The 2 main null hypotheses of this study were: (1) the 4-year surgical trauma–related degeneration within the hip abductor muscles after a minimally invasive approach to total hip arthroplasty would be similar to that following a conventional approach; and (2) no differences in perioperative blood loss or postoperative hip pain would be observed between the minimally invasive and conventional approaches.

In 40 consecutive randomly selected adult patients with unilateral primary hip osteoarthritis, a cementless Zweymüller-Plus THA (Smith & Nephew Orthopaedics, Baar, Switzerland) was implanted by a single surgeon in 1 institution during the same period. Twenty patients underwent a minimally invasive approach (group A), and 20 patients underwent a conventional anterolateral approach (group B). Four years postoperatively, the operated and contralateral nonoperated hips of 37 available patients from both groups were examined with magnetic resonance imaging to show any changes in the gluteus medius and tensor fascia latae. Simultaneously, hip abductor power was measured bilaterally in both groups. Anthropometric data, blood loss, Short Form 36 self-assessment questionnaire, visual analog pain score, and walking distance were also analyzed.

The reliability of magnetic resonance imaging and hip abductor power measurements was high. No difference was found in hip abductor power on the operated side between the 2 groups, whereas hip abductor power on the nonoperated side was significantly higher in both groups. This study revealed no mechanical and functional benefits in favor of patients undergoing minimally invasive vs conventional total hip arthroplasty.

Dr Vasilakis is from the Radiology Department and Drs Vitsas and Korovessis are from the Orthopedic Department, General Hospital “Agios Andreas,” Drs Solomou and Siamblis are from the Radiology Department, General University Hospital of Patras, Patras, Greece; and Mr Fennema is from the Department of Clinical Research, Smith & Nephew Orthopaedics AG, Baar, Switzerland.

Drs Vasilakis, Solomou, Vitsas, Korovessis, and Siamblis and Mr Fennema have no relevant financial relationships to disclose.

Correlative Analysis of MRI-evident Abductor Hip Muscle Degeneration and Power After Minimally Invasive Versus Conventional Unilateral Cementless THA

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Total hip arthroplasty (THA) is one of the most successful operations currently performed in joint reconstructive surgery. Although the main focus of THA was on implant design, materials, and fixation to bone in the past decade, minimally invasive surgery techniques have become popular in modern THAs. However, no consensus exists on the exact definition of the term minimally invasive surgery. Some orthopedic surgeons define it as a small skin incision (less than 10 cm),1 whereas others define it as a technique that causes no damage to the soft tissue and muscles.2 When minimally invasive surgery techniques are used, the reduced soft tissue damage allows for quicker mobilization and rehabilitation of the patient, especially in the early postoperative period.

Many studies in the literature have demonstrated reduced perioperative blood loss and decreased postoperative pain following implantation with minimally invasive surgery techniques compared with standard open techniques.3-5 However, objective investigations regarding faster improvement in terms of walking ability and subjective evaluation of postoperative functional outcome of patients managed with a minimally invasive surgery techniques are rare.6,7 Gait analysis has been used to assess the quality of gait following THA, with controversial results.8-10 Controversy exists in the recent literature regarding minimally invasive approaches to THA and abductor muscle trauma/fat degeneration seen on magnetic resonance imaging (MRI).11 One-year follow-up studies using MRI have reported either superior results12 or no advantages11 with a minimally invasive approach compared with a conventional approach.

Although MRI evidence for approach-related muscle trauma associated with minimally invasive surgery in the early postoperative period (ie, 3-12 months) was recently published,12,13 to the current authors’ knowledge, no study has investigated late degeneration in the main hip abductor muscles along with abduction power 4 years after successful cementless THA implantation in asymptomatic patients with MRI.

The 2 main null hypotheses of this study were: (1) the 4-year surgical trauma–related degeneration in the hip abductor muscles after a minimally invasive approach to THA would be similar to that following a conventional approach; and (2) no differences in perioperative blood loss or postoperative hip pain would be observed between the minimally invasive and conventional approaches.

Therefore, the main goal of this prospective, randomized study was to revaluate the clinical relevance and benefits of using a minimally invasive approach to implanting a cementless THA.

**MATERIALS AND METHODS**

Institutional review board approval was obtained, and all patients provided informed consent. Inclusion criteria were patients with unilateral primary osteoarthritis, a nondiseased contralateral hip, and a body mass index of less than 30 kg/m². Exclusion criteria were postoperative complications in the operated hip (eg, dislocation, infection, or length discrepancy greater than 2 cm), previous surgery, previous arthroplasties of other joints in the lower extremities, rheumatoid arthritis, developmental hip dysplasia and dislocation, and decreased mobility due to significant stiffness of the hip joint or nonjoint-related factors (eg, neurologic disease).

Patients were randomly assigned to receive the same cementless Zweymüller-Plus THA (Smith & Nephew Orthopaedics, Baar, Switzerland) using a minimally invasive technique (group A) or a conventional open technique (group B) (Figure 1). The contralateral nondiseased, nonoperated hip was used as control (group C) to avoid comparisons between different patients.

Hips were assigned to group A or B by a computer-generated randomization schedule. To improve precision in the comparison of treatments, assignment was done in a ratio of 1:1 in a complete block design of 10. Each clinical site was provided with a separate randomization schedule and received a set of sealed, opaque envelopes containing the randomization assignment for each patient. The treating surgeon and patient were blinded to group assignment until after surgical treatment.

![Figure 1: Flow chart showing allocation of patients. Abbreviations: F/up, follow-up; MIS, minimally invasive surgery; MRI, magnetic resonance imaging; SF-36, Short Form 36; THA, total hip arthroplasty; VAS, visual analog scale.](image-url)
From the initial 40 patients who fulfilled the inclusion criteria, 3 operated patients (1 in group A and 2 in group B) were excluded for reasons independent from surgery (eg, unavailable or change in residence). The remaining 37 patients (19 in group A and 18 in group B) were available for the final complete analysis (MRI and muscle power measurement) 4 years postoperatively.

The visual analog scale for pain and Short Form 36 (SF-36) self-assessment questionnaire for functional outcome were evaluated preoperatively and 4 years postoperatively (Tables 1, 2). Hematocrit was measured on admission and discharge. The indication for blood transfusion in the authors’ department is hematocrit less than 30%; thus, the cutoff in this study was 30%. The baseline characteristics of all 37 patients are shown in Table 1. Magnetic resonance imaging was performed for the operated and contralateral nonoperated hip in each patient by unbiased radiologists, and hip abductor power measurements were taken by orthopedic fellows. Radiologists (I.V., E.S.) and orthopedic surgeons (V.V., P.K.) were blinded to the surgical approach used.

All surgeries were performed by the senior author (P.K.), who has experience with more than 4000 THAs. In all 37 cases, the same standard type of implant was used (cementless Zweymüller-Plus THA: a Bicon double-conus threaded cup with an SL-Plus tapered straight stem [Smith & Nephew Orthopaedics]). The articulating partners were ceramic-on-ceramic with a 28-mm ceramic ball head.

**Surgical Technique**

**Minimally Invasive Technique**

In group A, the patient was positioned on the operating table in the supine position with only the involved lower limb draped in a sterile fashion. An oblique skin incision measuring 8 to 10 cm was made, extending distally from the anterior superior iliac spine and ending at the flare of the greater trochanter. After division of the subcutaneous tissue and fascia, the interval between the tensor fasciae latae and the gluteus medius was opened bluntly with the insertion of a finger. No muscle was split or detached. The hip capsule was divided in an H-shaped fashion and preserved. The acetabulum was prepared in a traditional fashion with the use of standard reamers. For preparation of the femur, the involved lower limb was placed in external rotation under the contralateral lower limb. In this position, an elevating retractor was placed posterior to the greater trochanter to lever the femur out of the wound. Again, no muscle was detached. Further preparation of the femur was similar to that in group B and was performed with the use of specific minimally invasive surgery instruments.

**Conventional Technique**

In group B, the patient was placed in the supine position with only the involved lower limb draped. A lateral skin incision approximately 14 to 16 cm in length was made, extending distally from the anterior

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**Table 1**

Preoperative Patient Baseline Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group A</th>
<th>Group B</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of F:M</td>
<td>15:4</td>
<td>13:5</td>
<td>&gt;.20</td>
</tr>
<tr>
<td>Age, y</td>
<td>66.7±10.07</td>
<td>65.3±11.3</td>
<td>.41</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>27.3±3.43</td>
<td>26.5±3.65</td>
<td>.72</td>
</tr>
<tr>
<td>VAS</td>
<td>7.7±0.97</td>
<td>7.4±1.7</td>
<td>.40</td>
</tr>
<tr>
<td>SF-36 physical function</td>
<td>20.5±11.7</td>
<td>26.5±20.6</td>
<td>.69</td>
</tr>
<tr>
<td>SF-36 mental health</td>
<td>52.0±13.3</td>
<td>48±18.5</td>
<td>.84</td>
</tr>
<tr>
<td>Hematocrit, % PCV</td>
<td>40.0±3.7</td>
<td>39.8±3.9</td>
<td>.95</td>
</tr>
<tr>
<td>Walking ability, km</td>
<td>0.2±0.4</td>
<td>0.3±0.4</td>
<td>.65</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index; PCV, packed cell volume; SF-36, Short Form 36; VAS, visual analog scale.

- Continuous variables presented as average±SD.
- Minimally invasive group.
- Conventional group.

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**Table 2**

Univariate Postoperative Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Average±SD</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAS²</td>
<td>1.6±1.7</td>
<td>.16</td>
</tr>
<tr>
<td>SF-36 physical function²</td>
<td>62.7±21.4</td>
<td>.91</td>
</tr>
<tr>
<td>SF-36 mental health²</td>
<td>64.8±19.8</td>
<td>.98</td>
</tr>
<tr>
<td>Hematocrit, % PCV²</td>
<td>34.6±3.7</td>
<td>.76</td>
</tr>
<tr>
<td>Walking ability²</td>
<td>1.3±0.8</td>
<td>.70</td>
</tr>
</tbody>
</table>

Abbreviations: PCV, packed cell volume; SF-36, Short Form 36; VAS, visual analog scale.

- Minimally invasive group.
- Conventional group.
- Mann-Whitney U test.
- At 4-year follow-up.
- At discharge.
superior iliac spine and ending at the flare of the greater trochanter. Using the modified Watson-Jones anterolateral approach, the fascia latae was split longitudinally and retracted. The distal half of the gluteus medius insertion at the greater trochanter was partially released to allow adduction for better orientation and hip dislocation.

The hip capsule was subtotally resected. For preparation of the proximal part of the femur, the involved lower limb was positioned in external rotation over the contralateral lower limb.

Postoperative Course

The postoperative course was the same for both groups. Mobilization started on postoperative day 1 with the use of 2 forearm crutches with 4-point walking. The use of 2 crutches was recommended for 3 weeks postoperatively. Patients were allowed to discontinue the crutches for full weight bearing as soon as possible, depending on the individual level of mobilization and pain. All patients were discharged after a minimum hospital stay of 3 days (range, 3-5 days).

Magnetic Resonance Imaging Examination

Patients were placed in the supine position with a pillow positioned under the knees, ensuring that they were lying symmetrically with weight evenly distributed across both sides. Magnetic resonance imaging was performed in all patients and for both hips simultaneously, under the supervision of the senior orthopedic surgeon and orthopedic radiologist 4 years after THA.

The use of coronal sections established the first cut from the lower one-third of the mass of the gluteus medius muscle between the iliac crest and trochanter major in each patient and at each side separately. The lower one-third of the muscle was considered by the authors as the part where the intraoperative surgical manipulations were made (Figure 2). 14

Magnetic resonance imaging was performed with a 1.0-T Gyroscan Intera (Philips, Best, the Netherlands) according to a standard protocol using clinically established MRI sequences, including: (1) coronal and axial T1-weighted spin-echo images (time repetition, 506 msec; time echo, 20 msec; section thickness, 5 mm, flip angle, 90°; field of view, 385 mm; rectangular field of view, 80 mm; matrix scan, 256×256; reconstruction, 256; scan percentage, 80%); and (2) coronal and axial T2-weighted turbo spin-echo images (time repetition/time echo, 3000/95 msec; section thickness, 5 mm; flip angle, 90°; field of view, 385 mm; rectangular field of view, 80 mm; matrix scan, 256×256; reconstruction, 256; scan percentage, 80%).

A coronal turbo inversion recovery magnitude sequence was also obtained (time repetition/time echo, 1500/90 msec; field of view, 390 mm; rectangular field of view, 80 mm; matrix scan, 256×256; reconstruction, 256; scan percentage, 80%; section thickness, 6 mm). The frequency-encoding gradient was always parallel to the longitudinal axis of the prosthesis (craniocaudal direction).

Two senior orthopedic radiologists (E.S., D.K.S.) independently calculated the cross-sectional contour of the gluteus medius and tensor fascia latae muscles in the MRI-specific section of T2-weighted turbo spin-echo sequences. 15 The region of interest was the whole cross-sectional area of the examined muscle (Figures 2-5), and the magnetic signal at this level was measured precisely. The low-intensity pixels as shown in the axial T2-weighted sequence turbo spin-echo 3000/95 msec indicate muscle tissue. Intensity pixels emerge from nonmuscle tissues with lower water content. Muscle degeneration due to surgical trauma or inactivity leads to replacement of muscle tissue by fat and other tissues with lower water content, whereas muscle tissue degeneration decreases the relative water content. The T2-weighted sequence turbo spin-echo
3000/95 msec provides an excellent opportunity to evaluate the muscle tissue quality by visualizing the water signals.16 The MRI region of interest was digitally drawn around the gluteus medius and the tensor fascia latae bilaterally (Figure 5).

**Figure 5**: Axial T2-weighted magnetic resonance image of a 59-year-old patient who underwent total hip arthroplasty of the right hip via a minimally invasive approach showing the tensor fasciae latae (TFL) (arrows). The fatty degeneration at the right side was 611, which was higher than at the left side (572).

**Table 3**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Side</th>
<th>Group A</th>
<th>Group B</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abductor force, kg</td>
<td>Operated</td>
<td>4.3 (3.8-4.8)</td>
<td>4.6 (4.1-5.1)</td>
<td>.376</td>
</tr>
<tr>
<td></td>
<td>Contralateral</td>
<td>5.8 (5.2-6.3)</td>
<td>5.6 (5.1-6.1)</td>
<td>.500</td>
</tr>
<tr>
<td>Degeneration tensor, mm³</td>
<td>Operated</td>
<td>751 (683-818)</td>
<td>677 (618-736)</td>
<td>.398</td>
</tr>
<tr>
<td></td>
<td>Contralateral</td>
<td>533 (466-601)</td>
<td>495 (436-554)</td>
<td>.105</td>
</tr>
<tr>
<td>Degeneration gluteus, mm³</td>
<td>Operated</td>
<td>586 (512-652)</td>
<td>542 (484-600)</td>
<td>.982</td>
</tr>
<tr>
<td></td>
<td>Contralateral</td>
<td>444 (377-510)</td>
<td>442 (384-501)</td>
<td>.321</td>
</tr>
</tbody>
</table>

“Minimally invasive group.”
“Conventional group.”
“Mann-Whitney U test.”

**Hip Abductor Power Measurement**

The power (kg) of hip abductors was assessed using a precision electronic scale mounted on a fixed vertical plane. Three consecutive abduction measurements for each hip (operated and contralateral nonoperated) of each patient and the average maximal power were recorded.17

**Statistical Analysis**

Intention-to-treat analysis was used for all clinical outcome variables and was performed by an independent external statistician (P.F.).13,15 Data were analyzed with Stata version 11.2 software (StataCorp LP, College Station, Texas). Univariate analysis of continuous data was performed with the parametric t test or the nonparametric Mann-Whitney U test. Because of the relatively small sample size, continuous variables were tested on normality using the Shapiro-Wilk test. When the P value was less than .05, data were assumed to not be normally distributed, and a nonparametric test was used. Univariate statistical tests are reported as parametric unless indicated.

Treatment comparison for the primary outcomes of interest was based on linear mixed models. Linear mixed models are a generalization of ordinary least-squares linear regression models. In the latter, independence of all observation is assumed. In linear mixed models, correlation between successive measurements of the same patient is accounted for. The authors also accounted for the fact that dependency would exist between ipsilateral and contralateral measurements within the same patients. These models are therefore suitable for analyzing repeated measurements within 1 patient.

Three-level variance component models were developed, including patient, site (ipsilateral vs contralateral), and 3 abduction force measurements. The model was tested against the more parsimonious 2-level models. Fixed effects in the saturated model included side (ipsilateral vs contralateral), sex, age, group, and preoperative visual analog scale. Also, the interaction term group×side was included. For the final model, fixed effects were eliminated based on their effect on study group and operated side.

Reliability of the repeated measurements was determined by the model-based intra-class correlation coefficient (ICC). The correlation between maximal abduction force and MRI-evident degeneration within the abductor muscles was tested with analysis of covariance.

**RESULTS**

All baseline variables were comparable (Table 1). On discharge, average postoperative hematocrit and pre- and postoperative visual analog scale pain score did not differ between groups (Table 2). At 4-year follow-up, no differences existed in terms of SF-36 scores and walking capability between groups (Table 2).

Model-based results of the mean values are provided in Table 3. According to these results, no difference existed regarding the effect of the 2 surgical techniques on abductor muscle degeneration. Furthermore, THA did not restore muscle function to the physiological level of the contralateral nonoperated hip.

The ICC of the muscle power measurements was 0.84. According to the results of the linear mixed model, no difference existed in abductor muscle force between groups (P=.376). For both groups, the nonoperated hip showed a significantly higher abductor force (P<.001).

The ICC of the MRI measurements was 0.71 and 0.95 for the tensor fascia...
Abductor Hip Muscle Degeneration | Vasilakis et al.

It was whereas others. A cadaver study showed greater muscle damage after minimally invasive THA compared with conventional THA.16

Physiologically, the current patients walked aided for 3 months postoperatively and usually the regained their previous walking function after several months depending on activity level and preoperative diagnosis and muscle functional status. Although the short-term (ie, 3-12 months) effect of intraoperative muscle damage on early functional recovery and walking ability is previously reported, the current authors believe that the return of the hip function lasts several months. After a lit-
erature search, they found no mid-term hip functional results 1 year after THA.\textsuperscript{11-13} The reason for this short follow-up is that many authors consider 12 weeks as the maximum needed duration of follow-up to show the benefits of minimally invasive THA.\textsuperscript{5,6,7,11}

Using 3-dimensional gait analysis 3 months postoperatively, Pospischil et al\textsuperscript{12} reported no significant differences between minimally invasive and conventional THA with regard to gait kinematics. Madsen et al\textsuperscript{18} examined the effect of anterolateral and posterolateral surgical approaches on gait. A pelvic drop on the swing side was rarely seen in either group, with no difference between the groups. This finding was explained by the loss of elasticity due to tissue scarring on the lateral side of the hip, which can reduce the amount of the pelvic drop below the horizontal plane during the stance phase.\textsuperscript{18} Such a mechanism could mask gluteal weakness.

Other causes of gluteus medius weakness after a lateral Hardinge approach were reported to be detachment or avulsion of the gluteus medius from the greater trochanter or traction injury to the superior gluteal nerve, which results in denervation of the tensor fasciae latae.\textsuperscript{19} In the current study, no MRI evidence existed for detachment or avulsion of the abductor muscles around the hip.

In a clinical study, DiGioia et al\textsuperscript{20} noted a significant improvement with regard to limping and the ability to climb stairs in the minimally invasive group 3 months postoperatively.\textsuperscript{20} However, in that study, a posterior approach with a split of the gluteus maximus and a release of the short external rotators was performed in both groups.\textsuperscript{20}

In a prospective, randomized study by Bennett et al,\textsuperscript{6} nine patients undergoing a minimally invasive THA and 8 undergoing a conventional THA were compared with gait analysis. In both groups, the same posterior approach with the same implant was used by a single surgeon; the only difference was the length of the incision.\textsuperscript{6}

Until now, examinations were based on direct analysis or cadaver studies,\textsuperscript{1,5,14,18} which suggest that muscle damage after a minimally invasive approach may be greater compared with that after a conventional approach.\textsuperscript{16}

In the past few years, several attempts have been made to study possible degeneration of the hip abductor muscles after minimally invasive or conventional THA using MRI.\textsuperscript{1,11,12} Müller et al\textsuperscript{11} compared minimally invasive and conventional approaches with regard to muscle damage during cementless THA.\textsuperscript{11} Magnetic resonance imaging performed preoperatively and 3 and 12 months postoperatively showed less trauma in the minimally invasive approach.\textsuperscript{11}

In another study, Müller et al\textsuperscript{17} assessed fat degeneration of the gluteus medius 3 to 12 months postoperatively using MRI in patients undergoing direct lateral or minimally invasive THA.\textsuperscript{17} The authors concluded that muscle trauma was demonstrably reduced using a minimally invasive approach, especially in older and overweight patients.\textsuperscript{17}

Müller et al\textsuperscript{11} reported a prospectively randomized study on 44 patients with primary osteoarthritis who underwent cementless THA via an anterolateral minimally invasive or modified direct lateral approach. They performed clinical and MRI examinations preoperatively and 3 and 12 months postoperatively, including Harris Hip Scores and pain scores. Magnetic resonance imaging analysis included assessment of the tensor fasciae latae and gluteus medius with regard to fatty degeneration and changes in the muscle cross-sectional area. Clinical scores were similar in the 2 groups. Magnetic resonance imaging showed a pronounced postoperative fatty degeneration of the anterior part of the gluteus medius and a compensatory hypertrophy of the tensor fasciae latae. Higher-grade degeneration of the tensor fasciae latae and gluteus medius did not occur with the anterolateral approach. The authors found no increased damage to the tensor fasciae latae with the anterolateral approach. The lateral approach was associated with increased partial gluteus degeneration and a compensatory hypertrophy of the tensor fasciae latae. Based on fewer structural changes in the musculature, the authors recommended the anterolateral minimally invasive approach.\textsuperscript{11}

In a prospective study, Müller et al\textsuperscript{13} reported 44 patients who underwent cementless unilateral THA through a minimally invasive or modified open approach. Clinical examinations included an abduction test and pain score. Using MRI, the authors evaluated fatty degeneration, tendon defects, and bursal fluid collection in the abductor muscle. Muscle and tendon damage occurred in both groups, but more lateral gluteus medius tendon defects (muscle degeneration in the anterior part of the gluteus medius) were found in patients undergoing the open approach. The clinical outcome in the conventional group was poorer compared with the minimally invasive group. No differences in muscle and tendon damage were found in the gluteus minimus muscle.\textsuperscript{13} Abductor muscle and tendon damage occurred with both approaches, but the gluteus medius muscle can be spared more successfully via a minimally invasive approach and accompanied by a better clinical outcome. Therefore, going through the intermuscular plane, with no detachment or dissection of muscle and tendons, minimizes perioperative soft tissue trauma. Furthermore, MRI is an important imaging modality in the evaluation of muscle trauma in THA.

The current study’s conventional surgical technique differed from that of Müller et al,\textsuperscript{17} and thus the MRI findings are not comparable. The current conventional surgical approach for THA was a maximum tissue–preserving technique and may not differ significantly from what other surgeons regard as a minimally invasive approach. This fact may be 1 reason why no major differences were found between the 2 groups.
A limitation of this study was that no preoperative MRI and abduction power measurements were recorded. However, the authors considered each patient’s contralateral nonoperated hip as a control, and this is the most reliable method to evaluate the operated muscle function in the same individual.

**CONCLUSION**

This study did not confirm the expected functional benefit of a minimally invasive THA technique with no muscle detachment in the early postoperative period compared with a standard transgluteal approach.

**REFERENCES**


