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ORIGINAL STUDY

Asymmetry and pelvic movements 6 months after total hip replacement Secondary analyses from a randomized controlled trial

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The aim was to investigate gait asymmetry and pelvic range of motion during walking and stair ascending after total hip replacement, and secondly to test whether these parameters were influenced by resistance training.

A consecutive sample of 32 patients within a randomized controlled trial (control versus exercise group) was included. Speed, asymmetry and pelvic range of motion (walk and stair test) and leg power were measured preoperative, 10weeks and 6 months postoperative.

Walking and stair ascending speed, leg power and pelvic movements (frontal plane) during walking increased to 6 months follow up (p<0.005). There were no significant changes in gait asymmetry or the remaining pelvic movements (p>0.05) and no between-group differences.

Pelvic movements in the frontal plane during walking increased after surgery. No changes occurred in gait asymmetry and pelvic movements 6 months after total hip replacement while leg power and speed during walking and stair ascending increased significantly.

Keywords : total hip arthroplasty ; gait ; rehabilitation ; muscle strength ; resistance training ; stair climbing.

INTRODUCTION

The gait pattern among patients with end-stage osteoarthritis scheduled for total hip replacement (THR) surgery is impaired with asymmetry and increased compensatory trunk movements compared to healthy controls *(5,20)*. Despite significant improvements after THR, evidence suggests that the gait pattern fails to normalize during the first year after surgery *(1)*. Furthermore, a recent systematic review reports that hip abduction moment deficit is present both in level walking and in stair ascent in THR patients compared to controls *(13)*. A meta-analysis concludes that walking velocity, stride length, hip abduction moment and hip range of motion (ROM) in the sagittal plane is reduced in THR patients compared to controls *(6)*. Reduced hip ROM in THR patients can lead to compensatory

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pelvic movements in order to achieve sufficient step length *(13)*.

The potential of using inertial measurement unit (IMU) to evaluate gait has been demonstrated in healthy subjects as well as after THR *(21,23)*. Gait asymmetry is highly associated with pathologies *(14,17)* and IMU based gait analysis can differentiate between normal and simulated limited walking *(21)* as well as between orthopaedic patients and healthy subjects *(12)*. The IMU has potential for use in functional tests other than walking, such as stair ascending *(12)*. Asymmetry in lower extremity muscle performance is associated with risk of falling and limping *(11,22)*. Muscle impairment measured as leg extension power has been shown to be closer related to functional performance than other strength measurements in elderly with functional limitations *(3)*.

The purpose of this study was 1) to investigate changes in gait asymmetry and pelvic ROM during maximal walking speed and stair ascending during the initial 6 months after THR, and 2) in an explorative analysis to test whether change in these parameters are influenced by 10 weeks of progressive resistance training. We hypothesized that gait asymmetry, pelvic ROM and interlimb difference in leg extension power would decrease after THR surgery.

METHODS

This paper reports results from secondary analyses from a single-blinded randomized controlled trial *(15)*. The data presented in the present paper have been collected in a consecutive sub-sample of patients within both randomization arms as an embedded mechanistic study which was pre-registered at ClinicalTrials.gov (NCT01214954).

MATERIAL

Between November 2011 and October 2012 we consecutively included THR patients as part of an ongoing randomized controlled trial reported separately *(15)*. Inclusion criteria were : Primary unilateral THR for hip osteoarthritis, preoperative hip dysfunction and osteoarthritis outcome score (HOOS) ADL subscale score ≤ 67, age > 18 years, residence within 30 km from the hospital and willing to participate in training twice a week for 10 weeks. Exclusion criteria were : Resurfacing hip implant, body mass index (BMI) >35, pre-planned supervised rehabilitation, pre-planned contralateral THR within 6 months, inability to speak or read Danish and mental or physical conditions impeding the intervention. Written informed consent was obtained from the patients and ethical approval was obtained from the Central Denmark Region Committee on Biomedical Research Ethics (VEK M-20090231) as well as the Danish Data Protection Agency (Journal number : 2010-41-4907).

Interventions

The peri-operative care as well as post-discharge rehabilitation was previously described *(15)*. In short, all patients followed a multimodal fast-track surgical program for THR with approximately 2 days of hospital admission. The surgery was performed by seven experienced orthopaedic surgeons using the posterior surgical approach. Patients were discharged to their home when meeting pre-defined functional discharge criteria, and two outpatient visits with a physiotherapist was offered to all patients (4 and 10 weeks after surgery). Prior to discharge patients were randomized (1:1) to either intervention or control group with different rehabilitation regimes.

Intervention group

In the intervention group patients performed progressive resistance training twice a week for 10 weeks initiated within the first week after surgery. The training was performed in a public fitness center with one-to-one supervision by physiotherapists from the hospital and consisted of : 30-40 minutes of unilateral resistance exercises (hip extension, knee extension/leg press, hip flexion and hip abduction) for the operated leg. The relative load increased during the 10 weeks from 10-12 repetition maximum (RM) to 8 RM. The absolute training load (kilograms lifted) was adjusted on a set-by-set basis for all exercises, using contraction to failure in every set. The remaining 5 days per week without supervised resistance training, the intervention group performed the same home-based exercises as in the control group.

Control group

The rehabilitation in the control group reflected standard care at the hospital and consisted of home-based exercises. The standardised exercise program consisted of unloaded exercises in the movement directions : hip flexion, -extension, -abduction and knee flexion/extension. Four weeks postoperative, the physiotherapist instructed the patients to perform the same exercises with a sports rubber band to increase the relative load. Patients were recommended to perform one set of 10 repetitions twice daily in their maximum possible range of motion. All patients were encouraged to supplement the hip exercises with aerobic training on a stationary bike or by walking. At the 10 week follow up visit patients in both groups were encouraged to continue their home-based training and gradually return to their usual activities.

OUTCOMES

Measurement times were prior to surgery (baseline), 10 weeks after and 6 months after THR. The primary measurement time was defined as the change from baseline to 6 months postoperative. Outcomes were walking test (speed, asymmetry and pelvic ROM), stair test (speed and pelvic ROM), leg extension power as described below.

In the 20 meter maximum walking speed test the participants stood behind a starting line and walked as fast as possible towards a cone placed 2 meters beyond the stopping line. Thus, the test included the acceleration phase but excluded deceleration. The test was repeated twice with a 30 second rest interval and data from the second trial were used for analysis. In the stair test the participants ascended two flights of stairs of 9 steps (height 16.5cm) as fast as possible without using the handrail. The test was repeated twice with a 30 second rest interval and data from the second trial were used for analysis.

An inertial measurement unit (IMU) (Inertia-Link®, MicroStrain®, Williston, United States of America) was used for analyses of pelvic movements during walking and stair tests (see Figure 2 for illustration of the set-up). The IMU was fixed to the skin over the sacrum between the posterior superior iliac spines using double adhesive tape. Real-time data from the IMU sensor were stored onto a PC using a Bluetooth connection with a sampling frequency of 100 Hz. Blinded data analysis was performed with analysis algorithms in MATLAB® 7.10.0 (MathWorks® version R2010a) developed by AHORSE Foundation (Atrium Medical Center, NL), based on algorithms of Zijlstra *(24)*. For gait, spatio-temporal parameters were derived after heel strike detection based on the zero crossing method described by Gonzalez *et al. (8)*. Step time asymmetry during walking was defined as percentage difference between legs in successive step times (heel strike to heel strike in the same leg). It was calculated as the difference in step times between the operated (OP) and not-operated (NOP) side, divided by the bilateral step time average by the formula : 100 x (step time OP – step time NOP)/((step time OP + step time NOP)/2)). Pelvic ROM during walking and stair ascending in the frontal and sagittal plane was obtained for each stride by an automated algorithm (AHORSE Foundation).

Leg extension power was measured with the Nottingham Power Rig (University of Nottingham Mechanical Engineering Unit, UK) and expressed as the product of force and velocity in a single-leg simultaneous hip and knee extension (see Figure 3 for illustration of the set-up) *(2)*. A minimum of six and a maximum of 12 trials to minimize learning effect and fatigue were obtained, and the highest measurement in watt was normalized for body weight in kg. The inter-tester reliability of this measurement procedure is excellent with an ICC of 0.91 (95% CI : 0.83 ; 0.99) and measurement error (SEM) of 10% (corresponding to 12.4 W) *(16)*.

Isometric muscle strength in hip flexion and hip abduction was measured using a hand-held dynamometer (Power Track II Commander, JTECH Medical, Salt Lake City, UT, USA). The procedure has been described earlier and has shown acceptable absolute and relative reliability when applied on

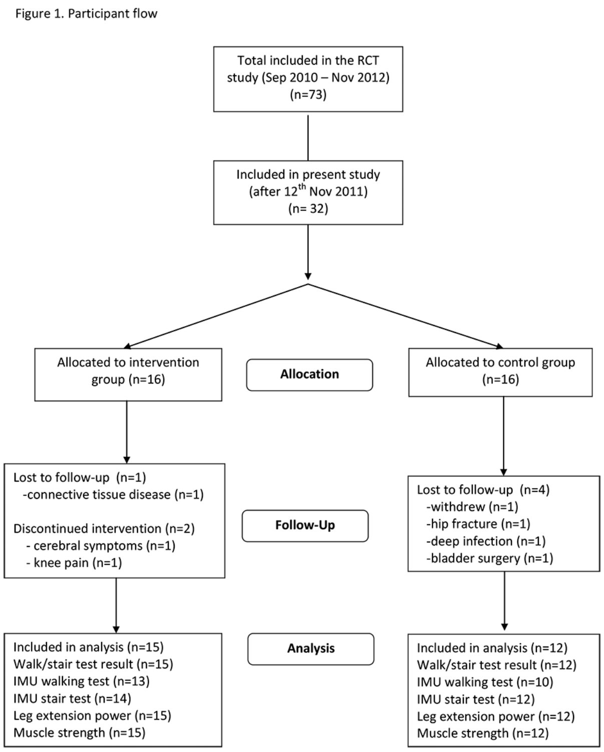

Figure 1. — Participant flow chart

patients after THR surgery *(16)*. Hip flexion was measured in the sitting position and hip abduction in supine. The measurement in Newton was normalized for leg length and body weight and is thus presented in Nm/kg.

HOOS 2.0 *(18)* was in this study used only at baseline to describe the sample and make comparison to other studies possible. The questionnaire measures patient reported outcome in the following subscales : Symptoms, pain, activities of daily living (ADL), function in sport and recreation and hip related quality of life (QOL). HOOS is valid and reliable when evaluating patients undergoing THR *(18)*. Scores range from 0 to 100, whith a score of 100 representing the best possible score.

Statistical analysis

Normal distribution of data was determined using histograms and probability plots. Data were presented descriptively by means and standard deviations (SD) if normally distributed and median and interquartile range (IQR) if non-normally distributed. The difference between baseline and

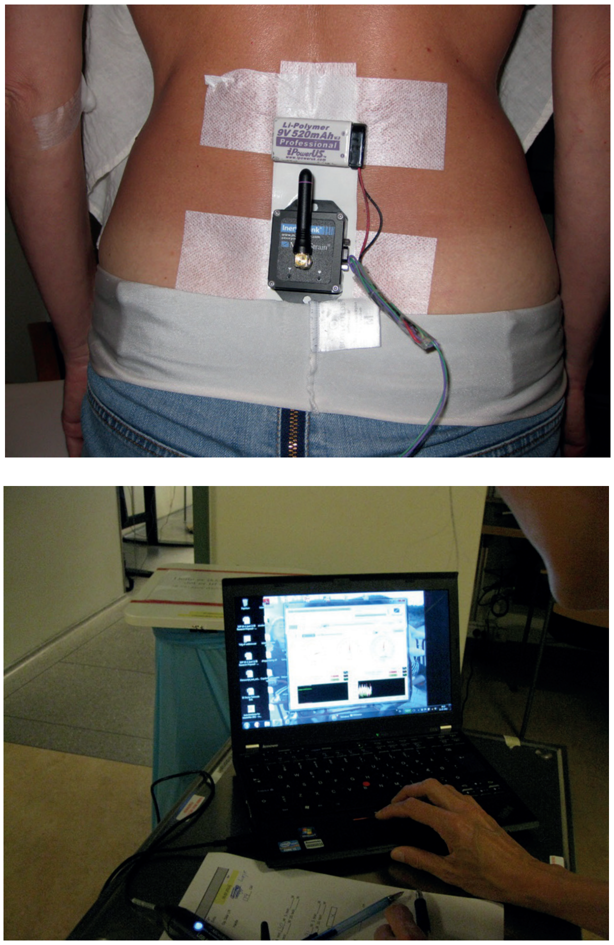

Figure 2. — The lab set-up with the Inertia Measurement Unit

Figure 3. — The lab set-up with the Leg Extensor Power Rig

Table 1. — Baseline characteristics of participants presented for the total sample and for the intervention and control groups separately

	All (n=27)	Intervention (n=15)	Control (n=12)
Female gender, n (%)	10 (37)	6 (40)	4 (33)
Age, mean (SD)	66.7 (9)	65.9 (8)	67.7 (11)
BMI, kg/m², mean (SD)	26.4 (4.0)	27.0 (4)	25.7 (4)
Physical status*, n (%)			
ASA I	11 (41)	6 (40)	5 (42)
ASA II	15 (55)	8 (53)	7 (58)
ASA III	1 (4)	1 (7)	0 (0)
THR, n (%)			
Cementless prosthesis	23 (85)	12 (80)	11 (92)
Contralateral THR	6 (22)	3 (20)	3 (25)
HOOS baseline score, mean (SD)			
Symptoms	44.4 (14)	44.7 (12)	44.2 (17)
Pain	48.4 (14)	45.5 (7)	51.9 (20)
ADL	51.2 (14)	48.4 (9)	54.7 (19)
Sport/rec	29.6 (16)	26.3 (9)	33.9 (22)
QOL	32.9 (13)	27.5 (6)	39.6 (16)

THR : Total hip replacement, BMI : Body Mass Index, ASA : *American Society of Anesthesiologists physical status classi-fication : I-Healthy patient, II-Patient with mild systemic disease, III+IV-Patient with severe systemic disease, HOOS : Hip osteoarthritis outcome scale, ADL : Activities of daily living, Sport/rec : Function in sport/recreation, QOL : Hip-related quality of life.

Table 2. — Results from walk and stair test, IMU meaurements, isometric muscle strength and leg extension power

Variable	Measurement time			Change	P *
	Baseline	1. FU	2. FU	Baseline-2. FU	
Test results (n=27)	Median (IQR)			Mean [95% CI]	
Walking time (sec)	13.2 (11.4;16.0)	11.1 (9.0;14.0)	10.2 (8.4;14.9)	-3.1 [-4.5;-1.7]	0.0001
Stair climb time (sec)	10.6 (7.3;16.0)	8.9 (7.4;12.5)	8.0 (6.7;11.2)	-4.1 [-6.8;-1.4]	0.004
IMU variables					
Walking (n=23)					
Step time asymmetry (%)	5.3 (2.2;11.1)	5.8 (1.8;8.3)	3.9 (2.1;10.5)	-1.4 [-4.2;1.3]	0.28
Pelvic ROM frontal (°)	6.9 (5.3;9.4)	9.9 (7.5;11.1)	9.4 (7.7;13.6)	3.6 [2.3;5.0]	<0.0001
Pelvic ROM sagittal (°)	7.7 (6.4;8.9)	9.0 (8.0;9.6)	8.4 (6.5;10.0)	0.9 [-0.4;2.1]	0.15
Stair climb (n=26)					
Pelvic ROM frontal (°)	17.1 (15.0;20.4)	17.2 (15.7;19.6)	18.5 (16.0;21.6)	1.2 [-1.0;3.4]	0.27
Pelvic ROM sagittal (°)	12.8 (10.2;151.7)	12.5 (9.4;15.9)	12.8 (10.9;16.4)	0.2 [-1.5;1.9]	0.80
Muscle function (n=27)					
LEP operated leg (W/kg)	1.5 (0.9;2.1)	1.8 (1.2;2.2)	2.0 (1.4;2.8)	0.5 [0.3;0.7]	<0.0001
LEP non-operated leg (W/kg)	1.9 (1.3;2.4)	2.0 (1.5;2.6)	2.8 (2.1;3.2)	0.2 [0.1;0.4]	0.006
Hip abduction strength (Nm/kg)	0.86 (0.7;1.0)	0.96 (0.8;1.3)	1.1 (0.9;1.4)	0.2 [0.1;0.3]	<0.0001
Hip flexion strength (Nm/kg)	1.1 (0.9;1.5)	1.3 (1.0;1.7)	1.3 (1.1;1.7)	0.16 [0.1;0.3]	0.003

IMU : Inertia measurement unit, ROM : range of motion, 1.FU : 10 week follow up, 2.FU : six months follow up, IQR : Interquartile range, *test of difference between baseline and 2. FU by paired t-test.

second follow up was tested with a paired t-test (normal distribution) or Wilcoxon signed-rank test on speed, gait asymmetry and pelvis ROM (frontal and sagittal plane) during gait and stair ascending as well as leg extension power. The explorative analysis on the effect of the progressive resistance training intervention was performed by comparing the change scores in the intervention and control group with unpaired t-test or Wilcoxon rank-sum test depending on data distribution.

We performed post hoc correlation analyses to further explore our findings on the IMU parameters.

Table 3. — Results from the walking and stair tests, IMU meaurements, isometric muscle strength and leg extension power in intervention and control groups, presented as median and inter-quartile range

Variable	Intervention		Control		P*
	Baseline	Δ to 2.FU	Baseline	Δ to 2.FU	
Test results (n=27)	n=15		n=12		
Walking time (sec)	12.7 (11.1;18.5)	-2.81 (-4.6;-1.0)	13.9 (11.9;15.8)	-2.8 (3.3;-1.3)	0.85
Stair climb time (sec)	10.3 (7.3;19.3)	-2.4 (-4.0;-0.6)	12.7 (8.5;15.9)	-1.9 (-3.7;-0.9)	0.59
IMU variables					
Walking	n=13		n=10		
Step time asymmetry (%)	6.9 (4.9;21.6)	-3.4 (-4.6;0.3)	3.7 (2.2;5.3)	0.2 (-2.4;5.7)	0.06
Pelvic ROM frontal (°)	6.9 (5.5;8.9)	2.8 (1.0;5.6)	7.1 (4.7;9.6)	3.4 (2.8;4.5)	0.76
Pelvic ROM sagittal (°)	7.3 (6.4;9.0)	0.4 (-1.2;2.7)	8.1 (6.1;8.5)	0.9 (-0.4;1.4)	0.95
Stair climb	n=14		n=12		
Pelvic ROM frontal	15.7 (13.3;18.2)	1.9 (-0.5;4.9)	18.3 (16.7;21.6)	-1.2 (-4.3;3.7)	0.28
Pelvic ROM sagittal	13.4 (10.9;15.7)	-1.3 (-3.3;5.1)	12.8 (10.1;16.2)	1.2 (-2.4;3.0)	0.72
Muscle function	n=15		n=12		
LEP operated leg (W/kg)	1.8 (0.9;2.0)	0.6 (0.3;1.0)	1.4 (1.1;2.1)	0.5 (0.0;0.8)	0.32
LEP non-operated leg (W/kg)	1.9 (1.2;2.4)	0.0 (-0.3;0.6)	2.0 (1.4;2.3)	0.3 (0.1;0.6)	0.22
Hip abduction strength (Nm/kg)	0.7 (0.7;1.0)	0.3 (0.1;0.4)	0.9 (0.7;1.1)	0.2 (0.0;0.5)	0.77
Hip flexion strength (Nm/kg)	1.0 (0.8;1.3)	0.2 (0.0;0.3)	1.3 (0.9;1.6)	0.0 (-0.1;0.4)	0.22

IMU : Inertia measurement unit, ROM : range of motion, 2.FU : 6 months follow up, LEP : Leg extension power. *Difference between groups in change score, tested with Wilcoxon ranksum test.

To investigate whether large pelvic ROM could be explained by high speed we tested the correlation between speed during walking and stair ascending to the corresponding pelvic ROM estimates 6 months postoperative.

No a priori sample size calculation was performed due to the embedded and explorative nature of the study. This paper reports on the second half of the patients included in the primary study, due to availability of the IMU equipment.

RESULTS

A participant flow chart is shown in Figure 1. Thirty-two patients were included in the trial (16 in each group). Of these, four patients were excluded due to major complications and one withdrew due to fatigue, leaving 27 patients in the study with complete follow up. In some patients the IMU data were incomplete (four patients in walk test and one in stair test), thus the sample size is decreased in those analyses. Two participants in the intervention group withdrew from the resistance training due to knee pain and cerebral symptoms but participated in the outcome measurements and are included in the analysis maintaining their group assignment.

The baseline characteristics for the participants are presented in Table 1 for the total sample and for the intervention and control groups separately. The majority of the participating patients were male (63%) and the mean age was 66.7 years (range : 44-82).

In Table 2 the results for the total sample from the walking and stair test, IMU measurements as well as the muscle function are presented for all measurement times and change from baseline to 6 months postoperative. Pelvic ROM in the frontal plane during walking increased significantly from baseline to 6 months follow up ($p<0.0001$). There were no significant changes in the remaining IMU measurements in both walking and stair test ($p>0.05$). Leg extension power, isometric muscle strength and speed in walking and stair test improved significantly from baseline to 6 months follow up ($p<0.01$).

The results are presented separately for the intervention and control groups in Table 3. There were no significant differences on change in IMU parameters or muscle function between the groups, however a tendentiously larger reduction in step time asymmetry is seen in the intervention group compared to the control group (p=0.06)

The post hoc analyses are presented and revealed a significant negative correlation between maximal walking speed and pelvic ROM in the frontal plane (r=-0.74, p=0.0001). The same tendency but not significant concerning pelvic ROM in the sagittal plane (r=-0.40, p=0.06). Speed in stair ascending was significantly correlated to pelvic ROM in both the frontal (r=-0.54, p=0.003) and the sagittal plane (r=-0.49, p=0.01).

DISCUSSION

The main finding in the present study was that no significant reductions in gait asymmetry or pelvic ROM occurred during the first 6 months after THR. On the contrary, a significant increase in pelvic ROM in the frontal plane during walking was found (52%, p<0.0001), while only small changes were seen in the remaining pelvic ROM variables (<12%). The expected improvements of the compensatory pelvic movements were lacking while considerable improvements in walking and stair climbing speed (23-39%) as well as muscle strength and power on the operated side (15-33%) were achieved. This discrepancy between test results and IMU measures of compensatory pelvic movements may be caused by exactly that increase in the pace of the performed walking and stair climbing. That is in line with the findings in our post hoc analysis as well as with previous studies reporting increased gait variability, including pelvic ROM, with faster walking speeds *(4, 12)*. Self-selected or a pre-defined pace probably would have reflected the patients' gait pattern more accurately. However, that approach could also be problematic, because self-selected pace does increase after THR *(7)* and a pre-defined pace could introduce other bias' due to the patients having to walk at unnatural paces. In a recent meta-analysis concerning gait pattern after THR compared to controls, the authors found that results on gait kinematics did not differ between studies that matched walking speed between patients and control in either test or analysis compared to those that did not *(13)*. Therefore we did not adjust for walking speed in our analysis, and we chose the maximal walking speed since it is considered a task of great importance in order to achieve full mobility outside, e.g. when crossing a road. Persisting compensatory pelvic movements, as found in the present study, has been suggested to be caused by decreased hip ROM in THR patients compared to healthy subjects *(6,13)*. Reduced hip ROM during walking can be related to muscle impairments such as reduced hip abductor moment and to limited hip ROM such as reduced passive hip extension *(6,13)*. In the present study, we found an increase in pelvic ROM in the frontal plane during walking which could indicate pelvic drop, also known as a Trendelenburg gait pattern which is a well-known phenomenon in patients with THR *(13)*. Gait asymmetry was insignificantly reduced by 26% (p=0.28) 6 months after THR compared to pre-operative, indicating some normalization of the gait pattern concerning interlimb difference in step time.

The exploratory analysis on between-group differences showed that changes in gait asymmetry and pelvic ROM were not affected by participation in resistance training. This finding is in line with the findings from the main study which showed no significant effect of the resistance training on muscle performance *(15)*. Moreover, the pelvic ROM may be affected by variables which we do not expect resistance training to improve such as hip ROM. We did find a borderline significant larger reduction in step time asymmetry in the intervention group compared to the control group (p=0.06), however this finding should be interpreted in light of a considerably larger asymmetry at baseline in this group compared to the control and thus a larger potential for improvement. Furthermore, we must consider the small sample size and thus the exploratory nature of these results from the group comparisons.

In comparison to other studies, our findings of no improvement of the gait pattern during the first six months after THA is in contrast to earlier studies reporting some normalization of the gait pattern in that period *(1,10,19)*. We aimed at including THR with functional limitations and thus excluded the best functioning THR patients. This may explain the lack of improvement in the compensatory pelvic movements in our study, if the more limited patients have a slower normalization of the gait pattern. When comparing our results to other studies using acceleration-based gait analysis we found slightly higher levels of both pelvic ROM and gait asymmetry than Hjort *et al* did on patients 5-7 years after THR *(9)*. This difference complies well with the later follow up time in their study which might indicate some further normalization of the gait pattern years after THR. The leg extension power in the operated side was higher in their study compared to the present (2.8 versus 2.0 W/kg) while comparable on the non-operated side, which could indicate further improvements also in leg extension power beyond the 6 months follow up.

We acknowledge that there are limitations to our study. Particularly the small sample size and lack of sample size estimation before initiation of the study, which gives the study an exploratory character. The findings of no improvement in the gait parameters could consequently be a type II error, however the directions of the estimates do not indicate so (except from gait asymmetry). The IMU-based method used to evaluate gait parameters also contains some limitations. When measuring pelvic ROM we estimate the total ROM in either the frontal or the sagittal plane but we cannot identify the direction of the movement.

In conclusion, no improvements were found in gait asymmetry and pelvic ROM six months after THR while muscle function and speed during walking and stair ascending increased significantly. Compensatory pelvic movements in the frontal plane during maximal walking increased after surgery. There seemed to be no influence of progressive resistance training on any of the outcomes. The lack of improvement in pelvic ROM parameters could be explained by the increased speed during walking and stair climbing at follow up. The exploratory character of the study impedes decisive conclusions.

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