Early Maximal Strength Training Is an Efficient Treatment for Patients Operated With Total Hip Arthroplasty

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Objective: To compare muscle strength, work efficiency, gait patterns, and quality of life in patients undergoing total hip arthroplasty (THA) randomly assigned to either maximal strength training or a conventional rehabilitation program.

Design: A randomized controlled study.

Setting: Research laboratory, rehabilitation center, and physical therapy clinic.

Participants: Patients (N=24) with osteoarthritis as the main reason for THA were randomly assigned to perform maximal strength training (n=12) or conventional rehabilitation (n=12).

Interventions: The maximal strength training group (STG) performed maximal strength training in leg press and abduction with the operated leg only 5 times a week for 4 weeks in addition to the conventional rehabilitation program. The conventional rehabilitation group (CRG) received supervised physical therapy 3 to 5 times a week for 4 weeks.

Main Outcome Measures: 1-repetition maximum (1RM), leg press strength, 1RM abduction strength, rate of force development (RFD), work efficiency, gait patterns, and quality of life.

Results: 1RM increased in the bilateral leg press (P<.002) and in the operated leg separately (P<.002) in the STG compared with the CRG. 1RM abduction strength in the operated leg (P<.002) and the healthy leg (P<.002) increased in the STG compared with the CRG. RFD increased in the STG compared with the CRG (P=.030), followed by a trend towards increased peak force in the STG (P=.053) (P = probability for differences between groups). Work efficiency tended to improve in the STG compared with the CRG (P=.065). No differences in gait patterns were revealed between the groups after the training intervention.

Conclusions: Early maximal strength training 1 week postoperatively is feasible and an efficient treatment to regain muscular strength for patients who have undergone THA, demonstrated by a significantly larger increase in muscular strength and a trend towards a better work efficiency in the STG compared with the CRG.

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TOTAL HIP ARTHROPLASTY is a common procedure in orthopedic practice.1 In 2004, the reported rates (per 100,000 population) for primary THA in the United States, Canada, Australia, and New Zealand ranged from 70 to 150.2,3 The number is expected to increase as the population ages, more people live longer, and a greater percentage of the population is obese.4 The main purpose of THA, besides pain relief, is to restore hip biomechanics leading to a minimal functional deficit, and to secure the longevity of the implant.5 A large group of patients who underwent THA still have mild to moderate long-term impairments postoperatively.6 The impairments include reduced walking efficiency,7 pain, muscle weakness of the hip abductors, contracture of the hip, gait disorders, and weakness of the hip extensors and flexors.8,9 These problems may, in turn, lead to complications such as loosening of the implant and joint instability.10,11 A major concern after THA is abductor weakness, particularly when the lateral approach is used. An unsuccessful reattachment or a denervation of the anterior glutal flap may occur with the lateral approach.12 Several studies report postoperative abductor weakness.13,12,14

Adequate strength of the muscles of the lower extremity and, in particular, the abductor muscles is required for a satisfactory gait pattern without limping15 and to prevent falls.14 To improve muscle strength, training intensity should exceed 60% of 1RM, and 80% to 90% of 1RM seems to be the optimal load.16,17 McDonagh and Davies18 reviewed several resistance training studies and reported that loads less than 66% of 1RM produce little increase in strength even if up to 150 contractions a day were performed. Maximal strength training is traditionally performed with high loads of 85% to 95% of 1RM, few repetitions, and with explosive movements.19 Several studies
demonstrate maximal strength training to be an efficient training method to improve muscle strength as well as work efficiency. The training method has been carried out successfully in healthy subjects as well as patients with chronic obstructive pulmonary disease, and in patients with coronary artery disease. Most patients are offered rehabilitation after surgery, either in a rehabilitation center or by outpatient physiotherapy. Traditionally, rehabilitation programs consist of hip joint mobilization, strengthening of surrounding muscles with low-resistance weight, and gait training. Small increases in maximal muscle strength of the operated leg are demonstrated after standard rehabilitation following THA. Andersen et al. found low levels of neuromuscular activity after conventional rehabilitation, and the risk the surgery implies for the patient. An ASA score of PI gives a summary of the preoperative status of the patient and surgery, and an ASA score of PI. This classification system indicates a healthy patient. Exclusion criteria included muscular or skeletal disease that might influence the training and physical testing performance, heart or lung diseases, and diabetes mellitus.

The study was approved by the regional ethics committee and conducted in accordance with the Helsinki Declaration. Each subject reviewed and signed consent forms that included detailed information about the study. The consent form was approved by the regional ethics committee.

**Methods**

**Study Design**

The study was designed as a randomized controlled study. We randomly assigned the patients manually by drawing lots. The procedure was performed by 2 persons not familiar with the different treatment options. We randomly assigned the patients to either the group performing maximal strength training in addition to the conventional rehabilitation program (STG), or to the group that participated in the conventional rehabilitation program only (CRG). Patients in the STG received inpatient treatment at the same rehabilitation center for 4 weeks. In the CRG, 2 patients stayed at home and received outpatient physical treatment. Other patients attended the same rehabilitation center as the STG, while the remaining 2 patients received inpatient treatment at other rehabilitation centers. The patients were tested preoperatively, 1 week postoperatively, and 5 weeks postoperatively. The trial profile of the study is displayed in figure 1.

**Patients**

We recruited 24 patients from patients scheduled for THA in the orthopedic department at St. Olav’s University Hospital in Trondheim, Norway. The STG consisted of 5 men and 7 women, whereas the CRG consisted of 4 men and 8 women. Inclusion criteria were age less than 70 years, a diagnosis of primary osteoarthritis as the main cause for elective THA surgery, and an ASA score of PI. This classification system gives a summary of the preoperative status of the patient and the risk the surgery implies for the patient. An ASA score of PI indicates a healthy patient. Exclusion criteria included muscular or skeletal disease that might influence the training and physical testing performance, heart or lung diseases, and diabetes mellitus.

The study was approved by the regional ethics committee and conducted in accordance with the Helsinki Declaration.

**Surgical Procedure**

Only the direct lateral approach was used. Following a posterior curve, lateral incision, the hip was exposed through a direct lateral approach as described by Frndak et al. and modified by Hardinge. Thus the common muscle plate of the anterior one-third of musculus vastus lateralis and musculus gluteus medius was dissected subperiosteally from the greater trochanter. The acetalubar component and the femoral component were inserted following the surgical procedures of the manufacturers. The femoral component was uncemented, customized porous and hydroxyapatite-coated with a 28-mm ceramic head. The acetabular component was an uncemented Trilogy cup with a cross-linked polyethylene liner. Under reconstruction of the abductor muscles, the common muscle plate was reinserted to the greater trochanter with 2 nonresorbable osteosutures (Premi-Cron®). Furthermore, this fixation was reinforced with a continuously sewed, slowly resorbable looped monofilament suture (MonoPlus®). Skin was closed with nonresorbable sutures (Dafilon®). All surgical procedures were performed by the same orthopedic surgeon specializing in THA surgery with 25 years of experience. By using a combination of nonresorbable and slowly resorbable sutures, the use of heavier loads in the postoperative training program is justified. The postoperative medical prescription included full weight-bearing. Training started 1 week postoperatively.

Hip offset was defined as the perpendicular distance between the long axis of the femur and the center of rotation of the femoral head. Postoperatively, measurements of the operated and healthy hip were compared.

**Training Protocol**

All patients received a medical prescription from the orthopedic surgeon who also gave exercise instructions for the conventional rehabilitation program. The conventional rehabilitation for all patients having inpatient treatment in a rehabilitation center consisted of individual sling exercise therapy in hip abduction/adduction, hip flexion/extension, exercises with low resistance (>12–15 repetitions), or no resistance and exercises performed in water when sutures had been removed. Each session lasted 1 hour and was performed 5 days a week for 4 weeks. The patients attended educational classes twice a week. The 2 patients in the CRG who stayed home after being discharged from the hospital received outpatient treatment supervised by a physician 3 times a week with instructions to carry out prescribed exercises at home 2 times a week.

In addition to the conventional rehabilitation program, all patients in the STG performed, from 1 week after the operation, 5 training bouts a week for 4 weeks consisting of a 10-minute warmup period performed by stationary cycling at an intensity corresponding to 50% of V_{O_{2,max}}. The maximal dynamic strength training regimen consisted of 2 exercises, leg press and hip abduction, that included 4 series of 5RM involving the operated leg only. 5RM corresponds to approximately 85% of 1RM. When the patients managed to perform 6RM, the load was increased by 5kg. The series were separated by resting periods of 2 minutes. Leg press was performed in a leg press ergometer in a seated position with a knee joint angle of 90° and a flexion angle of 90° maximum in the hip joint (to avoid hip luxation), with a range of motion of 90° to 45° in the hip joint and 90° to 0° in the knee joint (fig 2). Hip abduction was performed using a standard pulling apparatus. The patients
Fig 1. Flow chart of the study.
were standing in an upright position stabilized by parallel bars with a 15-cm broad sling placed at the medial malleolus of the trained leg (fig 3). The patients were instructed to stand in an upright position and to keep the foot pointing forward during the abduction exercise. Range of motion was 0° to 25° in the hip joint. When the patients managed to perform 6RM, the load was increased by 1kg. The training sessions were supervised by 2 exercise physiologists with experience from a hospital orthopedic hip joint unit.

Testing Procedures

Before testing procedures, the patients performed 10 minutes of treadmill walking at a given inclination and speed, or stationary cycling with an exercise intensity corresponding to 50% of $\dot{V}O_2_{\max}$. At the preoperative test, where $V_{O_2_{\max}}$ was unknown, the intensity was kept at a level where the patients were able to talk effortlessly. The patients performed the testing procedures in the same order at all tests.

Strength measurements. The physical tests started with determining bilateral 1RM leg press followed by testing the right and left leg separately. The patients performed the strength tests in a seated position in a leg press ergometer with a knee joint angle of 90° between the femur and tibia and a 90° joint angle in the hip. The initial weight load was based on a subjective estimation of the patient’s capacity to prevent the fitter patients from starting at too low an intensity. The patients used 4 to 5 attempts to determine 1RM. We increased the weight load by 5 to 10kg at each ramp and terminated the test when the patients no longer managed to perform the leg press movement.

We measured force development, determined as RFD and PF, with data collected at 2000Hz using a force platform with software specifically developed for the platform. The force platform consists of an aluminum top plate placed on top of 3-component force sensors that allows measurements of force and torque in 3 axes, that is, vertical, left, and right horizontal. The patients performed the test of RFD and PF in a seated position in a leg press ergometer with a knee joint angle of 90°. The weight load was 40kg during bilateral testing and 10kg during single leg testing for all patients. We mounted the Kistler force platform in front of the leg, placed in a vertical position on the leg press ergometer. RFD expresses the ability of the patient to develop muscle strength rapidly. PF is the highest force attained during the movement. RFD is determined as 10% to 90% of PF obtained from the maximum slope of the force-time curve. The RFD parameter has important functional significance, such as an athlete’s performance in the sprint or preventing a fall in an elderly person.

We measured 1RM abduction using a custom-made table. The patients were tested in a supine position. To enable maximum stabilization, we stabilized the pelvis by using an adjustable clamp arch against the ala ossis ilii. The patients performed 1RM abduction of the right and left leg. One leg was resting in a sling while the other leg was tested. We placed the testing leg in a 15-cm broad sling horizontally mounted to the pulling apparatus with a rope. We placed the lower edge of the sling at caput fibulae. We increased the weight load by 5kg at each ramp and terminated the test when the patients no longer managed to perform the abduction movement. We instructed the patients to perform the event with the arms placed on the chest and to keep the performing leg extended with the foot pointing forward using a horizontal movement. Range of motion in the abduction movement was 0° to 25°.

Gait patterns. We recorded gait patterns while the patients were walking at a standardized velocity of 4km/h on a horizontal treadmill (Runrace 1200 HC). We used a Pedar-X dynamic pressure distribution measure system for capacitive sensors. The Pedar measurement system has been proven to be a valid and reliable measure of contact area and peak pressure. Data were collected at 50Hz. Force was calculated as the sum of pressure multiplied by areal for all 99 sensors in each insole. We calculated step length, PF heel/toe, stance time, and impulse. Step length was defined as the interval between initial contact of each foot.

Two flexible insoles with sensors were placed in the right and left shoe, respectively. We logged pressure ranges during walking and analyzed them. Before recording, the patients walked with the measuring equipment for 2 minutes to ensure a steady state of walking, without being informed about the recording period. The recording measurement duration was 30 seconds, and we used the recorded steps from 11 to 20 in each subject in the analysis of gait parameters.
Work efficiency. The patients walked on a treadmill for 5 minutes at a standardized workload corresponding to 40W. We calculated work efficiency from 3.30 to 4.30 minutes during the 5-minute standardized workload test.\textsuperscript{44} We measured all ventilatory parameters and pulmonary gas exchange using the Cortex Metamax I portable metabolic test system.\textsuperscript{b} For measurements of heart rate, we used short-range radio telemetry with Polar accuracy watches.\textsuperscript{1} Net efficiency was calculated by the following equation:

\[
\text{Work efficiency} = \frac{\text{Load} \times \text{REE}}{\text{Energy expenditure} - \text{REE}}
\]

REE was calculated from standardized values of 3.5mL/kg\(^{-1}\)·min\(^{-1}\). Both VO\(_2\) and watts were converted to kilocalories to allow the calculation of percent work efficiency. Work efficiency reflects the percentage of total energy expended that contributes to external work, with the remainder lost as heat.\textsuperscript{25}

Maximum oxygen consumption. We tested VO\(_2\)max by treadmill walking. We determined VO\(_2\)max by increasing speed and inclination each minute until the patients decided to terminate the test. We measured all ventilatory parameters and pulmonary gas exchange using the Cortex Metamax I portable metabolic test system. For measurements of heart rate, we used short-range radio telemetry with Polar accuracy watches. The highest heart rate recorded during the last minute of the test was used as the maximum heart rate. VO\(_2\)max is defined as the highest VO\(_2\) the person can attain during exercise involving large muscle groups.\textsuperscript{46}

After the VO\(_2\)max test, the patients gave a subjective evaluation of perceived exertion by end-exercise leg effort and breathlessness using the Borg ratio scale. The scale ranges from 6 to 20, where 20 represents the highest degree of exertion.\textsuperscript{27}

Health-related quality of life. We used the SF-36 to determine health-related quality of life after each test. The survey contains an evaluation of both PCS and MCS. The scale ranges from 0 to 100, where 100 indicates optimal health.\textsuperscript{48} The SF-36 is a widely used and validated survey and has been translated and validated for Norwegian conditions.\textsuperscript{49}

Clinical function score of the hip. For clinical evaluation of hip function we used the Merle D'Aubigné and Postel scoring system preoperatively and after 5 weeks. The scoring system evaluates pain, joint mobility, and gait function with a range from 3 to 18, where 18 indicates optimal function of the hip.\textsuperscript{50}

Statistical Analysis

With a power of .80 and an expected increase in 1RM in the operated leg by 20kg after the intervention period,\textsuperscript{22} 9 patients were needed in each group. We used the software program SPSS 16.0 for statistical analysis. Data are presented as mean ± SD. We tested variables for normality by Q-Q plot. Preoperatively, we compared the groups by 2-sample t tests. We measured work efficiency by 2-sample t tests at all tests because of missing variables at the test 1 week postoperatively. We compared postoperative hip offset between the groups by 2-sample t tests. We studied variables obtained 1 week and 5 weeks postoperatively by 2-way analysis of variance for repeated measurements with time as within factor and STG versus CRG as grouping factor. When a significant interaction between main effects was found, a 2-sided multiple contrast test within each group and between groups at each point in time were performed with the appropriate adjustments of the degrees of freedom.\textsuperscript{51} We considered a P value less than .05 as significant for all measurements.

### Table 1: Preoperative Anthropometric Data for the STG and the CRG

<table>
<thead>
<tr>
<th>Subject Characteristics</th>
<th>STG (n=12)</th>
<th>CRG (n=12)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (M/W), n</td>
<td>5/7</td>
<td>4/8</td>
<td>.689</td>
</tr>
<tr>
<td>Age (y)</td>
<td>58±5</td>
<td>56±8</td>
<td>.343</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>84.6±11.2</td>
<td>86.2±18.4</td>
<td>.552</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174±4.9</td>
<td>170±11</td>
<td>.348</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>28.1±2.9</td>
<td>28.2±6.5</td>
<td>.967</td>
</tr>
<tr>
<td>Merle D’Aubigné Postel</td>
<td>10±1</td>
<td>10±1</td>
<td>.445</td>
</tr>
</tbody>
</table>

NOTE. Values are mean ± SD unless otherwise indicated. Abbreviation: BMI, body mass index; M, men; W, women.

### RESULTS

One week postoperatively, we excluded submaximal VO\(_2\) tests from analysis because of severe difficulties for the patients to walk without support for the time necessary to perform the test adequately. The variety of body mass normalization procedures (dimensional scaling) did not affect the results and are not presented in the Results section.

### Anthropometric Data

Body mass significantly decreased from the 1- to 5-week postoperative tests, averaging 2.2% (P<.001). Differences in offset between the operated and healthy leg were 1.1±2.7 and 2.6±2.5 in the STG and CRG, respectively, which was not significantly different between the groups (P=.223). The Merle D’Aubigné and Postel score was not significantly different between the groups either preoperatively or 5 weeks postoperatively.

Preoperatively, the Merle D’Aubigné and Postel score was 10±1 in both STG and CRG (P=.445). Five weeks postoperatively, the corresponding value was 17±1 in both groups (P=.207). No significant group differences in age, mass, height, or body mass index were found. Preoperative anthropometric data of the patients are presented in table 1.

### Strength Measurements

At 1 week after the operation, there was no difference between groups in 1RM bilateral leg press strength. At the 5-week test, a significant increase was found in 1RM bilateral leg press for both groups. The improvement was more pronounced, 40.9%, in the STG compared with the CRG (P<.002). The same pattern of change was found in corresponding results from the operated leg; 1RM was not different 1 week after the operation and increased in both groups, but increased more in the STG, being 65.2% higher compared with the CRG after 4 weeks of training (P<.002). After the operation, RFD in the operated leg was 64.5% higher in the STG compared with the CRG (P=.030) and increased in both groups between the first and the fifth postoperative week (P<.001).

Neither the bilateral PF nor healthy leg PF differed between groups 1 week after the operation. Both variables improved significantly in the STG compared with the CRG after 4 weeks of training: 61.7% for both legs (P<.002) and 48.3% (P<.02) for the healthy leg, respectively. Neither bilateral PF nor healthy leg PF increased significantly in the CRG 1 to 5 weeks postoperatively. There was a trend towards a higher PF in the operated leg in the STG compared with the CRG (P=.053). At 1 week after the operation, abduction strength did not differ between groups either in the operated or in the healthy leg. Abduction strength in the operated leg increased with training in both groups, but the increase was more pronounced in the STG, by 87%,
versus the CRG \((P<.002)\). In the healthy leg, only the STG increased strength from 1 to 5 weeks. At the 5-week test, abduction strength in the healthy leg was 48.6\% higher compared with the CRG \((P<.002)\). Strength measurements are presented in table 2.

### Gait Parameters

No significant differences between the groups were found at the 1- and 5-week tests. All gait parameters improved in the STG and the CRG 1 to 5 weeks postoperatively. The different gait parameters are presented in table 3.

### Work Efficiency

No significant difference between the groups was found after 1 week. Five weeks postoperatively there was a significantly lower heart rate in the STG by 11.4\% \((P=.041)\). There was a trend towards a better work efficiency in the STG after 5 weeks by 32.3\% \((P=.065)\). The results are presented in table 4.

### Maximum Oxygen Consumption

No significant differences between the groups were found in the \(V_{O_2}\)max tests. The \(V_{O_2}\)max, heart rate, and respiration

## Table 2: Strength Measurements for the STG and the CRG

<table>
<thead>
<tr>
<th>Measure</th>
<th>STG (n=12)</th>
<th>CRG (n=12)</th>
<th>ANOVA Main Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
<td>T3</td>
</tr>
<tr>
<td>1RM operated leg</td>
<td>193±71</td>
<td>103±36</td>
<td>193±54*</td>
</tr>
<tr>
<td>1RM operated leg</td>
<td>85±31</td>
<td>23±9</td>
<td>76±20*</td>
</tr>
<tr>
<td>1RM healthy leg</td>
<td>105±38</td>
<td>91±32</td>
<td>103±28</td>
</tr>
<tr>
<td>Force development (N·s(^{-1}))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RFD both legs</td>
<td>2572±1508</td>
<td>1321±948</td>
<td>2632±1435</td>
</tr>
<tr>
<td>RFD operated leg</td>
<td>1422±723</td>
<td>568±698</td>
<td>1880±816</td>
</tr>
<tr>
<td>RFD healthy leg</td>
<td>1581±780</td>
<td>1679±955</td>
<td>2080±924</td>
</tr>
<tr>
<td>Maximal force (N)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PF both legs</td>
<td>1005±422*</td>
<td>587±234</td>
<td>967±379*</td>
</tr>
<tr>
<td>PF operated leg</td>
<td>565±238</td>
<td>278±150</td>
<td>526±180</td>
</tr>
<tr>
<td>PF healthy leg</td>
<td>608±250</td>
<td>501±245</td>
<td>654±230*</td>
</tr>
<tr>
<td>Abduction strength (kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1RM operated leg</td>
<td>27±15</td>
<td>9±7</td>
<td>43±15*</td>
</tr>
<tr>
<td>1RM healthy leg</td>
<td>37±17</td>
<td>31±15</td>
<td>35±18</td>
</tr>
</tbody>
</table>

Note. Values are mean ± SD for each variable. Abbreviations: ANOVA, analysis of variance; T1, test preoperatively; T2, test 1 week postoperatively; T3, test 5 weeks postoperatively. *No significant differences after post hoc multiple contrast tests.

## Table 3: Gait Patterns at 4km/h for the STG and the CRG

<table>
<thead>
<tr>
<th>Measure</th>
<th>STG (n=12)</th>
<th>CRG (n=12)</th>
<th>ANOVA Main Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
<td>T3</td>
</tr>
<tr>
<td>Step length OL (cm)</td>
<td>63.4±8.9</td>
<td>51.1±13.9</td>
<td>67.3±6.7</td>
</tr>
<tr>
<td>Step length HL (cm)</td>
<td>64.9±8.2</td>
<td>56.3±11.3</td>
<td>68.9±5.3</td>
</tr>
<tr>
<td>PF OL (N)</td>
<td>714±134</td>
<td>517±136</td>
<td>653±118</td>
</tr>
<tr>
<td>PF HL (N)</td>
<td>713±72.0</td>
<td>559±94</td>
<td>659±65</td>
</tr>
<tr>
<td>PP OL (N·cm(^{-1}))</td>
<td>24.5±6.98</td>
<td>18.25±7.15</td>
<td>22.54±3.46</td>
</tr>
<tr>
<td>PP HL (N·cm(^{-1}))</td>
<td>25.1±11.06</td>
<td>19.27±3.46</td>
<td>22.67±3.97</td>
</tr>
<tr>
<td>PP HL heel (N·cm(^{-1}))</td>
<td>16.15±5.09</td>
<td>9.37±2.92</td>
<td>16.44±4.41</td>
</tr>
<tr>
<td>PP HL heel (N·cm(^{-1}))</td>
<td>17.61±6.44</td>
<td>14.18±4.43</td>
<td>18.59±4.14</td>
</tr>
<tr>
<td>PP OL footfall (N·cm(^{-1}))</td>
<td>24.20±7.37</td>
<td>16.77±5.83</td>
<td>22.08±4.05</td>
</tr>
<tr>
<td>PP HL footfall (N·cm(^{-1}))</td>
<td>24.58±6.30</td>
<td>17.10±3.76</td>
<td>22.10±4.01</td>
</tr>
<tr>
<td>Stance time OL (s)</td>
<td>0.59±0.02</td>
<td>0.790±0.097</td>
<td>0.602±0.064</td>
</tr>
<tr>
<td>Stance time HL (s)</td>
<td>0.605±0.035</td>
<td>0.885±0.113</td>
<td>0.620±0.047</td>
</tr>
<tr>
<td>Impulse, OL (N·s)</td>
<td>298±74</td>
<td>243±100</td>
<td>288±59</td>
</tr>
<tr>
<td>Impulse, HL (N·s)</td>
<td>300±41</td>
<td>319±92</td>
<td>264±56</td>
</tr>
</tbody>
</table>

Note. Values are mean ± SD for each variable. Abbreviations: ANOVA, analysis of variance; T1, test preoperatively; T2, test 1 week postoperatively; T3, test 5 weeks postoperatively. *No significant differences after post hoc multiple contrast tests.
maximal strength training to be highly effective. The strength by 230% (leg press) in the STG in the present study, indicating postoperatively. Muscle strength in the operated leg increased and hip abduction in the STG compared with the CRG 5 weeks training induced a great increase in strength both in leg press, corresponding to 80% to 90% of 1RM. Maximal strength the CRG. There was a trend towards higher walking efficiency production after the 4-week training intervention compared with 11.1 week significantly higher performance in leg press, RFD, and hip ab-duction after the operation. In the CRG, the score increased by 17.4% 11) 1 week 56 after the operation. Hauer et al.30 show increased strength and benefits from a weight-bearing program initiated 4 months postoperatively. Compared with the present study, the strength training was initiated relatively late. Initiating the massive strength training as soon as possible after the surgery is of great importance because major surgery and subsequent hospitalization are known to cause a severe decline in muscle mass and muscle strength.28,52 Muscle strength declines 3% to 4% a day during the first week of immobilization.53 Furthermore, because of activity-related pain and contracture of the hip, most patients experience a period of inactivity before surgery.

In the present study, work efficiency was expected to be significantly improved in the STG compared with the CRG after the intervention period, reflecting the greater muscle strength and the increased RFD in the operated leg in the STG. Several studies report a correlation between increased strength, RFD, and improved work efficiency.20-22,24 However, Bishop,24 Nakao,55 and colleagues failed to discover improvement in endurance performance despite increased IRM in leg strength, which is in line with the findings in the present study. It is reasonable to assume that a longer follow-up period would have demonstrated a higher effect on walking efficiency from the increased IRM in leg press and abduction. That is, 5 weeks postoperatively, the patients seem not able to fully benefit from the gained muscular strength to increase work efficiency.

No significant differences between the groups concerning gait variables were displayed after the intervention period. Loizeau et al.36 found that patients fitted with THA walked more slowly and had a longer stance time and a shorter stride length compared with healthy subjects. Sicard-Rosenbaum et al.38 compared patients undergoing THA 9 months to 6 years earlier with an age-and sex-matched control group. Maximum walking speed was higher in the control group, but gait parameters such as step and stride length, stance time, support base, step, swing, and single and double support time were not significantly different between the groups. Detecting differences in walking speed but not in other gait parameters is in

### DISCUSSION

The main finding in this study is that the STG shows significantly higher performance in leg press, RFD, and hip abduction after the 4-week training intervention compare with the CRG. There was a trend towards higher walking efficiency in the STG 5 weeks postoperatively. The study demonstrates that it is both feasible and safe to carry out maximal strength training 1 week after undergoing THA.

The patients in the STG performed training with a load corresponding to 80% to 90% of 1RM. Maximal strength training induced a great increase in strength both in leg press and hip abduction in the STG compared with the CRG 5 weeks postoperatively. Muscle strength in the operated leg increased by 230% (leg press) in the STG in the present study, indicating maximal strength training to be highly effective. The strength outcome and the concomitant increase in RFD are in line with the findings of Hoff,23 Karlsen,23 and colleagues. Suetta et al.28 demonstrated increased leg muscle strength by 22% to 28% after a 12-week resistance training intervention after THA. The resistance training started at approximately day 7 with an intensity of 50% of 1RM the first week, increasing to 80% of 1RM 6 weeks postoperatively. The increase in strength was less compared with the strength achieved in the present study, and the strength improvement occurred between 5 and 12 weeks when the training load was higher than 70% of 1RM. Abduction exercises were not conducted in the study by Suetta et al.28 Because strength of the abductor muscles is crucial for walking without limping and preventing falls, as mentioned earlier, it would be natural to include specific training of these muscles.

Trudelle-Jackson and Smith1 report strength and stability benefits from a weight-bearing program initiated 4 months postoperatively. Hauer et al.30 show increased strength and functional performance in patients undergoing hip surgery after intensive strength training starting 6 to 8 weeks postoperatively. Compared with the present study, the strength training was initiated relatively late. Initiating the massive strength training as soon as possible after the surgery is of great importance because major surgery and subsequent hospitalization are known to cause a severe decline in muscle mass and muscle strength.28,52 Muscle strength declines 3% to 4% a day during the first week of immobilization.53 Furthermore, because of activity-related pain and contracture of the hip, most patients experience a period of inactivity before surgery.

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### Table 4: VO₂max and Work Efficiency for the STG and the CRG

<table>
<thead>
<tr>
<th>Measure</th>
<th>STG (n=12)</th>
<th>CRG (n=12)</th>
<th>ANOVA Main Effects/ t test</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂max (mL·kg⁻¹·min⁻¹)</td>
<td>29.4±7.9</td>
<td>21.4±7.0</td>
<td>29.8±6.3</td>
</tr>
<tr>
<td>Max HR (beats·min⁻¹)</td>
<td>160±11</td>
<td>136±19</td>
<td>163±13</td>
</tr>
<tr>
<td>R (VCO₂/VO₂)</td>
<td>1.06±0.1</td>
<td>0.99±0.07</td>
<td>1.14±0.09</td>
</tr>
<tr>
<td>Borg scale* (6–20)</td>
<td>16±1</td>
<td>16±2</td>
<td>17±1</td>
</tr>
<tr>
<td>Work efficiency test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work efficiency (%)</td>
<td>16.2±5.9</td>
<td>ND</td>
<td>17.6±7.7</td>
</tr>
<tr>
<td>VO₂ (mL·kg⁻¹·min⁻¹)</td>
<td>17.4±2.5</td>
<td>ND</td>
<td>18.3±3.2</td>
</tr>
<tr>
<td>HR (beats·min⁻¹)</td>
<td>118±15</td>
<td>ND</td>
<td>114±15</td>
</tr>
</tbody>
</table>

NOTE: Values are mean ± SD for each variable. P<, P<, and P< probability for difference within and between groups and for interaction, respectively. Abbreviations: ANOVA, analysis of variance; HR, heart rate; ND, no data; R, respiration coefficient; T1, test preoperatively; T2, test 1 week postoperatively; T3, test 5 weeks postoperatively; VCO₂, carbon dioxide consumption.

* Borg scale, subjective evaluation of perceived exertion.

† Differences between the groups at T3 by 2-sample t tests.
line with the findings in the present study, except maximum gait speed, which we did not measure. However, Vaz et al. demonstrated abductor strength to be related to distance walked during a 6-minute walk test, confirming the importance of abductor strength in walking speed. Weak hip abductors may suffice for walking at a self-selected pace, and it can be speculated whether a faster walking speed than 4km/h would have revealed differences in some of the gait variables among the groups in the present study. Weaker abductor musculature on the operated side in the CRG may have contributed to poor trunk control during body weight transfer from the operated to the healthy leg. The poor trunk control in the CRG may have been more pronounced with faster walking speeds.

For decades, partial weight-bearing versus full weight-bearing in uncemented THA during the first 8 weeks has been discussed. Several authors now report no adverse effects of full weight-bearing immediately after surgery. Instead, full weight-bearing is documented to reduce hospital stay and improve the rehabilitation process. Questions can be asked about whether maximal strength training is recommended for patients immediately after THA. The reason for the problem to be addressed is whether the strength of the reattachments of the musculus gluteus medius to the greater trochanter when the lateral approach is used. In the present study, the Merle D’Aubigné and Postel mean score was 17 in both groups after 5 weeks, indicating a normal gait without limping and a sufficient reattachment of the gluteus medius to the trochanter major. Furthermore, biomechanical calculations demonstrate a torsion moment in the caput femoris of 37N.m in a 75-kg person if normal offset in single leg stance, such as stair climbing, which corresponds to 90kg. The weight load mimics the leg press intervention in the present study.

Quality-of-life measurements demonstrated a higher MCS in the STG at the test 1 week after surgery. This may be explained by the effect of being the intervention part of a study and the fact that the participants knew they would get extra follow-up time. No differences in the quality-of-life variables were detected 5 weeks postoperatively. An explanation may be that generic instruments, such as the SF-36, may often lack the sensitivity to detect differences between treatment policies that are compared in clinical trials. Disease-specific scales may have revealed differences among the groups because they generally are more responsive than generic health status measures.

Two of the patients in the CRG had outpatient treatment. The physical outcomes of the 2 patients, however, did not differ from the other participants in the CRG. Recent studies demonstrate no differences in functional outcomes, pain, or patient satisfaction between groups allocated to inpatient or outpatient rehabilitation, or to home- or center-based exercise programs.

In the present study, the training duration was relatively short. A longer duration of the training period (10–12wk) may have revealed differences between the groups in work efficiency as well as gait patterns. Future studies would benefit from a larger sample size and a longer training period for the participants. Adding the variables maximum walking speed or a 6-minute walking test may result in differences between the groups in gait variables. A higher work load than 40W may have been favorable in demonstrating differences in work efficiency.

**Study Limitations**

The sample size of the study was small based on strength differences in a maximal strength training intervention. Work efficiency and gait pattern data were not available for the patient group, and a higher sample size is required to detect statistical differences. Although different physicians supervised the patients in the study and 2 of the patients received outpatient treatment, the significant results show that early maximal strength training increases lower extremity strength after THA.

**CONCLUSIONS**

The present study demonstrates that maximal strength training is an appropriate treatment in an early postoperative phase after THA. Furthermore, maximal strength training improves muscular strength to a higher extent in the STG compared with the CRG, together with a trend towards higher work efficiency. No difference in gait patterns or quality-of-life measurements between the groups was detected after the intervention period.

**References**


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