperative protocols [1, 9-12].

However, strength training alone may not address the poor movement quality seen during activities of daily living such as transfers, walking, and stairs. Performing these activities without movement compensation depends on the ability of the body to produce stable, coordinated movements during functional tasks, which is also referred to as neuromuscular control [13]. To train movement without compensation, thus promoting neuromuscular control after THA, may require a different rehabilitative approach. Optimal neuromuscular control around the hip joint is demonstrated through maintenance of a horizontal pelvis on the femur during activity, primarily facilitated by the lateral hip muscles' ability to stabilize the pelvis during unilateral stance [14, 15]. During posterolateral approach THA surgery, these muscles are incised and divided, affecting their subsequent ability to stabilize. This, in turn, results in compensated movement which may explain the altered movement patterns seen during activities of daily living often observed after THA. Consequently, optimizing neuromuscular control through targeted exercise could address movement compensation and improve functional performance [16].

Neuromuscular reeducation, referring to the process of educating patients' movement patterns toward controlled, coordinated movement, as a means to provide stability during functional tasks, is one technique to improve neuromuscular control [13]. Neuromuscular reeducation techniques have been effective after anterior cruciate ligament reconstruction and following ankle sprain [17-20]. Emphasizing proper muscle recruitment, stability, and movement pattern training has effectively improved gait mechanics, increased hip abductor strength, increased joint stability, and prevented injury [17-20]. Similar movement pattern training has also improved strength, function, and hip mechanics in young people with hip pain [21].

Considering this conceptual framework, we propose that a potential strategy to improve functional performance after THA could include utilizing neuromuscular reeducation techniques to improve stability and control during movement. Therefore, a rehabilitation protocol utilizing neuromuscular reeducation techniques such as weight-bearing exercises to improve sensorimotor control, muscle coordination, and stability was created [13]. The purpose of this preliminary investigation was to examine the functional outcomes in response to the developed protocol. We hypothesized that by improving neuromuscular control, we would observe greater improvements in functional performance for patients after THA.

Methods

I Subjects

This study was a prospective, randomized investigation to explore the preliminary efficacy of a post-THA rehabilitation protocol utilizing neuromuscular reeducation techniques. Participants were recruited from area hospitals by physician referral or advertisement at preoperative educational sessions. Eligible participants were between the ages of 50-75 years and undergoing posterolateral approach THA for osteoarthritis. Exclusion criteria included a history of uncontrolled diabetes, body mass index >40 kg/m^2, or additional orthopedic or neurologic pathology that impaired function. Each participant provided written, informed consent. This study was approved by the Colorado Multiple Institutional Review Board, 09-1121. The trial was also registered at ClinicalTrials.gov**,** NCT01817010.

II Randomization

Randomization sequence was computer generated and was stratified by sex in block sizes of two and occurred 2 weeks after surgery. Participants were randomized into two groups: neuromuscular reeducation group (NMR) or control group (CON). The randomization process and maintenance of records was managed by a co-investigator not assessing patient outcomes.

III Interventions

Following randomization, the NMR group participated in outpatient rehabilitation 2 times per week for 8 weeks. Briefly, the NMR protocol consisted of:

i. Neuromuscular reeducation activities emphasizing early initiation of lateral hip muscle recruitment during bilateral and unilateral standing activities. Verbal and visual feedback emphasizing pelvic horizontal stability and ideal femoropelvic alignment was utilized to promote optimal movement quality during standing activities.
ii. Trunk stabilization exercise focusing on lower abdominal training to promote pelvic stability during functional activities.
iii. Progressive resistance exercise, utilizing 8-repition max principles, for the lower extremity musculature to remediate common muscle strength impairments after THA.
iv. Specific movement pattern training using visual, verbal, and tactile feedback to promote pelvic stability and optimal femoropelvic alignment during sit-to-stand, gait, and stair climbing activities.

The protocol was delivered by one therapist to ensure consistency. Each domain of exercise was progressed in intensity and complexity to maximize strength, movement quality, and stability. Additional protocol details are available in (Appendix 1). The CON group was supervised by the study physical therapist for 8 weeks after randomization via weekly home visits. Participants received advice for resuming activities of daily living, flexibility exercises, and isometric muscle training during weekly home visits. They did receive any specific movement pattern training. As there is no standard of care for rehabilitation following THA, and discussions with local physical therapists and area physicians indicated that patients do not routinely receive outpatient rehabilitation services, this protocol closely mirrored standard postoperative care in this community [1].

IV Outcomes

Testing sessions occurred prior to THA surgery (PRE) and following intervention (END) at the University of Colorado Interdisciplinary Movement Science Laboratory. Several outcome measures were collected to assess outcomes in response to the protocol. However, the stair-climb test (SCT) was designated as the primary outcome due to the high demand this task places on the hip. Standardized scripts and instructions were used to minimize bias during testing and one investigator (JW), who was blinded to group assignment, instructed patients during outcomes assessments and recorded all results. Data entry was completed by research assistants blinded to group assignment, and data analysis was supported by a statistician who was blinded to group assignments.

To assess functional performance, participants performed a stair climb test (SCT, primary outcome), a five-time-sit-to-stand test (FTSTS), the Timed-Up-And-Go test (TUG), 4-meter walk test (4MW), 6-minute walk test (6MW), and the Fullerton Advanced Balance Scale (FAB) [22]. The SCT is valid and reliable and is a valuable measure of function because of the demand placed on the hip during this task and its use in defining functional independence in older adults [8, 23, 24]. Participants completed a 12-stair ascent and descent as quickly as possible, using the handrail if necessary. The FTSTS measured the time it takes to stand from a chair (height 46 cm) and return to sitting five consecutive times [25]. The TUG measured the time to rise from a chair, walk 3m, turn around, and return to sitting [26]. Participants were instructed to complete these tasks as quickly and safely as possible and were permitted to use assistive device as necessary to ensure safety.

The 4-meter walk test (4MW) was used to measure gait speed, an important factor in determining functional capacity, and predicting morbidity and mortality in older adults [27]. Participants performed the 4MW with instructions to "walk as quickly but as safely as possible." The test included a two-meter distance from the start line to where timing was initiated and a two-meter distance to the stop line from where timing was terminated to allow for acceleration and deceleration. The 6-minute walk test (6MW) assesses how far a person can walk in 6 minutes [23]. This test has been validated as a measure of functional mobility following joint arthroplasty [28]. The test was performed in a 30.5-m hallway and the total distance covered, in meters, was recorded. The FAB is a validated tool measuring static and dynamic postural control in older adults, consisting of 10 individually scored items [29]. The FAB scale has been shown to be highly reliable, both in intra- and interrater reliability (0.92–1.00 and 0.91–0.95, respectively) [29].

To assess neuromuscular control and pelvic stability, participants performed a single limb standing task [30]. During the task, the patients' ability to maintain horizontal pelvic alignment during the task was assessed to approximate pelvic control during the single limb stance phase of gait [15]. Participants stood on one leg for up to 30 seconds and were videotaped. From each video, a still frame at 10 seconds into the task was created and imported into NIH Image J software (National Institutes of Health, Bethesda, Maryland) for analysis. Anatomical landmarks (bilateral anterior superior iliac spines, patella and sternum) were identified and marked using tools within the software. The coordinates of the landmarks were determined and pelvic tilt angle relative to horizontal was computed.

Maximal voluntary isometric contractions (MVIC) to assess muscle strength were performed using an electromechanical dynamometer (HUMAC NORM, CSMI Solutions, Stoughton, MA). Hip flexion and extension strength were assessed in supine at 40° of hip flexion, using a strap to stabilize the pelvis [31]. Hip abductor MVICs were performed in a side-lying position in 0° abduction/adduction and 0° flexion/extension using a strap to stabilize the pelvis [31, 32]. Knee extensor and flexor MVICs were performed seated in 85° of hip flexion and 60° of knee flexion [33, 34]. Data were sampled using a BiopacData Acquisition System (MP 150 Biodex Medical Systems, Inc., Shirley, NY) and analyzed using AcqKnowledge software, Version 3.8.2 (Biodex Medical Systems). All MVIC measurements were expressed in units of torque (Nm).

Participants were given visual targets from the dynamometer's output and strong verbal encouragement during each trial to maximize effort. MVICs were performed twice; a third trial was performed if maximal torque during the first two trials differed by more than 5%, as previously described [33, 35-37]. The trial with the highest torque was scaled to body mass (Nm/kg) and used in analysis [38]. In addition to the above outcomes, patient perceptions of physical function were captured with the Hip Dysfunction and Osteoarthritis Outcome Score (HOOS) questionnaire, assessing function in five subscales. Higher HOOS scores on each subscale indicate less disability [39].

V Statistical Methods

Sample size estimates were computed from preliminary stair climbing test data collected in our laboratory from 23 participants before and after THA. We estimated that enrolling 17 participants would yield 80% power with an α-level of 0.05 to detect an approximately 5 second difference in SCT time between groups. Anticipating a 20% drop-out rate, we enrolled 20 patients. The difference between groups was estimated using multiple linear regression models in which the change in outcomes from before to after intervention was regressed on baseline performance and group. Preoperative characteristics were compared using independent samples t-tests or chi-square test to evaluate equality between groups. All analyses were intention-to-treat comparisons. SAS version 9.3 (SAS Institute, Inc; Cary, NC) was used for all data analyses. An α-level of 0.05 was chosen to determine statistical significance.

Table 1: Baseline group demographic descriptions.

	NMR (n=10)	CON (n=10)	p-value
Age (years)	60.8 ± 7.6	63.0 ± 7.4	0.52
Height (cm)	170.1 ± 10.4	173.1 ± 7.6	0.46
Mass (kg)	86.2 ± 25.0	89.4 ± 20.1	0.76
BMI (kg/m2)	29.4 ± 6.6	29.6 ± 5.2	0.93
Men (%)	5 (50)	5 (50)	1.00
Women (%)	5 (50)	5 (50)	1.00

Data are mean ± standard deviation, BMI: body mass index.

Results

We assessed 227 patients for eligibility, and 120 were not eligible to participate. Thus, 23 participants were assessed preoperatively. Prior to randomization, one participant had an intraoperative complication and could not exercise, thus 22 participants were randomized. Two participants declined further participation after randomization. Therefore, 20 participants completed the study, 10 per group (Figure 1). There were no differences in age, height, weight, body mass index (BMI), sex, or baseline outcomes between groups (Tables 1 & 2).

Table 2: Preoperative Functional Performance and Strength Measures.

	NMR (N=10)	CON (N=10)	p-value
SCT* (s)	19.2 ± 10.9	20.4 ± 14.1	0.83
FTSTS (s)	21.3 ± 10.0	16.4 ± 6.3	0.21
TUG (s)	11.2 ± 3.1	12.5 ± 7.9	0.64
FAB	23.2 ± 4.6	25.7 ± 4.3	0.24
6MW (m)	366.1 ± 138.0	430.6 ± 170.4	0.37
4MW (s)	3.0 ± 0.9	2.9 ± 0.6	0.83
Pelvic tilt angle (degrees)	0.18 ± 6.74	0.16 ± 5.01	0.99
Surgical limb knee flexor strength (Nm/kg)	0.65 ± 0.22	0.64 ± 0.22	0.92
Surgical limb knee extensor strength (Nm/kg)	1.35 ± 0.63	1.52 ± 0.41	0.48
Surgical limb hip flexor strength (Nm/kg)	0.83 ± 0.46	0.99 ± 0.52	0.46
Surgical limb hip extensor strength (Nm/kg)	0.50 ± 0.21	0.90 ± 0.68	0.10
Surgical limb hip abductor strength (Nm/kg)	0.59 ± 0.32	0.65 ± 0.36	0.72
HOOS ADL	47.61 ± 16.51	57.35 ± 24.29	0.35
HOOS pain	40.31 ± 18.73	47.78 ± 22.17	0.46
HOOS QOL	22.66 ± 14.54	31.94 ± 18.87	0.27
HOOS SPR	27.34 ± 24.31	32.64 ± 19.96	0.63
HOOS Symptom	40.00 ± 23.90	57.22 ± 22.65	0.15

Data are mean ± standard deviation measure, SCT: Stair Climb Test, FTSTS: Five-time-sit-to-stand, TUG: Timed-up-and-go, 6MW: 6-minute walk, 4MW: 4-meter walk test, FAB: Fullerton Advanced Balance Scale, HOOS: Hip dysfunction and Osteoarthritis Outcome Score.
*Primary outcome.

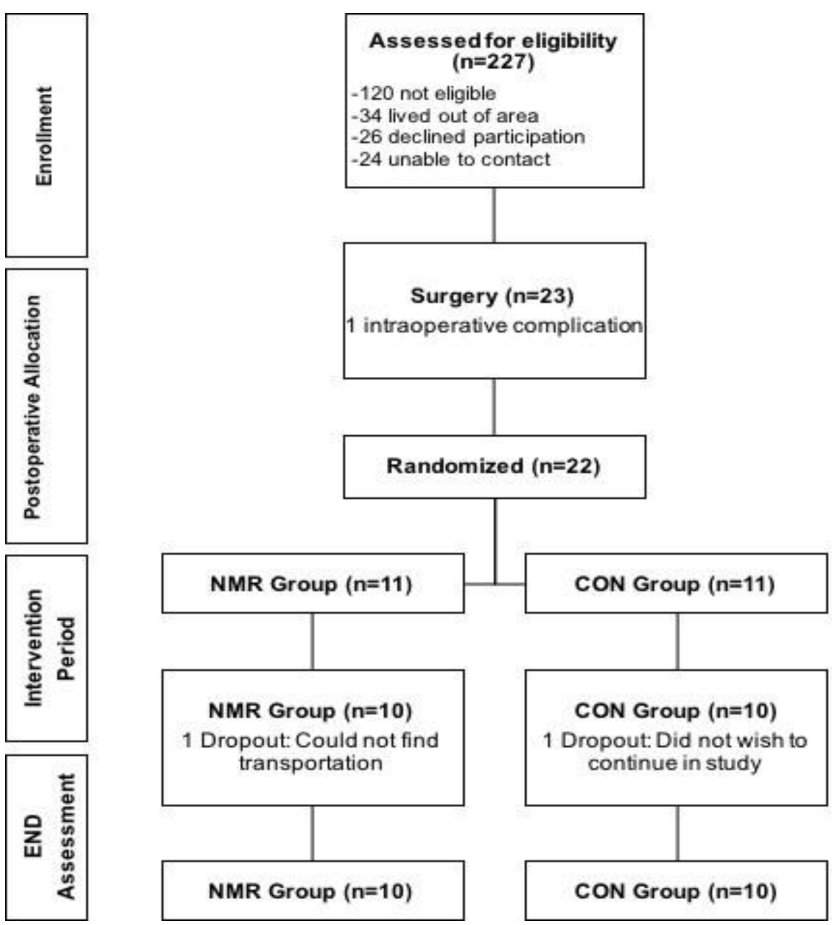

Figure 1: Participant enrolment flowchart.
NMR: Neuromuscular Reeducation Group; CON: Control Group.

I Functional Performance

Following intervention, significant differences in the change in each outcome measure from preoperative values existed in the NMR group for all functional performance measures, with the exception of the FTSTS and the TUG (Table 3). Additionally, the NMR group showed clinically important improvements in these functional performance measures compared to their preoperative values including an improvement above the cut-off score for determining fall risk [40, 41]. Conversely, the CON group did not improve functional performance significantly and did not improve by clinically meaningful levels in the stair climbing or walking tests, except for improvement in the TUG [42-45]. Additionally, the CON group had a 5% decline in performance on the FAB, and the group mean fell below the cutoff score for determining fall risk [41].

Table 3: Change in Functional Performance and Self-Reported Functional Outcomes.

	Change PRE-END				
	Control	**NMR**	**Between Group Difference**	**p -value**	**Effect Size†(Cohen's *d*)**
SCT (s)*	-1.59 ± 1.32	-5.90 ± 1.32	-4.31 ± 1.87	**0.03****	0.81
6MW (m)	36.48 ± 14.64	112.11 ± 14.64	75.63 ± 20.94	**0.002****	0.64
4MW (s)	-0.01 ± 0.09	-0.52 ± 0.08	-0.51 ± 0.12	**0.001****	1.08
FAB	-0.45 ± 0.77	3.60 ± 0.73	4.05 ± 1.09	**0.002****	0.81
FTSTS (s)	-5.88 ± 1.00	-7.33 ± 1.00	-1.45 ± 1.45	0.33	0.18
TUG (s)	-2.47 ± 0.57	-3.68 ± 0.57	-1.21 ± 0.81	0.15	0.66
Pelvic Tilt Angle (degrees)	-4.33 ± 5.77	-0.43 ± 5.12	3.9 ± 0.65	0.07	0.83
HOOS ADL	19.945 ± 3.600	35.835 ± 3.825	15.890 ± 5.329	**0.010****	1.12
HOOS pain	28.844 ± 3.515	44.425 ± 3.732	15.580 ± 5.173	**0.009****	1.27
HOOS QOL	25.120 ± 5.185	42.834 ± 5.513	17.714 ± 7.720	**0.04****	1.11
HOOS SPR	16.514 ± 9.244	28.297 ± 9.810	11.783 ± 13.533	0.40	0.54
HOOS Symptom	19.366 ± 4.386	33.213 ± 4.672	13.847 ± 6.633	0.06	0.64

Data are mean change ± standard deviation, SCT: Stair Climb Test, FTSTS: Five-time-sit-to-stand, TUG: Timed-up-and-go, 6MW: 6-minute walk, 4MW:4-meter walk test, FAB: Fullerton Advanced Balance Scale, HOOS: Hip dysfunction and Osteoarthritis Outcome Score.
*Primary outcome measure.
**indicates significant differences in change in outcome preoperatively to postoperatively ($P<0.05$) based on regression analysis.
†Effect size calculated from means and standard deviation in each group at the END time point.

Table 4: Changes in isometric Muscle Strength Outcomes.

	Change PRE-END				
	Control	**NMR**	**Between Group Difference**	**p-value**	**Effect Size†(Cohen's *d*)**
Normalized knee flexor strength (Nm/kg)	0.10 ± 0.06	0.12 ± 0.06	0.02 ± 0.09	0.82	0.11
Normalized knee extensor strength (Nm/kg)	-0.04 ± 0.10	0.26 ± 0.10	0.30 ± 0.15	0.06	0.35
Normalized hip flexor strength (Nm/kg)	-0.03 ± 0.06	0.08 ± 0.06	0.11 ± 0.09	0.22	0.18
Normalized hip extensor strength (Nm/kg)	0.05 ± 0.08	0.14 ± 0.08	0.10 ± 0.12	0.43	0.43
Normalized hip abductor strength (Nm/kg)	-0.01 ± 0.07	0.17 ± 0.07	0.17 ± 0.10	0.09	0.39

Data are mean change ± standard deviation.
* indicates significant differences in change in outcome preoperatively to postoperatively ($P<0.05$) based on regression analysis.
†Effect size calculated from means and standard deviation in each group at the END time point.

II Neuromuscular Control

There was a trend toward better stability of the pelvis during the single-limb stance task in the NMR compared to the CON group, however the difference was not statistically significant, despite the large effect size (Table 3).

III Isometric Muscle Strength

Differences in strength changes between groups were not observed. There tended to be greater improvements in the change in hip abductor strength and knee extensor strength in the NMR group compared with the CON group (Table 4), yet these differences were not significant.

IV Self-Reported Functional Outcomes

The NMR group had greater improvements in three of the five HOOS subscales (Table 3) compared to preoperative values. However, there were no differences in the change in the Sports and Recreation subscale or HOOS Symptom subscale.

Discussion

Rehabilitation is one modality to restore functional capacity after THA. Systematic reviews by Di Monaco and Castiglioni [1] and Minns-Lowe *et al.* concluded that rehabilitation could improve strength and functional outcomes following THA [46]. However, the variability in initiating rehabilitation and in prescribed exercise suggests uncertainty regarding the optimal type of exercise following THA [1]. The intervention used in this investigation was based on a conceptual framework for improving functional performance by optimizing neuromuscular control through lateral hip and pelvic muscle training combined with movement pattern retraining for patients post THA. Using this framework, we developed a novel post-THA rehabilitation protocol based on principles of neuromuscular reeducation to promote pelvic stability and femoropelvic alignment to improve functional performance. We proposed that by improving muscle performance to provide ideal pelvic stability and neuromuscular control, we would observe greater improvements in functional performance for patients after THA.

Outcomes in the NMR group provide preliminary support for our conceptual framework. First, findings trended toward improved pelvic stability during functional tasks for the NMR group. These differences did not reach statistical significance, despite the large effect size, and should be further investigated in a larger study. However, the measured pelvic drop angle during the single limb stance task tended to be greater in the CON group, indicating increased pelvic obliquity and larger hip adduction angle. This posture suggests an inability of the lateral hip musculature to stabilize the pelvis during the task which can have a negative effect on hip joint loading during gait, and is associated with a decrease in hip abductor moments, slower gait speeds, and observable gait deviations, such as a Trendelenburg-compensated gait pattern often seen after THA [6, 47]. Therefore, an improved ability to stabilize the pelvis could lead to better gait mechanics and could translate to gait speed and endurance, thus aiding overall functional performance.

Second, participants in the NMR group saw greater improvements in postural control measured by the Fullerton Advanced Balance Scale (FAB). Trudelle-Jackson *et al.* and Nallegowda *et al.* report that individuals demonstrate poorer postural control and postural stability up to 1 year after surgery, indicating that this is a persistent problem after THA [48, 49]. The role of the lateral hip musculature, in coordination with lumbopelvic complex, is to continually and instantaneously adapt to movement in order to maintain a stable base for functional activity [16]. However, when these muscles are compromised, compensatory movements, such as a Trendelenburg compensated gait pattern, negatively impacting functional performance are observed [14]. The neuromuscular reeducation techniques used in the intervention focused on training the lateral hip musculature to stabilize the pelvis and femur against external joint moments caused by movement, eliminating compensations by improving stability [16]. In conjunction with improvements in postural control, the NMR group also demonstrated greater change in their ability to climb stairs, and in their walking speed and endurance. Taken together, the combination of improved postural control and functional performance on stairs and walking supports our hypothesis that better stability and postural control, leads to improved functional performance.

Despite the greater improvements in some functional outcomes, there were no differences between groups in other functional outcomes, specifically the TUG and FTSTS. These tasks rely more on the contribution of bilateral lower extremities, potentially allowing individuals to use the non-operative limb to assist, thus, aiding performance, and improving recorded times on these outcomes. Without further kinetic analysis, it is difficult to differentiate whether this type movement compensation is occurring. Notably, the NMR group demonstrated greater improvements in more challenging tasks that have a greater unilateral focus, such as stair climbing and walking, suggesting that neuromuscular reeducation techniques may have a larger impact on these more difficult tasks. Specifically, the intervention included single-limb, closed-kinetic chain exercises to promote stability through muscle co-contraction around the hip during unilateral standing activity, such as is needed in gait [13]. Theoretically, this retraining contributed to improved performance on tasks which require strength and stability on one leg such as stair climbing and fast walking, rather than bilateral tasks.

Although this protocol yielded initial support for the conceptual framework, significant differences in changes in muscle strength between groups were not observed. By the end of the intervention period, both groups saw improvements in strength in most muscle groups. One explanation for this observation may be that the training in this protocol promoted a different role of this musculature than was measured with the current methods. Our chosen strength outcome, a one-time, open-chained, maximal contraction during isometric strength testing, represents a different demand on the muscle than the type of strength training the protocol provided. The training promoted a lower, but more persistent, motor activity required from these muscles to stabilize the pelvis, which may not translate to isometric strength changes. Despite this, the fact that significant differences were seen in functional performance measures and not muscle strength outcomes supports the idea that muscle strength, alone, may not optimize functional performance after THA. Due to the fact that some muscle strength differences approached significance, further study is needed.

Study Limitations

This study has limitations. First, the smaller sample size may have been too small to detect statistically significant differences between groups in strength and between group in neuromuscular control outcomes. Second, the intervention has multiple modes of therapeutic exercise, limiting the ability to determine which part of the intervention contributed most to the observed improvements. Lastly, all THA procedures were performed via posterolateral surgical approach, therefore, it is unknown if these findings apply to other surgical approaches to THA.

Conclusion

Often, adults decide to undergo THA to alleviate pain associated with hip osteoarthritis. However, the primary reasons that lead individuals to the final decision to have surgery are due to limitations in activities of daily living, work duties, and recreational activities, therefore it is prudent that rehabilitation meets patient needs [50]. Although THA surgery is successful in relieving pain, residual impairments in strength and functional performance may not restore individuals' full functional capacity. This investigation provides preliminary support for a rehabilitation protocol derived from a conceptual framework suggesting that improving muscle performance to provide ideal pelvic stability and neuromuscular control would lead to improvements in functional performance for patients after THA. Despite this, there are still questions to be answered regarding the efficacy of this protocol, as well as the mechanisms behind the observations. Therefore, this preliminary work has set the stage for future investigations, with larger samples sizes and longer follow-up, to explore whether neuromuscular reeducation training post-THA should be considered in clinical practice.

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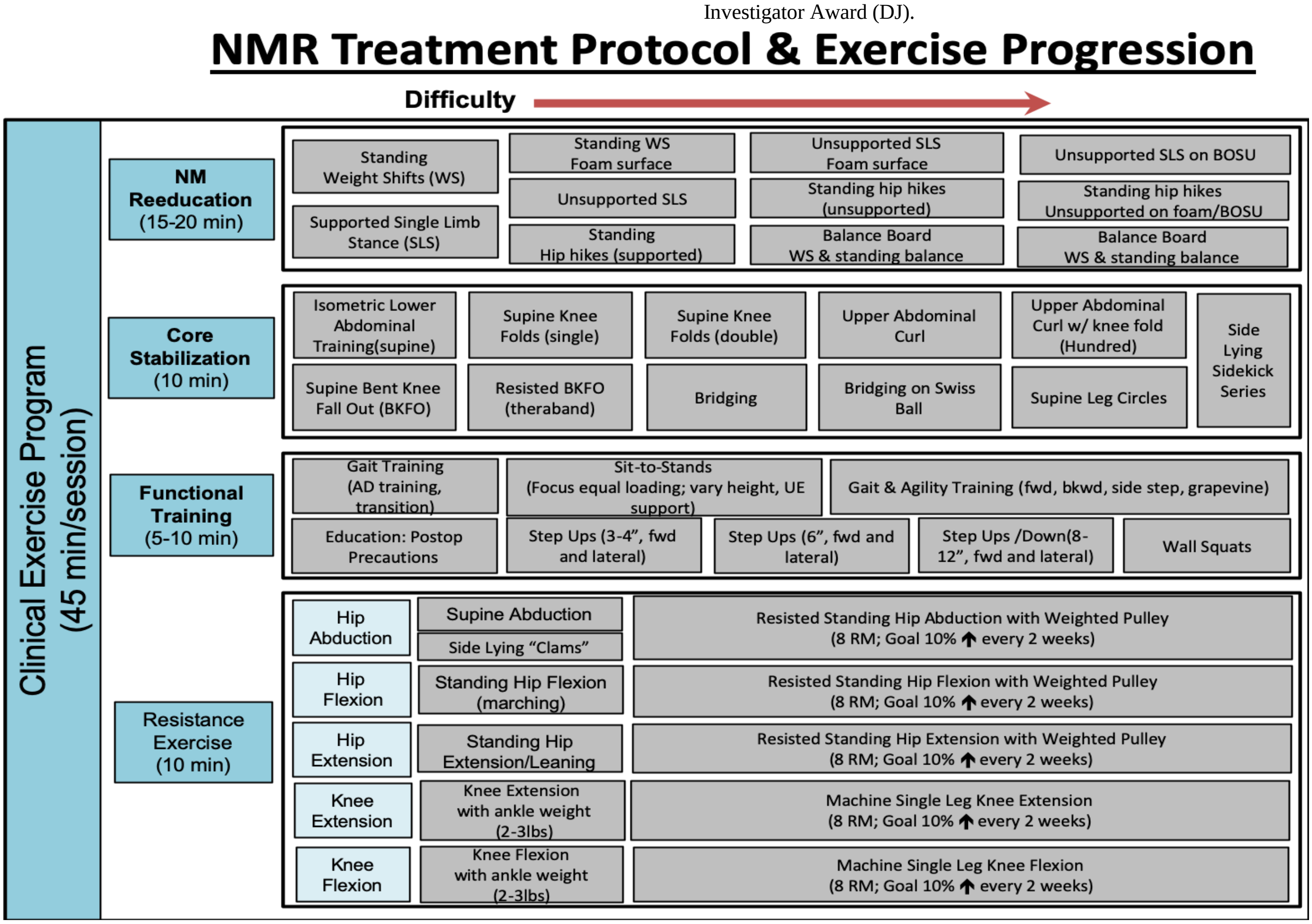

Appendix 1: Neuromuscular Reeducation (NMR) group exercise protocol details.

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