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Increased Muscle Strength Limits Postural Sway During Daily Living Activities in Total Hip Arthroplasty Patients

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Objective: The aim of the study was to investigate the effect of maximal strength training on postural sway after total hip arthroplasty, performed before and after a battery of physical performance tests that resemble daily living activities.

Design: This study is an exploratory study based on data from a 3-mo randomized controlled trial involving 54 total hip arthroplasty patients performing maximal strength training or conventional rehabilitation. At 3, 6, and 12 mos postoperatively, postural sway was evaluated in two gait tests; ie, one test before and one test after conducting a battery of physical performance tests.

Results: At 3 mos postoperatively, postural sway in the test after was significantly higher for the conventional rehabilitation group than the maximal strength training group ($P = 0.045$); however, there was no between-group difference at the test before ($P = 0.670$). Postural sway was also significantly higher in the test after compared with the test before in the conventional rehabilitation group ($P < 0.001$). No difference was found between the test before and test after in the maximal strength training group ($P = 0.713$). At 6 and 12 mos postoperatively, there were no statistically significant within- or between-group differences in postural sway.

Conclusions: Increased muscular strength limits postural sway 3 mos postoperatively in total hip arthroplasty patients after a demanding battery of physical performance tests simulating daily living activities.

Key Words: THA, Muscle Strength, Gait, Postural Stability

(*Am J Phys Med Rehabil* 2020;99:608–612)

Muscle strength is reduced in total hip arthroplasty (THA) patients preoperatively, mainly due to inactivity and pain, and it is further reduced after surgery and hospitalization.^{1,2} After THA, early improvements in gait pattern compared with preoperative levels are demonstrated; however, deficits remain at 1 yr postoperatively when compared with healthy individuals.³ The patients experience both weakness in the lower limbs and reduced physical function, quality of life, and activity levels many years after surgery.^{4–9} Although the patients intend to resume previous physical activities or start new physical

What Is Known

- Total hip arthroplasty (THA) patients experience several shortcomings compared with healthy subjects' years after surgery. Well-known deficiencies include reduced muscle strength, physical function, activity levels, and quality of life, whereas gait and postural stability have been less widely focused on. There is a lack of literature concerning postural sway and the concomitant role of muscle strength in postural stability.

What Is New

- This study demonstrates that walking in a rested condition does not challenge the THA patient's muscle capacity or, therefore, postural stability. However, after performing several demanding daily living activities, increased muscle strength limits postural sway.

activities postoperatively,¹⁰ they have considerably lower activity levels 1 yr postoperatively than those of healthy controls.¹¹ Muscle strength in the lower limbs of THA patients is related to factors such as pain, physical function, quality of life, and gait.^{12–17} Muscles surrounding the hip are also important for postural stability, and the surgical trauma during hip replacement affects these structures. In combination with reduced muscular strength, postural imbalance might therefore be expected.^{18,19} Leijendekkers et al.²⁰ found that muscle strength was significantly reduced after THA compared with muscle strength in healthy subjects and that postoperative trunk lateral flexion asymmetry during gait was evident and differed compared with healthy subjects.

It is important to start postoperative rehabilitation as soon as possible to prevent further muscle deterioration, as muscular strength and physical performance are important for maintaining an active lifestyle and managing daily living activities. It has been suggested that THA patients may benefit from rehabilitation that is more intensive, by focusing on strength symmetry through unilateral exercise to reduce gait asymmetry and fall

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The study was supported by a grant from the Liaison Committee between the Central Norway Regional Health Authority (RHA) and the Norwegian University of Science and Technology.

Financial disclosure statements have been obtained, and no conflicts of interest have been reported by the authors or by any individuals in control of the content of this article. Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.ajpmr.com).

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ISSN: 0894-9115

DOI: 10.1097/PHM.0000000000001382

risk in older adults.²¹ Studies focusing on intense interventions to efficiently restore muscle strength after THA demonstrate that maximal strength training (MST) is significantly more efficient compared with less intensive strength training.^{22,23} Previously, results demonstrating that MST increases muscle strength in the lower limbs considerably more than conventional rehabilitation (CR) in THA patients after a 3-mo rehabilitation program has been published.²³ The present exploratory study aimed to investigate the effect of MST on postural sway after THA, performed before and after a battery of physical performance tests that resemble daily living activities.

METHODS

Design

The study is an exploratory study based on previously unpublished data from a prospective randomized controlled trial in which patients were operated on by the posterior approach and randomly assigned to receive different postoperative rehabilitation interventions, either MST or CR.²³ The rehabilitation period lasted for 3 mos and was conducted at municipality physiotherapy institutes. The MST consisted of leg press and abduction performed by the operated leg. The patients exercised 3 days a week while being supervised by a physiotherapist in one-to-one sessions involving performing 4–5 repetitions \times 4 series with a load equal to 85%–95% of one-repetition maximum. The patients in the CR group received conventional physiotherapy, consisting of different types of strength exercises with low or no external load (10–20 repetitions). Warm-up exercises were mainly cycling, step, and treadmill walking. Other workouts used were aquatic exercises, balance training, range-of-motion exercises, massage, and sling exercises. The main findings from the study by Winther et al.²³ demonstrated that the MST patients became 25%–50% stronger regarding leg press and abduction than the CR patients 3 and 6 mos postoperatively ($P \leq 0.002$).

Outcomes and Measurements

As a follow-up from study by Winther et al.,²³ the primary outcome in the present study was postural sway in the test before (TB) and test after (TA) conducting a battery of individually validated physical performance tests that resemble daily living activities (to assess postural sway in a rested condition and in a tired condition, respectively) at 3, 6, and 12 mos postoperatively. In a standardized order, the patients performed a series of tests, which were managed by 2 nonblinded experienced physiologists at St. Olavs University Hospital. First, an initial walking test (the TB) was conducted as each patient walked back and forth along a 5-m OptoGait walkway, a floor-based photocell system with a validated electronic walkway system for movement analysis (Microgate Bolzano, Italy),

at a preferred self-selected speed. The system was equipped with optical sensors working at a frequency of 1000 Hz with an accuracy of 1 cm, detecting the relevant space and time parameters to assess gait. Body sway was assessed using a validated body-worn inertial measurement tool (Gyko Inertial System; Microgate, Bolzano, Italy) placed in a belt at the lower back, as described by the manufacturer. Body sway is defined by the area of the ellipse covering 95% of the trajectory points resulting from anteroposterior and mediolateral movements; the larger the ellipse, the more sway the subject has. Thereafter, the patient performed the battery of physical performance tests, which consisted of endurance and strength exercises (a 6-min walking test in which they walked as far as possible, followed by maximal strength tests [one-repetition maximum] of the hip and knee extensors and hip abductors). Finally, a second walking test in the walkway was conducted (the TA). The testing procedure is illustrated in Figure 1.

Inclusion Criteria

The inclusion criteria were as follows: diagnosis of primary hip osteoarthritis as the main cause for elective THA, scheduled for THA at the Orthopedic Department of St. Olavs University Hospital, Norway, and resided near the hospital.

Exclusion Criteria

Before study participation, an orthopedic surgeon assessed the patients for eligibility. The exclusion criteria were as follows: severe hip osteoarthritis of the contralateral hip, not fully recovered from a previous THA, or any illness/disease that could influence the ability to accomplish training and/or physical testing performance, such as muscular diseases, rest symptoms from stroke, and paralysis of the peroneus muscles.

Subjects

A total of 60 patients were included in a previously published prospective controlled trial, in which sample size calculation and patient enrollment are further described.²³ The randomization was concealed by using a web-based service provided by the research department at the university. A total of 54 patients, 27 in the MST group and 27 in the CR group, completed the 3-mo intervention and were eligible to participate in the present explorative study. Because of technical problems related to computer failure at the 3-mo follow-up, only 21 and 18 patients in the MST and CR groups, respectively, had their 3-mo data analyzed. Flow chart of patients is presented in Figure 2. Descriptive statistics of the demographic variables of the patients are presented in Table 1.

Ethics Considerations

The study was approved by the regional ethics committee (2010/3373) and conducted in accordance with the Declaration

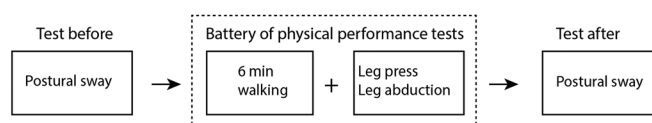


FIGURE 1. Testing procedure at 3-, 6-, and 12-mo follow-up; the TB and TA conducting the battery of physical performance tests.

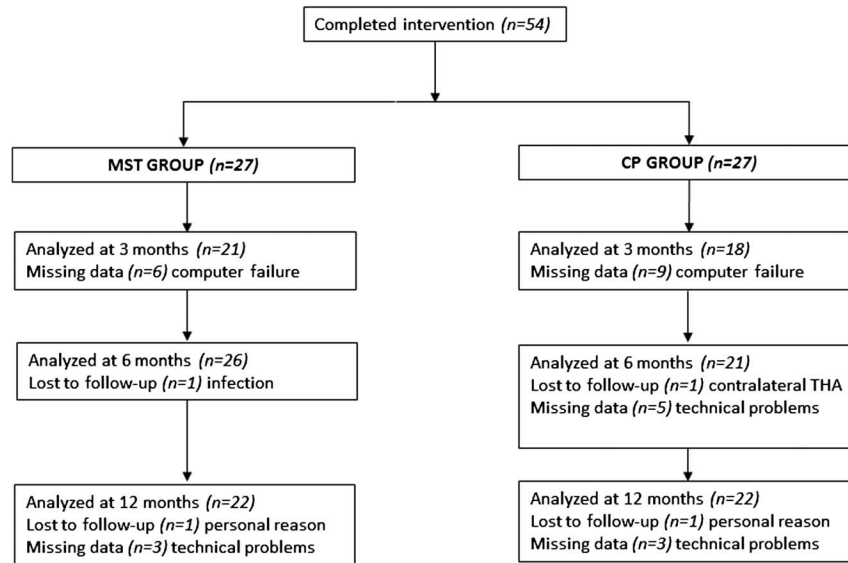


FIGURE 2. Patient follow-up in the MST and CR group.

of Helsinki. All patients provided written informed consent before study participation. The study was registered at ClinicalTrials.gov (NCT02498093). The study conforms to all CONSORT guidelines and reports the required information accordingly (see Supplemental Checklist, Supplemental Digital Content 1, <http://links.lww.com/PHM/A941>).

Statistical Analyses

A general linear mixed model was used to analyze body sway. The measurement variable was log transformed to achieve normality of residuals. Histograms were used to verify normality of model residuals. Age and sex were used as covariates in the analysis to correct for baseline group differences. The statistical model used group, time, and test number as fixed factors and included a random subject intercept. Interaction terms were used to obtain group comparisons for different tests at given time points. Sequential Bonferroni correction was used to adjust for multiple comparisons. Figure 3 shows the model estimates, adjusted for covariates. Statistical analyses were performed using the software package IBM SPSS Statistics for Windows Version 25 (IBM Corp, Armonk, NY).

RESULTS

Postural Sway

At 3 mos postoperatively, postural sway in the TA was significantly higher in the CR group compared with the MST group ($P = 0.045$). At 6 and 12 mos postoperatively, no between-group differences were found ($P > 0.312$; Fig. 3).

At 3 mos postoperatively, postural sway in the TA was significantly higher compared with that in the TB in the CR group ($P < 0.001$). However, there was no difference in postural sway between the TB and TA in the MST group ($P = 0.713$). At 6 and 12 mos postoperatively, no within-group differences in postural sway were found ($P > 0.095$; Fig. 3). Postural sway significantly decreased from 3 and 6 mos to 12 mos, in both the MST group ($P < 0.003$) and the CR group ($P < 0.006$).

Gait Parameters

All patients had a higher preferred speed in the 5-m walkway in the TA compared with the TB ($P < 0.001$). At 6 mos postoperatively, the CR group walked at a higher speed at the TB compared with the MST group ($P = 0.021$), but there were no between-group differences in speed at the 3- or 12-mo follow-up points ($P > 0.085$). Step length was not different between the groups at any follow-up point ($P > 0.132$). An overview of the speed and step lengths is presented in Table 2.

DISCUSSION

After the completed 3-mo intervention period, at the 3-mo follow-up, postural sway during walking was significantly higher in the CR group compared with the MST group after the battery of physical performance tests. Patients in the CR group also had significantly more postural sway after, compared with before, the battery of physical performance tests, whereas no such difference was found in the MST group. At 6 and 12 mos postoperatively, no between- or within-group differences in postural sway were found.

We anticipated that only walking back and forth along a 5-m walkway does not appreciably challenge muscles in the lower limbs. Therefore, the patients first performed one walking test in a rested condition (the TB) and then, to resemble daily living activities, the patients performed a battery of physical performance tests and were tested again in the walkway in a tired condition (the TA; Fig. 1). The battery of physical performance tests consisted of a 6-min walking test and two maximal strength tests of the lower limbs (leg press and abduction).

TABLE 1. Patient characteristics in the MST group and the CR group

		Female/Male	Age, Mean	BMI, Mean
Group	MST	14/13	60	28
	CR	12/15	66	27

BMI, body mass index.

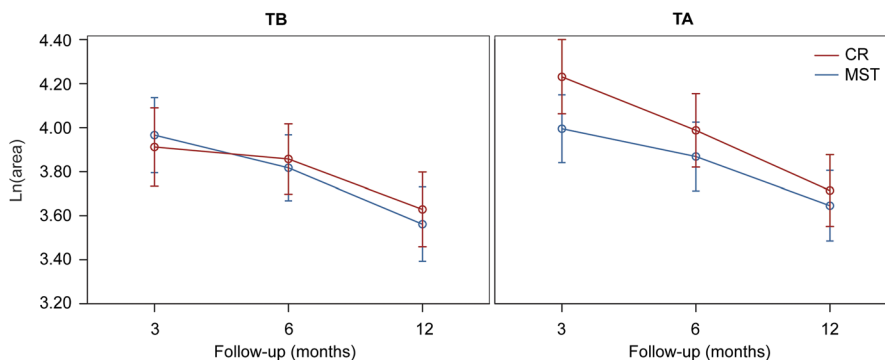


FIGURE 3. Postural sway in the MST group and CR group at the TB and TA conducting the battery of physical performance tests. Model estimate with 95% confidence intervals.

These tests resemble daily living activities, such as walking, stair climbing, squat, and lifting. The results from the present study demonstrate that THA patients walking at a preferable speed in a horizontal walkway for 10 m does not seem to challenge the leg muscular capacity or strength, as there was no between-group difference in postural sway when the patients were in a rested state. However, at 3 mos postoperatively, after performing the physically demanding activities in the battery of physical performance tests, the muscular shortcomings seem to manifest, as the CR group had a significantly larger postural sway compared with the postural sway for both the CR group's TB and the MST group's TA. As previously demonstrated, the MST group was significantly stronger than the CR group after the intervention period.²³ Therefore, it is likely that the demanding battery of physical performance tests did not affect the MST patients' muscular strength and subsequent postural stability, as it did in the CR group. Previous research demonstrated a relationship between muscle strength and both postural stability and limping in THA patients.^{12,13,15,24} For example, Horstmann et al.¹⁵ demonstrated that limping was related to muscle strength, not pain, and their results are supported by the findings from Gomi et al.²⁵ who demonstrate that gait abnormality persisted 3 mos postoperatively despite a pain-free hip, and Colgan et al.²⁶ who demonstrated that pain, functional ability, and range of motion significantly improved postoperatively, although this did not result in improved gait. In contrast, Rasch et al.²⁷ found that a pain-free hip with muscular weakness and atrophy resulted in absence of limping 6 mos postoperatively and concluded that joint pain is a more important factor than hip abductor strength for inducing limp. They did not find any improvement in static postural sway after THA and concluded that it does not seem to be a clinically important impairment of postural stability due to hip osteoarthritis before or after THA.²⁷ Rasch et al.²⁷ assessed sway by unilateral standing and not during walking as in the present study. This might explain their results as postural sway during unilateral standing probably relates to several other factors, in addition to muscle strength.

In the present study, there was no healthy age-matched control group to define normative data on muscle strength or gait parameters. However, others have found that THA patients are significantly weaker and have differences regarding gait symmetry compared with healthy subjects.^{20,28} Rapp et al.²⁸ found that THA patients had improved gait symmetry after an intensive rehabilitation program, but they were still impaired

1 mo postoperatively compared with healthy control subjects. It is reasonable to anticipate that just 1 mo of rehabilitation, as demonstrated in the study by Rapp et al.²⁸ was too short a time to restore muscle strength and gait symmetry. Based on findings from the present study, in which the MST group that underwent 3 mos of intensive MST had significantly higher strength with less postural sway than the CR group, it can be speculated that the prolonged intensive MST period may have mitigated the strength deficits and concomitant postural sway that is frequently seen in THA patients when compared with healthy age-matched subjects.

All patients in the present study were operated on by the posterior approach. Although it has been reported less pain, narcotic consumption, and higher Harris hip score in patients operated on with the anterior approach,²⁹ the posterior approach induces only minor muscular trauma and has the least impact on muscle strength and postural parameters the first 2 postoperative months.^{19,30} This might explain why there was no between-group difference in postural sway in the TB, as both groups were relatively fit and highly capable of performing the less demanding physical test (i.e., walking at a preferable speed in a walkway in a rested condition). However, in the TA, postural sway was higher in the CR group, which had lower muscular strength in the operated leg than in the MST group. The TA probably induced greater demands on the muscle capacity, as the test was performed immediately after a demanding battery of physical performance tests. At the 6-mo follow-up, 3 mos after the training intervention was completed, the MST group was still significantly stronger than the CR group,²³ but there was no difference in postural sway. It should be noted that muscle strength in the MST group decreased after the MST intervention period was completed, whereas muscle strength in the CR group increased after the CR intervention period. At the 12-mo follow-up, there was no difference in

TABLE 2. Gait parameters at each follow-up point in the MST group and the CR group

	Group	Follow-up		
		3 mos	6 mos	12 mos
Step, cm	MST	69.4	69.7	71.6
	CR	69.0	71.4	72.5
Speed, m/sec	MST	1.32	1.33	1.38
	CR	1.30	1.38	1.42

muscle strength between the groups.²³ From 3 and 6 to 12 mos postoperatively, postural sway significantly decreased in both groups, as the patients recovered, and the overall physical fitness increased. Postural sway was found to be significantly higher in the CR group at the 3-mo follow-up, when the muscle strength difference was at its highest. In addition, when the between-group difference in muscle strength decreased at the 6-mo follow-up and was absent at the 12-mo follow-up, no difference in postural sway was found. This might indicate that muscle strength plays an important role in preventing postural sway. It has previously been found that despite good to excellent clinical functional outcomes among THA patients operated on by the posterior approach and provided with CR, gait does not return to normal within 1 yr postoperatively.³¹

It has been demonstrated that gait asymmetry increases with increased speed.²¹ In contrast, Leijendekkers et al.²⁰ found that increased walking speed in THA patients did not result in increased asymmetries in gait kinematics and kinetics. Their findings might be explained by the findings from Lee et al.³² who demonstrated that a larger sway is associated with increased gait velocity in those with a clinical normal gait but not in those with abnormal gait pattern, and that the relationship between trunk sway and gait velocity differs depending on whether gait is clinically normal. At 3 mos postoperatively in the present study, both groups had significantly increased preferable speed in the 5-m walkway during the TA compared with the TB. However, although the speed increased in both groups, postural sway only increased in the CR. This might be a result of the greater muscle strength in the MST group, which probably helped stabilize the trunk as the speed increased. At 6 mos postoperatively, the CR group walked at a higher speed in the TB compared with the MST group, but no difference in postural sway was found. As discussed earlier, during the TB, the muscles are not appreciably challenged, and as the patients walked at their preferable self-selected speed, the observed difference is most likely caused by other factors than muscle strength. Established preoperative gait patterns may also affect postoperative walking, and we do not know whether a difference in walking speed between the groups existed preoperatively. There were no other between-group differences in speed or step length at any follow-up points.

This explorative study has some limitations that should be considered. The sample size was not based on the primary outcome from the present study, we did not have any preoperative gait data, and there were technical problems during the follow-ups that resulted in some missing data. The dropouts occurred randomly in both groups, resulting in a smaller sample size than planned; however, statistically significant differences in postural sway were revealed. This might indicate that the study was underpowered to reveal other potential gait differences between the groups. Because of the explorative design, the results should be interpreted as hypothesis generating rather than conclusive findings.

The results from the present explorative study indicate that when demanding exercises that resemble daily living activities are conducted, improved muscle strength might limit postural sway in THA patients.

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