Original Scientific Article
Acta Medica Academica 2026
DOI: 10.5644/ama2006-124.512

Effects of Anti-Gravity Treadmill Training on Functional Outcomes After Total Hip Arthroplasty: A Randomized Controlled Trial

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Received: 2 January 2026; **Accepted:** 19 May 2026

Abstract

Objective. Total hip arthroplasty is one of the most common orthopedic procedures. When the surgery is successful and followed by high-quality physiotherapy, the patients' quality of life usually improves. This randomized controlled trial aimed to investigate the impact of anti-gravity treadmills on functional outcomes after total hip arthroplasty. **Materials and Methods.** The trial was conducted at the Special Hospital for Medical Rehabilitation of Heart, Lung, and Rheumatic Diseases Thalassotherapia Opatija. The sample consisted of patients admitted for inpatient rehabilitation three months after total hip arthroplasty. A total of 34 subjects were randomly assigned to two groups: an experimental group (N=18) and a control group (N=16). The outcome measures included abductor muscle strength, range of motion, numeric pain rating scale, Timed Up and Go test, and 40-meter Fast-Paced Walk test. **Results.** A statistically significant between-group difference was observed only for hip abduction range of motion, favoring the experimental group (P=0.044). The other measured variables did not show any statistically significant intergroup differences. **Conclusions.** Anti-gravity treadmill training improved hip abduction range of motion but did not demonstrate superiority over conventional rehabilitation in the other assessed functional outcomes.

Key Words: Arthroplasty ▪ Hip ▪ Anti-Gravity Treadmill ▪ Muscle Strength ▪ Pain ▪ Functional Mobility.

Introduction

Total hip arthroplasty (THA) is one of the most common orthopedic procedures. When the surgery is successful and followed by high-quality physiotherapy, patients' quality of life usually improves, and they return to their daily activities more quickly. However, even with proper bone healing and rehabilitation, some patients continue to experience functional limitations and pain. The most common factors are hip muscle weakness, calf muscle weakness, trochanteric bursitis, and anterior knee pain. Among these, hip abductor muscle weakness (1) is the most prevalent and often results in limping, impaired balance, and an increased risk of falling (2). Studies have shown that up to 40% of people over the age of 65 experience at least one fall annually following total hip or knee replacement surgery (3). Although hip replacement surgery is a common and often routine procedure, rehabilitation does not always progress smoothly. Rehabilitation methods and medical equipment are constantly evolving to accelerate functional improvement.

An anti-gravity treadmill (AT) allows exercise with reduced body weight using an airtight chamber to decrease the effects of gravity. The AT enables patients to exercise with minimal stress on the joints, making it possible to reduce pain and enhance muscle strength and cardiopulmonary endurance (4). Mikami et al. demonstrated that gait training with the AT had a positive effect on muscle strength, walking endurance, distance walked, oxygen consumption, and patients' perception of their ability to perform tasks independently (5). In another study, the same authors compared traditional rehabilitation with programs that incorporated AT and found improvements in muscle strength, pain reduction, and functional mobility following total hip arthroplasty (6). Overall, AT has been shown to have a positive effect on muscle strength and endurance, pain levels, range of motion, oxygen consumption, and mobility. Despite its potential, research on the role of AT in physiotherapy remains limited, partly due to the high cost of the equipment, which restricts its widespread use.

Our study aimed to investigate the impact of the AT on hip abductor muscle strength as the primary outcome. The secondary outcomes included hip joint range of motion, pain, and functional mobility at three months after THA.

Materials and Methods

The study was conducted between January and June 2023 at the Special Hospital for Medical Rehabilitation of Heart, Lung, and Rheumatic Diseases Thalassotherapia Opatija, Croatia. The study protocol was approved by the appropriate institutional ethics committee, and all participants provided written informed consent prior to inclusion in the study (Approval No.01-000-00-63/2-2023).

Initially, 42 participants were assessed for eligibility, and 34 completed the study protocol. The detailed completed CONSORT 2010 flow diagram was assessed in relation to the criteria and is presented in Supplement 1. Eligible participants included adults of all ages and both sexes who underwent THA using the classic cemented lateral surgical approach. The classic lateral approach to THA is a technique consisting of a longitudinal incision and the partial dissection of the gluteus medius and minimus muscles (7).

The exclusion criteria were as follows: revision hip replacement, acute illness, cognitive impairment, and declining participation in the study. All participants began rehabilitation three months post-surgery. Conducting the study before the third month post-surgery was neither technically nor organizationally feasible, as rehabilitation took place in a state-owned inpatient facility, which constrained us to the administrative framework of the public healthcare system.

Patients were randomly assigned to one of two groups: the experimental group (EG) (N=18) received AT therapy in combination with a standard rehabilitation protocol, and the control group (CG) (N=16) followed only the conventional rehabilitation protocol. Randomization was conducted using sealed envelopes labeled "A" and "B." Envelopes marked "A" corresponded to the EG, while "B" indicated the CG. Randomization was performed by an individual who was not involved in any other aspect of the study. The allocation sequence was concealed from the investigators involved in participant recruitment and assessment.

Sample Size Estimation

A dual approach was employed to determine the sample size for this study. First, we considered the number of participants reported in similar studies (5, 8, 9). Second, a power analysis was performed with a significance level of $\alpha=0.05$ and $\beta=0.20$. Assuming a 5-point difference in abductor strength between groups (10), a standard deviation of 4 points, and a ratio between groups of 1. The calculated sample size was 11 participants per group. We enrolled additional participants to ensure an adequate sample size at the end of the study.

Study Design and Interventions

This was a single-center, open-label study conducted in accordance with the Consolidated Standards of Reporting Trials (CONSORT) guidelines (11). No blinding of participants, therapists, or outcome assessors was performed. Both groups received the same core physiotherapy interventions. Each session included 25 minutes of individualized therapeutic exercises focused on breathing, mobility, strength, and balance. In addition, the participants received 25 min of electrical stimulation of the quadriceps femoris muscle and 25 min of hydrotherapy in a swimming pool, for a total of 75 min of therapy per session. The EG also completed 20 min of daily exercise on an AT (ALTERG VIA, Lifeward CA, Inc., Milmont Drive, Fremont, CA, USA), supervised by a physiotherapist, resulting in a total session duration of 95 min.

All participants were enrolled in a standardized physical therapy program prescribed by a specialist physician and provided through the public health system, which could not be modified; therefore, the anti-gravity treadmill could only be applied as an additional intervention. AT training involved walking in a straight line at a self-selected, comfortable pace—without running, shortness of breath, or pain. The treadmill chamber was set to reduce the effective body weight of the participants to 20% of their actual body weight (slight unloading was applied to reduce the need for handrail support and prevent the use of compensatory mechanisms). This level of body weight support was selected based on clinical considerations to ensure patient safety and tolerance, while minimizing compensatory movement patterns during gait. This level of unloading was considered sufficient to reduce joint loading without substantially altering normal movement mechanics. Given the lack of clear consensus in the literature regarding the optimal degree of unloading, this parameter was chosen as a pragmatic and clinically applicable setting. The determination of training duration and load was guided by the recognition that functional capacity varies among patients at three months postoperatively. Based on extensive clinical experience with orthopaedic patients, the training load was set at a level that participants could tolerate without using compensatory biomechanical mechanisms, such as limping. Both groups underwent therapy daily for three weeks (a total of 15 sessions). Follow-up evaluations were conducted at two time points: baseline and after three weeks (end of therapy).

Outcome Measures

The range of motion (ROM) of the hip joint was assessed using a two-arm goniometer. The measurements included active hip flexion with the knee flexed and active hip abduction. Two physical therapists performed the measurements. Hip abductor strength was measured using a Cybex isokinetic device (HumacNorm, 2009 model) following a standardized protocol (12). The highest recorded peak torque value was used for the analysis (13).

The Numeric Pain Rating Scale (NPRS) was used to assess subjective *pain intensity*. According to Jensen et al. (14), the NPRS categorizes pain intensity as follows: 0 indicates no pain; 1–3, mild pain; 4–6, moderate pain; and 7–10, severe pain.

The Timed Up and Go Test (TUG) measures the time taken by a patient to stand up from a chair, walk 3 meters, turn around, walk back, and sit down. According to Steffen et al. (15), healthy individuals aged 60 to 80 years typically complete the TUG in 10 seconds or less. Barry et al. (16) suggested that a time greater than 13.5 seconds indicates reduced functional mobility and a higher risk of falls.

The 40-Meter Fast-Paced Walk Test (40 mFPWT) evaluates the time required for a patient to walk a 10-meter section as quickly (but safely) as possible, turn around, return to the starting point, and repeat the sequence. Kennedy et al. (17) recommend a performance benchmark of approximately 0.90 seconds per meter for individuals following hip or knee arthroplasty.

Statistical Analysis

Frequencies and relative frequencies were presented for the demographic variables. The normality of the distribution of numerical variables was analyzed using the Kolmogorov-Smirnov test. Numerical variables are presented as medians and interquartile ranges (IQR) and were compared between independent groups using the Mann–Whitney U test due to the non-normal distribution of the variables. Effect sizes were calculated as point-biserial correlations. Categorical variables were compared between groups using Fisher's exact test. Data entry and processing were performed using Microsoft Office Excel 2016 and Statistica (version 13.5.0.17, 1984-2018 TIBCO Software Inc.). We have calculated the sample size with MedCalc Statistical Software version 16.2.1 (MedCalc Software bvba, Ostend, Belgium; https://www.medcalc.org; 2016). All statistical tests were performed at a significance level of P<0.05. Given the number of outcomes assessed, no formal adjustment for multiple comparisons was applied. Therefore, the results should be interpreted with caution due to the potential risk of type I errors.

Results

The analysis was conducted on participants who completed the study protocol. The demographic characteristics of the patients are presented in Table 1. A total of 34 patients participated in the study, with 18 and 16 assigned to the EG and CG, respectively. The groups did not differ significantly in terms of age, sex, or the frequency of right versus left hip operations, as is also shown in Table 1.

Significant longitudinal improvements from before to after rehabilitation were observed within both the experimental and control groups individually in: abductor muscle strength (EG-P<0.001, CG-P<0.001), hip joint flexion with the knee bent (EG-P<0.001, CG-P=0.002), hip joint abduction (EG-P<0.001, CG-P=0.002), TUG test (EG-P<0.001, CG-P<0.001), and 40mFPWT (EG-P<0.001, CG-P<0.001).

Table 1. Baseline Demographic and Clinical Characteristics of Participants

Variables	Experimental group	Control group	P
Age			
Median (P25–P75)	60.5 (54.0-70.0)	63.0 (56.0-70.0)	0.593*
Gender			
Female (N; %)	8 (45)	10 (62)	0.240†
Male (N; %)	10 (55)	6 (38)	
The operated side			
Left side (N; %)	7 (38)	6 (38)	0.607†
Right side (N; %	11 (62)	10 (62)	

*Mann-Whitney U Test; †Fisher's exact test.

Table 2. Between-group Comparisons of Hip Abductor Muscle Strength Before and After Rehabilitation

Strength of abductors (Nm*)	Median (P25–P75)	MWU test†(P)	Effect size (r_{pb}‡)
Before rehabilitation			
Experimental group	23.0 (11.0-30.0)	129.5	0.10
Control group	25.0 (10.5-36.0)	0.629*	
After rehabilitation			
Experimental group	34.5 (23.0-46.0	126.5	0.12
Control group	35.0 (16.0-47.0)	0.558*	

*Newton meter; †Mann-Whitney U test; ‡Point-biserial correlation coefficient.

The results of the between-group comparisons of hip abductor muscle strength before and after rehabilitation are presented in Table 2.

Although both groups showed an increase in median strength after rehabilitation, the differences between the experimental and control groups remained statistically non-significant (P>0.05).

The results of the between-group comparisons of hip joint flexion range of motion before and after rehabilitation are presented in Table 3.

Both groups demonstrated an increase in median knee flexion angles after rehabilitation, the differences between the experimental and control groups remained statistically non-significant (P>0.05).

Hip joint abduction range of motion comparisons are presented in Table 4. No significant difference was observed between the groups prior to rehabilitation (P=0.162); however, a statistically

Table 3. Between-Group Comparisons of hip Joint Flexion Range of Motion Before and After rehabilitation

Flexion with bent knee (°)	Median (P25–P75)	MWU test* (P)	Effect size (r_{pb}†)
Before rehabilitation			
Experimental group	90.0 (80.0-100.0)	141.5	0.01
Control group	90.0 (77.5-100.0)	0.945	
After rehabilitation			
Experimental group	100.0 (90.0-110.0)	132.5	0.07
Control group	95.0 (90.0-107.5)	0.704	

*Mann-Whitney U test; †Point-biserial correlation coefficient.

Table 4. Between-Group Comparisons of Hip Joint Abduction Range of Motion Before and After Rehabilitation

Abduction in the hip joint (°)	Median (P25–P75)	MWU test* (P)	Effect size (r_{pb}†)
Before			
Experimental group	22.5 (15.0-30.0)	103.0	0.28
Control group	17.5 (12.5-25.0)	0.162	
After			
Experimental group	32.5 (25.0-40.0)	85.0	0.40
Control group	25.0 (17.5-30.0)	0.044	

*Mann-Whitney U test; †Point-biserial correlation coefficient.

significant difference was observed after rehabilitation (P=0.044), with a medium effect size (r_{pb}=0.40).

The results regarding pain before and after rehabilitation are shown in Table 5.

Table 5. Between-group Comparisons of Pain Intensity (Numeric Pain Rating Scale) Before and After Rehabilitation

NPRS (points)	C (25-75 percentile)	U (P*)	Effect size (r_{pb})
Before			
Experimental group	0.0 (0.0-1.0)	124.0	0.13
Control group	0.5 (0.0-2.5)	0.501	
After			
Experimental group	0.0 (0.0-1.0)	118.5	0.17
Control group	0.0 (0.0-1.0)	0.388	

C=Median; *Mann-Whitney U test; r_{pb}=Point-biserial correlation coefficient.

Pain intensity scores on the NPRS were low in both groups at baseline and showed no statistically significant differences between the experimental and control groups (P>0.05).

There was no statistically significant difference in functional mobility between the groups after rehabilitation (Table 6). No significant differences were observed in the TUG test results before and after rehabilitation.

Although the difference in TUG performance between groups did not reach statistical significance (P=0.051), this borderline result may still be clinically relevant. Given the small sample size, the study may have been underpowered to detect modest but meaningful differences in functional mobility. Prior to rehabilitation, three participants in the EG were at risk of falling (TUG score > 13.5 seconds), whereas no participants were at risk after rehabilitation.

Table 6. Between-Group Comparisons of Functional Mobility (Timed Up and Go Test) Before and After Rehabilitation

TUG (s)	C (25-75 percentile)	U (P*)	Effect size (r_{pb})
Before			
Experimental group	7.65 (6.74-9.05)	112.0	0.22
Control group	9.72 (6.75-10.95)	0.325	
After			
Experimental group	5.35 (5.03-6.70)	87.0	0.39
Control group	6.50 (5.30-8.30)	0.051	

C=Median; *Mann-Whitney U test; TUG=Timed Up and Go Test; r_{pb}=Point-biserial correlation coefficient.

The results showed no statistically significant difference in functional mobility between the groups, as measured by the 40 mFPWT, either before or after rehabilitation (Table 7).

Table 7. Between-Group Comparisons of Walking Performance (40-meter Fast-Paced Walk Test) Before and After Rehabilitation

40 m FPWT (s/m)	C (25-75 percentile)	U (P*)	Effect size (r_{pb})
Before			
Experimental group	0.76 (0.65-0.95)	102.0	0.29
Control group	0.84 (0.68-1.03)	0.152	
After			
Experimental group	0.63 (0.52-0.72)	99.0	0.31
Control group	0.68 (0.61-0.85)	0.125	

C=Median; *Mann-Whitney U test; r_{pb}=Point-biserial correlation coefficient.

Discussion

The results of this study showed no statistically significant differences between anti-gravity treadmill and conventional rehabilitation in tested variables, except for the hip joint abduction range of motion, although the experimental group received a longer total duration of therapy compared to the control group (95 vs. 75 minutes per session). However, when each group was analyzed individually, both showed statistically significant improvements in all tested variables, except for pain, after rehabilitation.

No significant differences in hip abductor muscle strength were observed between the EG and CG following rehabilitation. Kim et al. (18) have demonstrated the positive effects of AT training on lower extremity muscle strength following femoral fractures. In addition, patients who trained with the AT experienced significantly less postoperative decline in knee muscle strength than those who underwent conventional therapy (6). In contrast, Unlu et al. (19) and Trudelle et al. (20) reported that standard physiotherapy and postural stability exercises can significantly improve abductor strength (by 41.2%) and extensor strength (by 47.8%). The benefits of conventional rehabilitation, including strength, endurance, flexibility, gait, and balance training, three to five months and one year after THA, have also been confirmed by Heiberg et al. (21) and Nankaku et al. (22). No significant differences in hip abductor muscle strength may be attributed to the nature of the anti-gravity treadmill exercise, which reduces body weight load and creates a more relaxed training environment, thus potentially limiting the stimulus needed to build muscle strength.

This study also assessed the ROM of the hip joint. A significant increase in abduction ROM was found in favor of the EG (P=0.044), whereas no statistically significant difference was observed in hip flexion ROM between the groups (P=0.704). The statistically significant finding for hip joint abduction should be interpreted with caution, as multiple outcomes were tested, and no correction for multiple comparisons was applied. Currently, no studies have specifically examined the effect of AT training on hip flexion with the knee bent or in abduction. Evidence supports the positive impact of AT use on ROM in other parts of the musculoskeletal system, including improvements in the ankle following fractures, the knee following tibial plateau fractures and osteoarthritis, and joint mobility post-running injuries and partial knee arthroplasty (23-28).

No statistically significant differences were observed between the groups regarding pain. Notably, 50% of all participants reported no pain before or after rehabilitation, which may explain the modest reduction rate observed. This finding suggests a potential floor effect, limiting the sensitivity of the NPRS to detect differences between groups and reducing its usefulness as an outcome measure in this population. This may be related to the timing of rehabilitation onset, as participants entered the study three months after surgery, when pain levels were typically reduced. Contrary to our results, several studies have reported a reduction in pain following therapy using an AT (22, 29).

In the present study, functional mobility did not differ significantly between the groups after rehabilitation. These findings align with those of Mikami et al., who assessed the impact of AT use two weeks before and after THA in 44 patients and reported no significant group differences (6). However, other studies have identified the beneficial effects of AT training on mobility, functionality, and gait (25, 26, 30), although these effects were observed in the context of conservative management of injuries.

Limitations of the Study

This study has several limitations that should be considered when interpreting the findings. First, the relatively small sample size may have limited the ability to detect significant between-group differences. The open-label design, without blinding of participants, therapists, or assessors, introduces the possibility of performance and expectation bias. Expectation and performance bias cannot be excluded and may have affected internal validity. Although randomization was employed, the single-center design may limit generalizability and does not fully exclude the possibility of selection bias. Also, the presence of a floor effect in pain scores, together with the relatively late initiation of rehabilitation, may have affected both the sensitivity of outcome measures and the generalizability of the findings. Finally, we did not perform a sensitivity intention-to-treat analysis, which could potentially impact the findings.

Conclusions

Anti-gravity treadmill training, when added to standard rehabilitation, was associated with improvements in hip abduction range of motion following total hip arthroplasty, while no clear additional benefit was observed in other assessed outcomes compared with standard rehabilitation alone. Future research with larger samples, balanced treatment exposure, and varying levels of body weight support, including higher levels of unloading than those applied in this study, is needed to further clarify the role of anti-gravity treadmill training in postoperative rehabilitation.

What Is Already Known on This Topic:

To date, studies have examined the effects of anti-gravity treadmill rehabilitation in various clinical populations, including patients with neurological disorders, individuals following femoral fractures, and those with osteoarthritis. The results of these studies indicate the positive effects of AT training on functional mobility, gait, and reduction of lower limb loading. However, despite the available evidence supporting its use in these conditions, no studies have investigated the effects of AT training following THA. Furthermore, no study has compared rehabilitation outcomes using anti-gravity treadmill training with standard rehabilitation protocols in patients after THA.

What This Study Adds:

This study provides data on the effects of rehabilitation using an AT on functional outcomes in patients who have undergone THA compared with standard rehabilitation without the use of an AT. Outcome measures included range of motion in the hip joint, hip abductor muscle strength, the Timed Up and Go Test, the 40-Meter Fast-Paced Walk Test, and pain intensity. The rehabilitation program lasted for three weeks.

Authors' Contributions: Conception and design: ID, MV and BM; Acquisition, analysis and interpretation of data: SS, GSK, BM, KB, ID and HV; Drafting the article: MV, GSK, BM and ID; Revising it critically for important intellectual content: KB, GSK and HV; Approved final version of the manuscript: KB, MV and SS.

Conflict of Interest: The authors declare that they have no conflict of interest.

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