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# Recovery in mechanical muscle strength following resurfacing vs standard total hip arthroplasty – a randomised clinical trial

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SUMMARY

*Objectives:* To evaluate the effect of resurfacing vs standard total hip replacement on post-surgery hip and knee muscle strength recovery in a prospective randomised controlled trial at the Department of Orthopaedics, University Hospital, Odense, Denmark.
*Methods:* Forty-three patients were randomised into (A) standard total hip arthroplasty (S-THA) and (B) resurfacing total hip arthroplasty (R-THA). Pre-surgery assessment and follow-up were conducted (8, 26 and 52 wks). Maximal isometric muscle strength (Nm) and between-limb asymmetry for the knee extensors/flexors, hip adductors/abductors, hip extensors/flexors were analysed.
*Results:* Maximal knee extensor and hip abductor strength were higher in S-THA than R-THA at 52 wks post-surgery ($P \leq 0.05$) and hip extensors tended to be higher in S-THA at 52 wks ($P = 0.06$). All muscle groups showed substantial between-limb strength asymmetry (7–29%) with the affected side being weakest ($P \leq 0.05$) and hip flexors being most affected. Asymmetry was present in half of the muscle groups at 26 wks ($P \leq 0.05$), and remained present for the hip flexors and hip adductors at 52 wks ($P \leq 0.05$).
*Conclusions:* R-THA patients showed an attenuated and delayed recovery in maximal lower limb muscle strength (in 2/6 muscle groups) compared to S-THA. Notably, the attenuated strength recovery following R-THA was most markedly manifested in the late phase (1 yr) of post-surgical recovery, and appeared to be due to the detachment of the lower half of the gluteus maximus muscle rather than implant design *per se*. Thus, the present data failed to support the hypothesis that R-THA would result in an enhanced strength rehabilitation compared to S-THA. Further, between-limb asymmetry remained present for hip flexors and adductors after 52 wks.
Trial registration: NCT01229293


## Introduction

It seems well-established, based on self-reported data, that total hip arthroplasty (THA) successfully relieves pain[1,2] and successful outcome is not related to pre-surgery osteoarthritis (OA) severity[3]. However, mild-to-moderate impairments and disabilities seem to exist post-surgery, including problems performing activities of daily living (ADL), multilevel muscle weakness[4,5], hip abductor weakness[4,6], hip extensor plus hip flexor weakness[7], and long-term (6–48 months) reduction in maximal hip abductor muscle strength[8]. The literature also suggests that standard hip arthroplasty (S-THA) may not provide a lasting solution for the young and active patient[9,10].

Resurfacing total hip arthroplasty (R-THA) could be an alternative. The potential benefits are e.g., minimal volumetric wear[11], revision to a standard femoral component if necessary[12], and lower risk of dislocation as the femoral component approach anatomical head size[13]. Also, the conservation of proximal femoral bone[14,15] facilitates close to normal hip anatomy, which may provide a more physiological loading pattern, and could lead to improved function[16]. The early to mid-term results from specialized centres have been encouraging[15,17], and narrowing of patient selection criteria and refinements of surgical technique have shown results comparable to those of S-THA[12,18]. In comparative studies similar functional scores but higher activity levels using R-THA compared to standard 28-mm THA have been reported[18–21]. However, inferior clinical results have also been reported[22,23]. Also, an improved functional performance in terms of a more normative gait pattern, increased speed and enhanced postural stability have been suggested after R-THA[24,25]. R-THA therefore seems to be an attractive concept for the young and active patient with end-stage OA.

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The effect that short-term muscle disuse imparts on the neuromuscular system has been demonstrated to include decreased muscle strength and a diminished neural drive to muscle fibres[26–28]. Moreover, recent data have indicated that young-old (61–71 yr) may show a reduced ability to regain lower limb muscle mass following short-term immobilization compared to young-adult (21–27 yr) individuals[28]. This suggests that some age groups might need longer time to recover from surgery or more effective rehabilitation efforts may be needed[5,29–32]. Thus, it seems relevant to examine the long-term consequences of surgery on lower limb muscle strength recovery in the elderly, but also whether the recovery is affected by type of surgery.

Substantial loss in maximal muscle strength in the operated limb compared to the non-operated limb has also been reported following total hip replacement surgery, but primarily for selected muscle groups[4,7,29]. Less seems to be known about the extent to which surgery will impact on mechanical muscle strength recovery in all the major lower limb muscle groups (hip and thigh).

The purpose of this study was therefore to (1) investigate the long-term post-surgery recovery in maximal lower limb muscle strength after resurfacing vs standard THA and (2) to determine the magnitude of between-limb muscle asymmetry. It was hypothesized that maximal hip and thigh muscle strength would recover more effectively with R-THA than S-THA.

## Materials & methods

### *Participants*

Two hundred and sixty-nine patients with unilateral primary OA were assessed for eligibility but forty-three participated in the study, which was conducted at the Department of Orthopaedic Surgery and Traumatology, Odense University Hospital, Denmark (Fig. 1). A total of 226 patients were excluded prior to randomization (175 subjects failing to comply with inclusion criteria), seven subjects declined to participate and 22 subjects choosing surgery at another hospital due to hospital strike, while 13 decided not to have surgery. A total of two patients were not randomised despite being eligible. Exclusion criteria were osteoporosis, defined as T-score less than 2.5 standard deviation (SD) the average bone density in the lumbar spine or proximal femur, BMI > 35, severe acetabulum dysplasia (AP centre edge <15–20°), femur anteversion >25°,

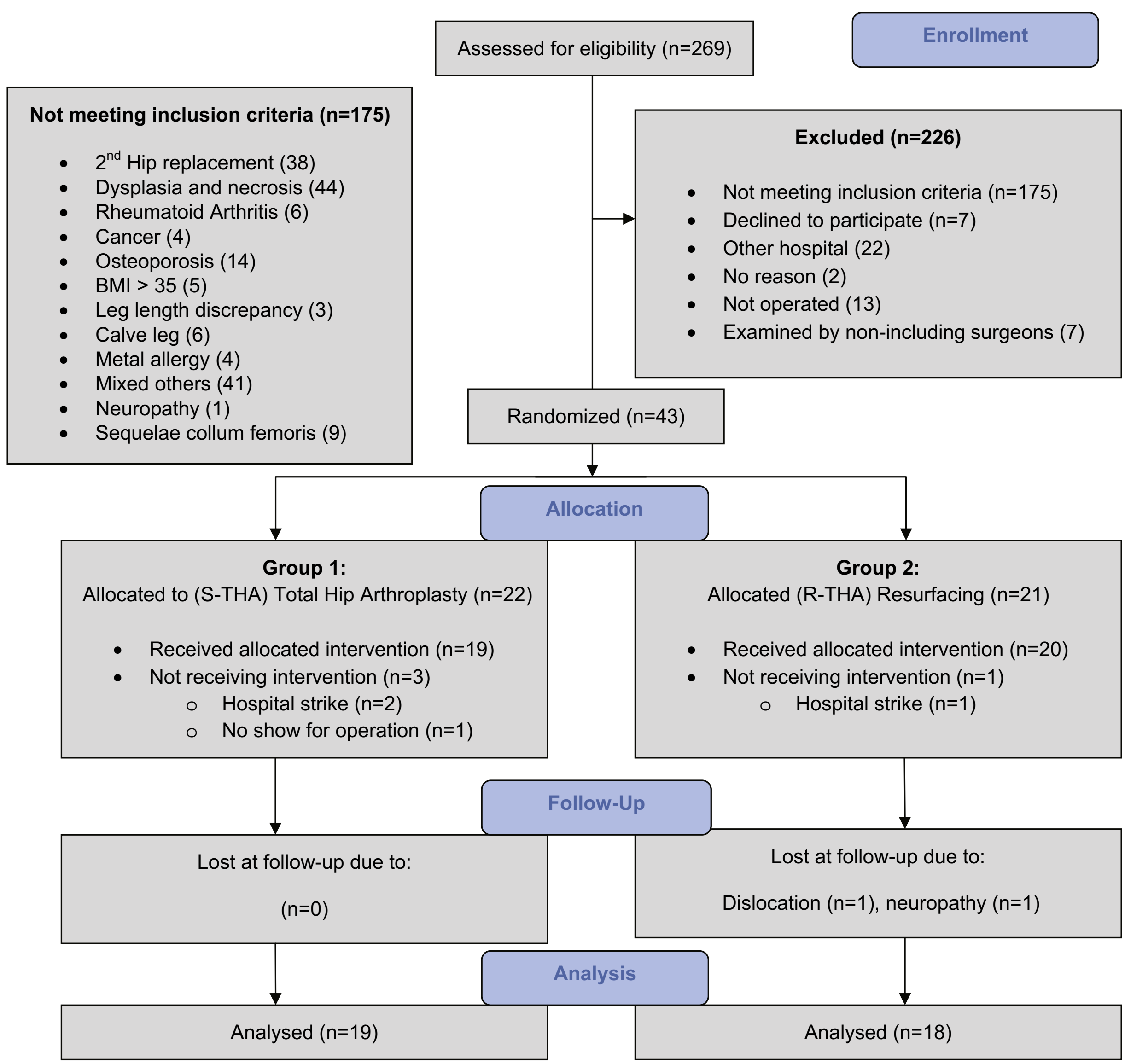


**Fig. 1.** Flow chart of participant's throughout the RCT.

femoral head deformity, leg-length discrepancy >1 cm, offset problems, earlier fracture of the ipsilateral proximal femur, rheumatoid arthritis, and neuromuscular or vascular disease. Of the 43 patients randomised three had surgery at a private hospital (hospital strike), while one never showed up and finally two patients were not available at follow-up (Fig. 1). Consequently, the study group consisted of 10 women and 27 men. None of the patients used external aids and were radio graphically evaluated pre-surgery and diagnosed with end-stage OA. The trial was performed in compliance with the Helsinki Declaration and personal related data were kept in a password encrypted database in accordance with Danish Data Protection Agency's privacy policy. The study was approved by the local Ethical Committee and patients were informed orally and in written form about the study conditions. All study participants gave their written informed consent.

*Study design*

The study was designed as a randomised clinical trial (no. NCT01229293) and patients were assigned to either S-THA or R-THA based on lots drawing using sealed envelopes. Block randomization was used to prevent bias from a potential surgical learning process. Subsequently, investigator blinding was not possible because the size of the surgical incision differed, and patients could not be blinded because of movement restrictions. All randomization were handled by a nurse who did not take part in the patient evaluation. The patients did also take part in a clinical study on migration of implants and clinical outcome (NCT01113762).

*Surgical intervention*

R-THA patients received ASR®, (DePuy, Warsaw, IN, USA) which was made in high-carbon cobalt–chromium alloy and mean head size was 51.8 mm (47–57 mm) and cup size 58.1 mm (52–64 mm). The cup was placed cement less in press-fit and the femoral component was cemented with SmartSet™ GHV Bone Cement (DePuy, Warsaw, IN, USA). S-THA patients received a Mallory-Head cup (Biomet®), with polyethylene liner. On the femur side they had a 28 mm Ceramic head (Ceramtec) on a titanium Bimetric (Biomet®) stem. The components were inserted according to the manufactures instructions. Intended cup inclination angle was of 45° with 20° anteversion. In both procedures the gluteus maximus was divided blunt and external rotators were detached but reinserted during closure of the wound. To ensure a homogenous R-THA group the tendious insertion of gluteus maximus was detached and reinserted in all R-THA patients without exception. In contrast, the S-THA components were inserted without detachment of the gluteus maximus muscle tendon. All surgical procedures were performed by consultant orthopaedic surgeons specialized in hip surgery, using the posterior-lateral approach. The two surgeons had comparable experience levels and both received extensive R-THA training at certified centres. Prior to the study both surgeons had operated +30 patients and in the present study both types of surgical procedures were performed by both surgeons to avoid systematic bias.

*Post-surgical rehabilitation*

All patients were allowed full weight-bearing immediately post-surgery and in-hospital rehabilitation was supervised by a trained physiotherapist. The exercise protocol consisted of six basic dynamic exercises (knee extensors/flexors, abductors/adductors and extensors/flexors of the hip) performed in the early phase of recovery using rubber bands as resistance and was identical for both treatment groups. The R-THA had free hip range of motion whereas the S-THA group had restrictions for 8 wks following surgery (No internal rotation or hip flexion >90°).

*Femoral and acetabular cup offset*

Offset measurements were performed on standardized anterior posterior radiographs of the pelvis. Measurements were taken pre-surgery and the same observer made all measurements in both groups. Femoral offset was defined as the distance from the centre of rotation of the femoral head to the anatomical femoral axis. The cup offset was defined as the distance from the centre of rotation of the femoral head to the medial aspect of the acetabular teardrop. In addition, we defined total offset as the sum of femoral and cup offsets.

*Maximal muscle strength assessment*

Maximal muscle strength (Nm) was measured during maximal voluntary unilateral knee extension–flexion (seated), hip extension–flexion, and hip adduction–abduction (standing), respectively (Fig. 2). Both the affected (AF) and non-affected (NA) legs were assessed pre-surgery (6 ± 2 wks prior to surgery) and at 8, 26 and 52 wks post-surgery. Warm-up prior to testing consisted of 5-min level walking in the lab at self selected and at maximum speeds. One to two sub-maximal contraction efforts to become familiarized with the setup were allowed. For each exercise, three trials of approx. 4-s contraction duration were performed and the trial with highest isometric strength was selected for further analysis. On-line visual feedback of the exerted force was provided to the subjects on a PC-monitor. To stabilize the body and minimize contra-lateral muscle compensation, subjects were secured during all up-right exercises with a wide strap positioned just below the iliac crests and further support was offered by use of handrails [Fig. 2(A–B) and (D–E)]. During seated exercises the waist strap was positioned across the proximal part of femur and participants were allowed to hold on to the construction for further support [Fig. 2(C–F)].

Hip flexion, -adduction and -abduction contractions were all performed in a neutral up-right position whereas hip extension was performed with a forward lean of 45° to test the hip extensors (gluteus maximus, hamstring muscles) in a mechanically more effective position relevant for several daily activities such as walking, stair ascend and chair rise. All knee contractions were performed at a knee joint position of 90°. Strict adherence was given to ensure test contractions performed in the same postural posture at all test sessions by use of rulers that were fixed to the construction. Pauses between successive contractions were 15–30 s. Patients were asked to rate pain intensity following each of the six test contractions on each of the four sessions (pre, 8 wks, 26 wks and 52 wks). In all cases pain was assessed within 30 s after the last contraction. The M-VAS was presented to the patients with instructions on how to indicate his/her level of pain. The scoring device presented to the patients consisted of a mechanical slide ruler with a 100 mm long line with ends marked "no pain" and "worst pain ever". On the flip-side the recorded vales were rounded to the nearest integer. Pain for both the affected and non-affected limb was recorded.

*Test–retest reliability*

The test–retest reliability was established for all exercises using a subgroup ($n = 20$) of patients. The two test occasions were separated by less than 7 days.

*Outcome measure*

The primary outcome (maximal isometric muscle strength) and secondary outcome (between-limb asymmetry) calculated as

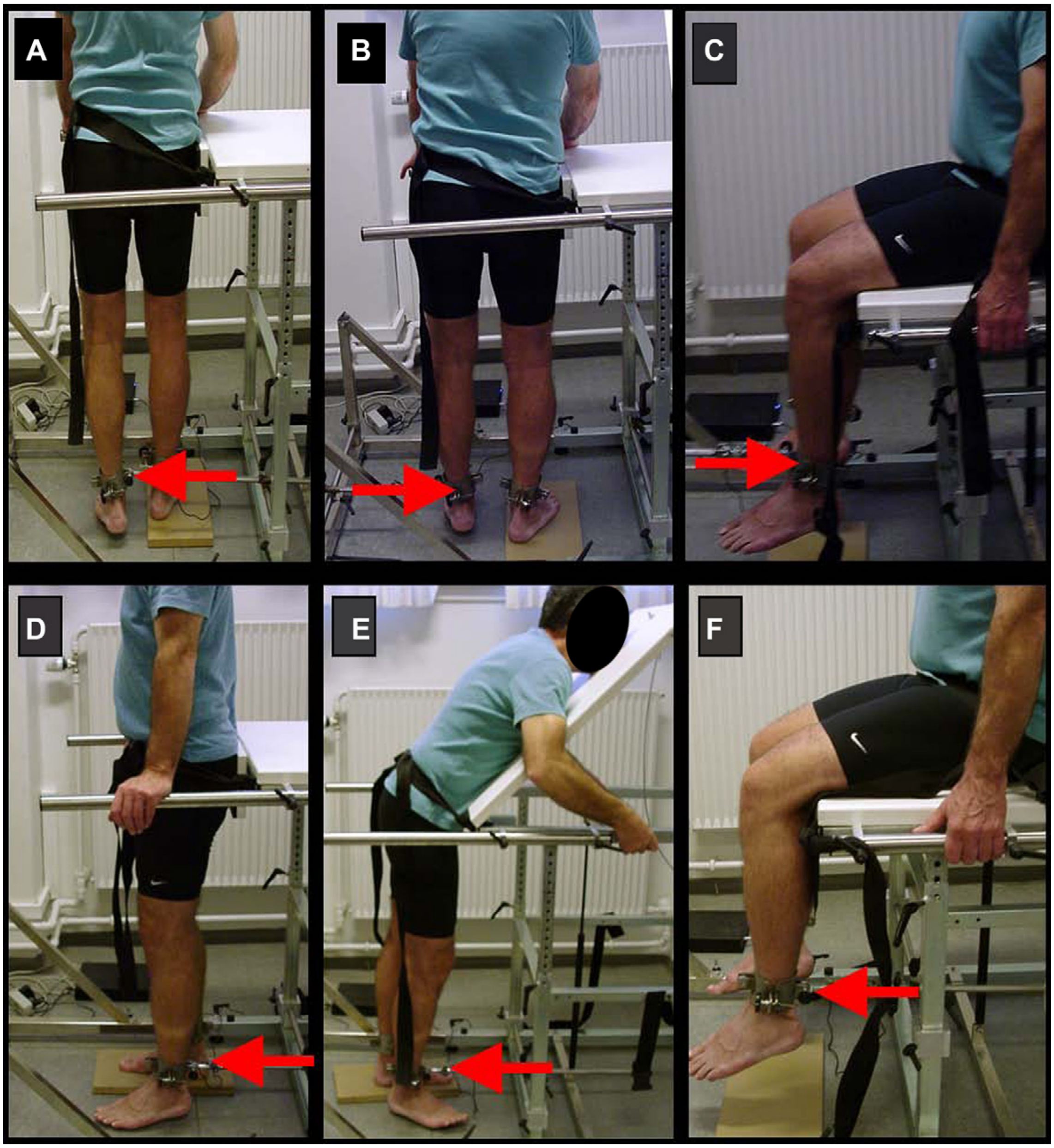


**Fig. 2.** Setup of the isometric test contractions: (A) Hip abductors, (B) Hip adductors, (C) Knee flexors, (D) Hip flexors, (E) Hip extensors, (F) Knee extensors.

strength deficit between affected (A) and non-affected (NA) limb [(A − NA)/NA × 100] were obtained for knee extensors/flexors and hip adductors, abductors, extensors and flexors, respectively.

*Sample size*

Power and sample size estimation was performed using one pre-operative and three follow-up assessments and a correlation between follow-up measurements of 0.4. We estimated a change of 20% would be of clinical relevance, and used a SD of 20 Nm. To achieve a statistical power of 80% ($\beta = 0.80$) it was calculated that a sample size of $n = 13$ was needed in each intervention group in order to detect statistical significant differences at $\alpha = 0.05$ level.

*Statistical analysis*

To evaluate the treatment effect (mean difference between the groups at 8, 26 and 52 wks) and magnitude of between-limb asymmetry we employed the random effects mixed linear model analysis (repeated measures) and point estimates[33]. This model includes the interaction between treatment and elapsed time, adjusted for pre-surgery values and assuming that data were missing completely at random (MCAR)[33]. Model assumptions were checked by residual plots. We checked all outcome measures for Gaussian distribution and found that parametric statistics were appropriate except for the M-VAS scores, gender distribution and operated leg. Consequently, those data were analyzed using Mann–Whitney rank sum test. All statistics test used an $\alpha$-level of 0.05 and data are presented as means with SD unless otherwise stated.

## Results

*Reliability*

The mean within-subject variability ($CV_{w\text{-}s}$) for all six isometric muscle measurements was 7.6% (range: 5.0–10.8%). Smallest detectable change with a significant probability level of 95% ($SDC_{95\%}$) mean was 25 Nm (range, 14.9 Nm–39.0 Nm). Intraclass correlations were >0.8, for all exercises.

*Patient characteristics*

Thirty-seven of the 39 patients, who received the allocated intervention, completed the study. There were no significant differences between the two treatment groups pre-surgery or in the follow-up times (Table I). Overall, more men were operated compared to females (73%) and the majority of patients were operated on their left leg (65%). This distribution was similar in both groups. Pre- and post-surgery measurements of the femoral, cup and total offset are displayed in Table II. In R-THA all offsets were unchanged after surgery. In S-THA, post-surgery measurement showed an increased femoral offset from 33.1 to 36.8 mm ($P = 0.03$) and a decreased cup offset from 34.9 to 29.9 mm ($P = 0.01$). In result, total offset was unaltered following surgery. However, absolute differences between pre-surgery and post-surgery measurements were small suggesting that the biomechanical stability of the hip reconstruction procedure was about similar with both arthroplasties.

*M-VAS scoring*

Pain scores were below 2 for both the affected and non-affected legs during all test sessions, and did not differ between R-THA and S-THA patients. Low scores were persistent throughout the follow-up period and at no time point did median score exceed 2.

*Maximal muscle strength*

We did not observe any differences in maximal strength between the treatment groups pre-surgery, post-surgery at 8 and 26 wks. However at 52 wks post-surgery both knee extensor and hip abductor strength were higher in S-THA than R-THA ($P \leq 0.05$) [Fig. 3(A and D)]. Moreover maximal hip extensor strength tended to be higher in S-THA at 52 wks ($P = 0.06$) [Fig. 3(E)]. The remaining muscle groups did not show any differences. The largest relative improvement pre-surgery to 52 wks (% change) was observed for S-THA hip extensors and abductors [54.0%, 44.7%, Fig. 3(D and E)], whereas hip adductor strength only improved 14% and 11% for S-THA and R-THA respectively [Fig. 3(C)].

Except for knee flexors an increase over time was observed for all muscle groups independent of treatment group at both 26 and 52 wks compared to 8 wks ($P \leq 0.05$). Knee flexors became significantly increased after 52 wks ($P = 0.005$). Both groups generated the highest values of isometric strength during hip extension followed by abduction and knee flexors being the weakest muscle group. Men were stronger than females for all hip muscle groups examined 17–42 Nm ($P \leq 0.05$), and borderline for knee extensors (12 Nm, $P = 0.06$) but no gender difference for knee flexors were observed ($P = 0.70$). An overall decline in strength was observed for both genders equivalent to 1 Nm/yr.

**Table I**
Baseline characteristics of patients included in the study

| Characteristic | S-THA ($n = 19$) | R-THA ($n = 18$) |
|---|---|---|
| Age at surgery, yr | 55 ± 6.2, (44–64) | 57 ± 5.1, (45–65) |
| Body mass index, kg/m$^2$ | 28.4 ± 2.8, (23.4–36.5) | 27.3 ± 5.1, (19.2–36.5) |
| Gender, F:M | 3:16 | 7:11 |
| Affected side, L:R | 13:6 | 11:7 |
| Follow-up, T1, wks | 8.7 ± 1.0, (8–10) | 8.2 ± 1.0, (6–10) |
| Follow-up, T2, wks | 24.5 ± 1.4, (23–28) | 24.4 ± 0.8, (23–26) |
| Follow-up, T3, wks | 52.3 ± 1.2, (51–56) | 52.2 ± 1.9 (48–56) |
| Leg-Length, cm | 86.1 ± 3.0 | 88.4 ± 6.1 |

No significant difference between any of the group variables (mean ± SD, range), F = female, M = male, L = Left, R = Right.

**Table II**
Measurements and analysis of total, femoral and acetabular cup offset in the affected hip

| | R-THA | | P | S-THA | | P |
|---|---|---|---|---|---|---|
| | Pre | Post | | Pre | Post | |
| Total offset, mm | 68.0 ± 8.7 | 67.4 ± 9.4 | 0.77 | 68.6 ± 8.9 | 67.5 ± 8.5 | 0.59 |
| Femoral offset, mm | 34.1 ± 4.9 | 33.9 ± 6.3 | 0.93 | 33.1 ± 5.9 | 36.8 ± 7.8 | 0.03 |
| Cup offset, mm | 33.5 ± 5.5 | 34.1 ± 4.3 | 0.68 | 34.9 ± 5.1 | 29.9 ± 3.3 | 0.01 |

Two-sample mean-comparison test (paired) used.

*Affected leg vs non-affected leg*

Maximal between-limb asymmetry ranged from 7% to 29%, ($P \leq 0.05$) and hip flexor maximal strength was significantly more affected than the remaining muscle groups (29.2%, $P < 0.001$, Fig. 4). Pre-surgery all muscle groups showed substantial strength asymmetry with the affected side being weakest ($P \leq 0.05$). Post-surgery limb asymmetry increased at 8 wks for four out of six muscle groups ($P < 0.05$). At 26 wks post-surgery knee extensor, and hip adductor and flexor strength remained asymmetric ($P < 0.05$). One year post-surgery side-to-side asymmetry persisted for the hip flexors and hip adductors ($P < 0.05$).

## Discussion

The present study is the first to prospectively investigate the longer-term (1-yr) recovery in both maximal hip and knee muscle strength and between-limb asymmetry in patients following elective hip replacement surgery. The main finding of the present study was that R-THA demonstrated impaired muscle strength gains (in 2/6 muscle groups examined at 52 wks) compared to S-THA even though patient and peri-operative management were the same. These findings were contrary to our initial hypothesis. Moreover, despite longitudinal gains in maximal muscle strength in the affected (operated) limb, substantial between-limb muscle asymmetry persisted 26 wks following surgery, and remained present for the hip flexors and adductors at 52 wks.

S-THA patients did not experience a slower muscle recovery at 8 wks post-surgery compared to the R-THA group, although they had post-surgery movement restrictions imposed on them. In fact, no differences in lower limb muscle strength were observed between S-THA and R-THA during the first 26 wks following surgery. However, at 52 wks post-surgery maximal knee extensor and hip abductor muscle strength were higher in S-THA than R-THA with a similar trend ($P = 0.06$) observed for the hip extensors. Interestingly, the differences in muscle strength between the two treatments emerged only in the longer term (1 yr), and could therefore not be explained by pre- to post-surgery modifications to joint geometrics. As a possible explanation for the observed differences at 52 wks, the lower half of the gluteus maximus muscle was detached from its tendious insertion on the femur (gluteal tuberosity) during R-THA surgery. As time progresses this may have lead to partial muscle atrophy and/or changes in the mechanical properties, resulting in impaired hip extensor strength and to a lesser degree impaired abductor strength. This notion is supported by others who compared step-test performance between large head THA and R-THA patients and reported a superior function in THA patients[34]. It was suggested that the release of the gluteus maximus tendon during R-THA could have produced a deficit in mechanical muscle function, which would be particularly apparent during stair climbing[34]. In addition, a direct

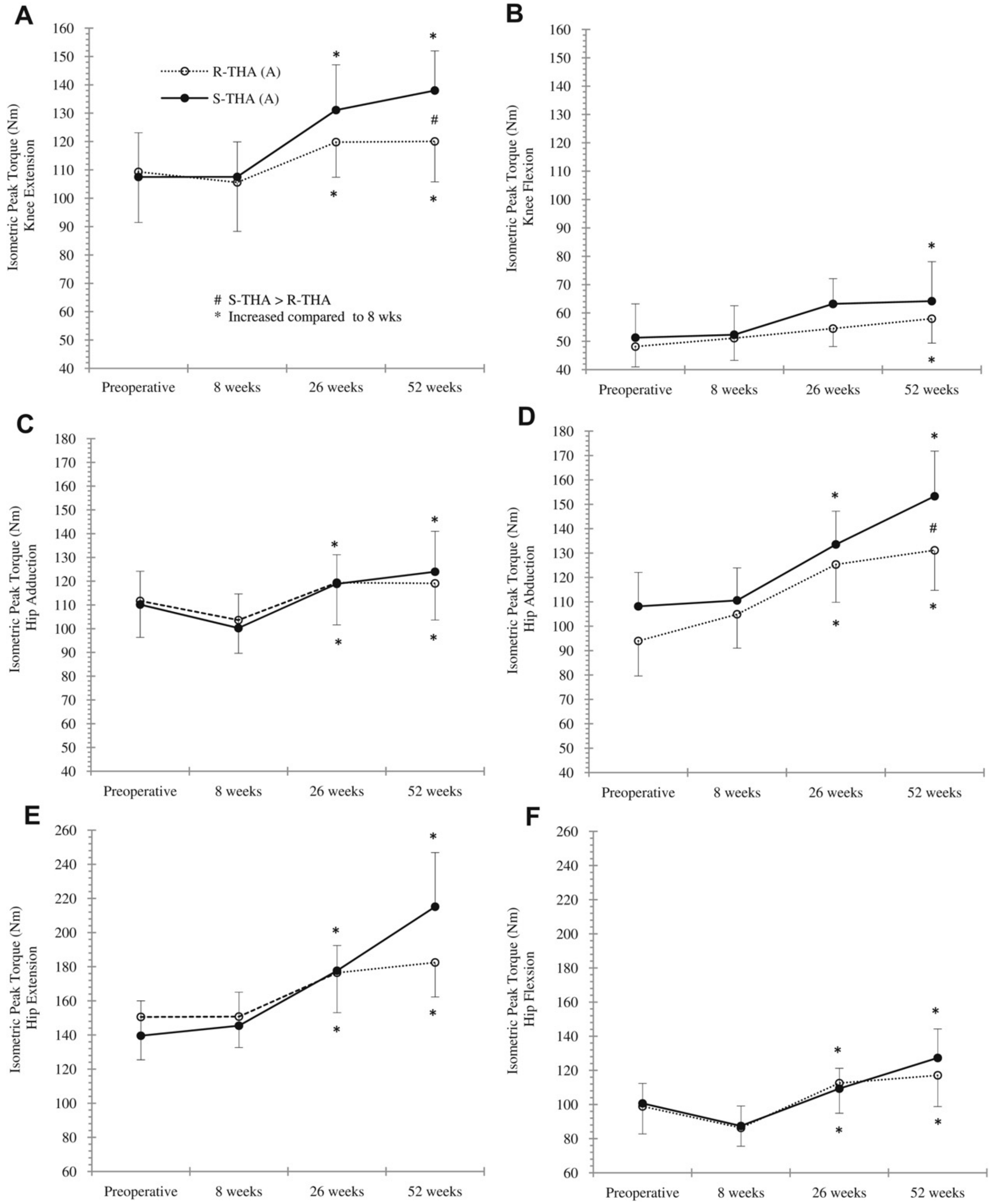


**Fig. 3.** Longitudinal development in maximal lower limb muscle strength (Nm) for the knee extensors (A), knee flexors (B), hip adductors (C), hip abductors (D), hip extensors (E), and hip flexors (F) in the affected limb pre-surgery and at 8, 26, 52 wks post-surgery for S-THA (●) and R-THA (○) implants (mean ± 95% C.I.). # S-THA > R-THA, * increase compared to 8 wks ($P < 0.05$).

trauma of the gluteus maximus muscle caused by the preserved femoral head and retractors during surgery might also have contributed to the weaker muscle strength in the R-THA.

The operated (affected) limb demonstrated increased maximal muscle strength for the hip extensors (+54%), hip abductors (+42%) and hip flexors (+30%) from pre- to 52 wks post-surgery. Despite such longitudinal strength gains hip replacement patients may not be capable of reaching muscle performance levels similar to those seen in non-operated age-matched subjects. Previous reports suggest that hip patients experience prolonged muscle weakness compared to matched controls[7,35]. Specifically, S-THA patients were only able to generate 60% of the muscle strength recorded in community-dwelling controls during isometric hip flexion, and 87%, 84% of hip extension and abduction strength, respectively. Thereby

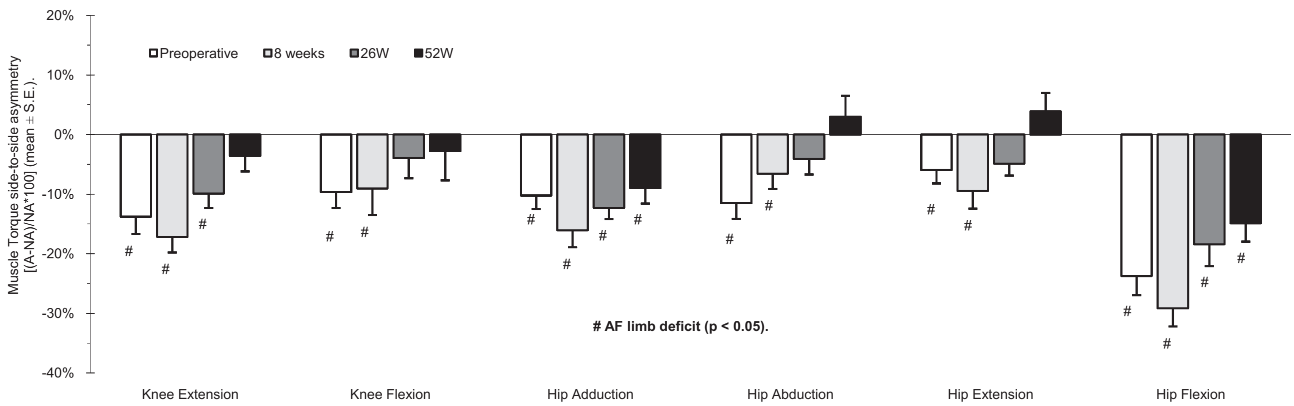


**Fig. 4.** Maximal between-limb strength asymmetry [(AF − NA)/NA × 100] (mean ± S.E.) for knee extensors, knee flexors, hip adductors, hip abductors, hip extensors and hip flexors pre-surgery and at 8 wks, 26 wks and 52 wks follow-up. # signing AF limb deficit ($P < 0.05$).

demonstrating that mechanical muscle strength may not be normalized 4–5 months post-surgery[7].

The present study also identified substantial muscle strength asymmetry between affected and non-affected limbs for all muscle groups (7–29%). Our asymmetries in strength are in accordance with previous reports based on isometric[6,36] and dynamic muscle strength assessments[4,29], and those reported in knee replacement patients[37,38]. Notably, increased asymmetry was observed 8 wks after surgery for the knee extensors, hip adductors, hip extensors and hip flexors, after which time point improvements were noted. This negative short-term trend likely was due to immobilization and post-surgical stress, and possibly accompanied by reduced neuromuscular activation and reduced muscle size[28]. However, 26 wks post-surgery substantial asymmetry persisted in 50% of the muscle groups investigated, and for the hip adductors and hip flexors significant asymmetry was sustained throughout the study period (cf. Fig. 4).

We found hip flexor strength was more severely impaired than any of the other muscle groups examined (29%, Fig. 4). This finding supports previous reports by Shih *et al*., who also compared hip flexors, extensors and abductors and reported hip flexors to have the slowest strength recovery in the first year following THA[4]. Also, the hip flexors and hip abductors remained asymmetric even 2-yrs after THA when both hip extensors and hip adductors had normalized[39]. Thus, this suggests that current rehabilitation protocols may not adequately restore hip flexor strength and future rehabilitation should perhaps involve intensified focus on the adductors and flexors of the hip. In further support of this notion, the flexors and adductors of the hip were the most loaded muscle groups during walking and stair descend[40].

General muscle weakness has been associated with an impaired performance during ADL in aging individuals[41–43]. Furthermore, between-limb muscle power asymmetry appears to represent an increased risk of falls[44]. These and present findings collectively suggest that the post-surgical rehabilitation in hip replacement patients should have increased focus on effectively increasing maximal muscle strength and power, in order to remove the apparent persistence muscle weakness and asymmetries. For this purpose, intensive resistance training in post-surgery hip replacement patients has been indicated to be safe and more effective than conventional rehabilitation therapy alone for inducing longitudinal gains in muscle mass, neuromuscular function, mechanical muscle output and locomotor performance, respectively[4,29,30,32]. Surprisingly, no improvements in quality-of-life scores were detected after strength training intervention in THA patients[32] or when muscle asymmetry was still present[39] but sample sizes in both studies were small. Although, muscular impairments are associated with functional limitations in frail elderly, adequately powered studies linking improvements in strength or asymmetry to similar improvements in patient reported outcome measures (PROMs) in the THA population is lacking.

Surgery-induced shifts in the location of the hip joint centre could potentially have affected the joint torque-generating capacity of the muscles post-surgery. In muscle simulation modelling introducing a 20 mm displacement in hip joint centre the torque-generating capacity of the hip muscles was substantially affected, especially in the case of superior displacements[45]. However, mediolateral joint centre displacement also affected the magnitude of simulated hip adductor and abductor muscle torque[45]. In the present study total offset did not differ between S-THA and R-THA whereas femoral offset and cup offset were increased and decreased respectively in the S-THA group by 3–5 mm (Table II). The slight medial displacement observed in S-THA cup offset would not be expected to affect the mechanical action of the hip extensors or flexors but might have reduced the torque-generating capacity of the hip adductors. The reduced cup offset post-surgery in the S-THA group was compensated by increased femoral offset of similar magnitude leaving the overall torque-generating capacity of the hip abductors unchanged. In a recent study a significant reduction in the femoral offset was found in the resurfacing group making the authors believe that R-THA did not restore hip mechanics as accurately as S-THA[46]. However, our offset changes were consistent with those reported in other studies where no change was observed in R-THA patients[47].

Potential limitations may exist with this study. Firstly, an age and gender matched non-operated control group was not included. Previous studies have used the non-affected contra-lateral leg as control, however in the present study small albeit significant gains in maximal muscle strength were observed for the non-affected leg after 26 wks for all strength tests (data not included). Based on these observations the non-affected leg could not be justified as an unbiased control leg. The lack of controls prevented us from making comparison in absolute values with healthy population data. Finally, the muscle testing involved isometric contractions alone, whereas most ADL are performed using dynamic contractions. However, there is no evidence to support that individuals with high isometric muscle strength should be weak when performing dynamic contractions, or *vice versa*[48,49]. Further, measures of isometric strength conditions bear a strong predictive relation with functional capacity[50].

## Conclusions

Based on the present data we could conclude that R-THA resulted in an attenuated and delayed recovery in mechanical muscle strength compared to S-THA, despite that peri-operative management was the same. Notably, the impaired recovery with R-THA was most accentuated in the late phase (1 yr) of post-surgical recovery, suggesting that R-THA may have negative consequences for the longer-term recovery in lower limb muscle strength. Thus, the present data could not support our initial hypothesis that R-THA results in a more efficient rehabilitation of muscle mechanical strength compared to S-THA. Further, the impaired recovery in mechanical muscle strength following R-THA appears to be due to the detachment of the lower half of the gluteus maximus muscle rather than implant design *per se*. Although continuous improvements in mechanical muscle strength were observed, substantial asymmetries remained present 26 wks following surgery, and were sustained for the hip flexors and adductors 1 yr after surgery. However, given the novel experimental approach, the present trial is exploratory as well as hypothesis generating, and the observed results should be confirmed in future trials.

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## Author contributions

CJ contributed to the development of the dynamometer used for muscle recording, data collection, analysis and interpretation; and writing of the manuscript. SO and PA contributed to the study design, development of muscle dynamometer, data analyses and interpretation of the data and writing of the manuscript. First and last authors take responsibility for the integrity of the work as a whole, from inception to finished article. E-mail Last Author: soeren.overgaard@ouh.regionsyddanmark.dk.

## Conflict of interest

There were no conflicts of interest.

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## Supplementary material

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.joca.2011.06.011.

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