

Randomized controlled trial of abductor muscle damage in relation to the surgical approach for primary total hip replacement: minimally invasive anterolateral versus modified direct lateral approach

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Abstract

Introduction Minimally invasive total hip arthroplasty (THA) is claimed to be superior to the standard technique, due to the potential reduction of soft tissue damage via a smaller and tissue-sparing approach. As a result of the lack of objective evidence of fewer muscle and tendon defects, controversy still remains as to whether minimally invasive total hip arthroplasty truly minimizes muscle and tendon damage. Therefore, the objective was to compare the influence of the surgical approach on abductor muscle trauma and to analyze the relevance to postoperative pain and functional recovery.

Materials and methods Between June 2006 and July 2007, 44 patients with primary hip arthritis were prospectively included in the study protocol. Patients underwent cementless unilateral total hip arthroplasty either through a minimally invasive anterolateral approach (ALMI) ($n = 21$) or a modified direct lateral approach (mDL) ($n = 16$). Patients were evaluated clinically and underwent MR imaging preoperatively and at 3 and 12 months postoperatively. Clinical assessment contained clinical examination, performance of abduction test and the survey of a function score using the Harris Hip Score, a pain score

using a numeric rating scale (NRS) of 0–10, as well as a satisfaction score using an NRS of 1–6. Additionally, myoglobin and creatine kinase were measured preoperatively, and 6, 24 and 96 h postoperatively. Evaluation of the MRI images included fatty atrophy (rating scale 0–4), tendon defects (present/absent) and bursal fluid collection of the abductor muscle.

Results Muscle and tendon damage occurred in both groups, but more lateral gluteus medius tendon defects [mDL 3/12mth.: 6 (37%)/4 (25%); ALMI: 3 (14%)/2 (9%)] and muscle atrophy in the anterior part of the gluteus medius [mean-standard (12): 1.75 ± 1.8 ; mean-MIS (12): 0.98 ± 1.1] were found in patients with the mDL approach. The clinical outcome was also poorer compared to the ALMI group. Significantly, more Trendelenburg's signs were evident and lower clinical scores were achieved in the mDL group. No differences in muscle and tendon damage were found for the gluteus minimus muscle. A higher serum myoglobin concentration was measured 6 and 24 h postoperatively in the mDL group (6 h: $403 \pm 168 \mu\text{g/l}$; 24 h: $304 \pm 182 \mu\text{g/l}$) compared to the ALMI group (6 h: $331 \pm 143 \mu\text{g/l}$; 24 h: $268 \pm 145 \mu\text{g/l}$).

Conclusion Abductor muscle and tendon damage occurred in both approaches, but the gluteus medius muscle can be spared more successfully via the minimally invasive approach and is accompanied by a better clinical outcome. Therefore, going through the intermuscular plane, without any detachment or dissection of muscle and tendons, truly minimizes perioperative soft tissue trauma. Furthermore, MRI emerges as an important imaging modality in the evaluation of muscle trauma in THA.

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Introduction

Minimally invasive total hip arthroplasty (THA) is well established in orthopedic surgery and is frequently applied. The assumed reduction of soft tissue trauma was decisive for the euphoric introduction of the minimally invasive surgery (MIS) technique at the beginning of this century. Many studies have reported that the minimally invasive implantation technique leads to essential benefits compared to conventional techniques, which might be attributed to the purported lack of muscle and tendon damage [3, 4, 7, 10, 13]. In contrast, some authors see the only gain of MIS as a smaller skin incision and cosmetic benefit [26], while others even report a higher complication rate with a minimally invasive approach [22, 27, 34]. Consequently, controversy has arisen in the orthopedic society over the potential and actual efficacy of MIS [6, 16, 32].

A variety of minimally invasive approaches have been described, including mini-incision approaches, muscle-sparing approaches or a combination of the two, with a single or two incisions [4, 7, 8, 10, 24, 35]. Anatomical studies have shown that muscle damage occurs in all approaches [20, 21]. However, cadaveric tissue may not possess the same physical and mechanical properties as in vivo tissue and may not respond like living tissue during the procedure. Furthermore, the relative value of each type of structural damage and its individual relevance to postoperative pain and functional recovery cannot be examined either.

One of the single incision MIS approaches to the hip is the minimally invasive anterolateral (ALMI) approach. This approach uses the intermuscular plane between the gluteus medius and the tensor fasciae latae, the muscle integrity of which remained unaffected [8]. Due to the lack of objective evidence of unaffected muscle and tendons, it remains unclear whether and to what extent total hip arthroplasty performed using the anterolateral minimally invasive muscle-sparing approach truly minimizes muscle and tendon damage.

For the evaluation of muscle damage and function, different tests and methods are available. Clinical examination, scoring systems, blood indices and dynamometric muscle testing are established analyses. To study soft tissue structures and corresponding pathologies in vivo, one of the most useful tools is magnetic resonance imaging (MRI). Improvements regarding artifact-reducing techniques and utilization of titanium prostheses now enable good-quality imaging [23, 28, 30].

Therefore, the aim of the present study was to investigate abductor muscle trauma in relation to the surgical approach and the individual relevance to postoperative pain and functional recovery. Potential differences between the standard and the minimally invasive approach will be

clearly indicated. In view of the postulated reduction of soft tissue trauma of a muscle-sparing approach, we hypothesize that less conspicuous pathological findings in MRI and better functional outcome will occur in the MIS approach compared to the direct lateral approach.

Materials and methods

Between June 2006 and July 2007, 44 patients with primary hip arthritis were prospectively included in the study protocol. The study protocol was approved by the institutional review board (EA 1/068/06) and registered in a clinical trial registry (GCTR, registry number: DRKS00000152). Informed consent was obtained from all patients.

Patients were randomly matched either into a minimally invasive anterolateral or a modified direct lateral group. Randomization was done by throwing a dice, whereby an uneven number meant the standard approach and an even number the minimally invasive approach. A sealed envelope opened before surgery was used to determine the patient group.

Exclusion criteria were major architectural malformations (Crowe type II and beyond), fractures of the hip, necessity for femoral osteotomy, a history of previous surgery to the affected hip, inflammatory polyarthritis, arthrosis or arthroplasty of the contralateral side or any physical or mental disability. Demographic data, body mass index, side, operative time and incision length are given in Table 1. The dropout rate was 16%. This was mainly the result of failed MRI examinations due to claustrophobia (five patients). One patient failed to appear for follow-up examinations and another withdrew his/her consent without giving a reason.

Surgery was performed using either a modified direct lateral (transgluteal) approach of Hardinge or a minimally invasive anterolateral approach by two experienced surgeons (S.T. and C.P.) who had each previously done more

Table 1 Demographic data on the patients' body mass index, side, operative time and incision length

	ALMI	mDL	<i>P</i> value
No. of hips (<i>n</i>)	24	20	
Dropout	3	4	
Age (range)	66 (52–79)	64 (35–80)	0.689 [#]
Gender (F/M)	12/12	12/8	0.115*
BMI (kg/m ²)	28 (23–37)	26 (24–34)	0.144 [#]
Side right/left	15/9	12/8	0.2*
Incision length (cm)	8.0 ± 1.6	10.4 ± 2.0	0.043 [#]
Operative time (min)	51 ± 6.8	50 ± 7.4	0.6 [#]

[#] Mann–Whitney *U* test, * Chi-square test

than 1,500 arthroplasties. We chose the modified lateral approach, because it has been well established for over 30 years and is commonly used in orthopedic surgery.

The lateral approach was described initially by Bauer and Hardinge [2, 15]. Compared to the approach of Bauer and Hardinge, in the modified form [25, 31] the skin incision was minimized to approximately 10 cm. The gluteus medius was incised along the fiber course to a maximum length of 3 cm to protect the inferior branch of the superior gluteal nerve. To expose the joint capsule, the anterior third of the gluteus medius was detached together with the underlying gluteus minimus in toto ventrally from the trochanter major. Lengthening of the incision into the vastus lateralis was strictly avoided. The glutei tendons were refixed to the trochanter with two or three periosteal sutures (2.0, Ethibond, Ethicon, Somerville, US).

The minimally invasive anterolateral approach is a modified Watson–Jones approach and was introduced by Bertin and Rottinger [8]. This approach uses the intermuscular plane between the gluteus medius and the tensor fascia latae and provides good exposure to the hip joint while preserving muscle integrity.

The patients were treated with a straight cementless titanium stem (Zweymüller, Smith and Nephew®, Rotkreuz, Switzerland) and an uncemented titanium press-fit cup (Allofit®, Zimmer®, Warsaw, Indiana, US).

All randomly included patients experienced the same standardized postoperative care, narcotic protocol, pain management and rehabilitation. Mechanical foot pumps and pharmacological antithrombotic prophylaxis were used. Physical therapy was initiated on the 1st postoperative day. The goals of therapy were to enable the patients to independently transfer, ambulate with full weight bearing using two crutches and negotiate stairs. All patients were transferred after successful completion of wound healing to a rehabilitation clinic for a 3 week standardized recovery program. This includes exercises for the entire lower extremity, the ankle, knee and all the muscles surrounding the hip. The goals for the patients were to regain full ROM/flexibility, regain strength and endurance, and nearly all proprioception. Crutches had to be used for at least 6 weeks, depending on the preoperative muscular condition of each patient. No further therapy was provided after the rehabilitation program.

Patients were evaluated clinically and underwent MR imaging preoperatively and 3 and 12 months postoperatively. Clinical assessment included clinical examination and the survey of a function score using the Harris Hip Score (15), a pain score using a numeric rating scale (NRS) of 0–10 (0, no pain to 10, severe pain) and a satisfaction score using an NRS of 1–6 (1, very satisfied to 6, no satisfaction). Trendelenburg's sign was evaluated to test the function of the abductor muscles. It was rated as either

negative, slight positive (wobbly, unstable one leg stand, but without limping) or severe positive (unable to stand on one leg, with limping). Additionally, hip abduction strength of the affected side was assessed preoperatively and 3 and 12 months postoperatively, using a handheld dynamometer. Therefore, the patient was in an upright position and the pelvis was stabilized by the investigator. The dynamometer was fixed on the standing leg, at the height of the ankle joint. The affected limb was connected with a belt to the dynamometer in 10 degrees of abduction. The patient was instructed to push against the dynamometer with the affected limb, for approximately 2–4 s with maximal effort. All analysis of the clinical data was carried out by the same single observer (M.M.) who was blinded to the patients. As a blood index of muscle damage, serum myoglobin concentration and creatine kinase (CK) activity were measured preoperatively and 6, 24 and 96 h postoperatively.

MR imaging

MR imaging was performed using a 1.5-Tesla MRI (Symphony; Siemens Medical Solutions, Erlangen, Germany) according to a standardized protocol. A flexible wraparound phased-array coil was applied. Coronal T1-weighted turbo spin-echo [TSE, 667/12 ms (repetition time (TR)/echo time (TE)), 5 mm section thickness, flip angle (FA) of 150°, 400 × 400 mm field of view (FOV), 512 × 256 matrix, 195 Hz/Px bandwidth (BW), 0.8 × 1.6 × 5.0 mm³ voxel size, 12 echo train length (ETL), 3:51 min:s acquisition time (AT), 27 slices], transverse T1-weighted TSE sequence (667/12 ms (TR/TE), 6 mm section thickness, 420 × 275.52 mm field of view, 512 × 168 matrix, 195 Hz/Px BW, 0.8 × 1.6 × 6.0 mm³ voxel size, 12 ETL, 2:32 min:s AT, 28 slices], turbo-inversion recovery magnitude (TIRM) coronal T2-weighted fast spin echo [6040/30/150 ms (TR/TE/inversion time), 6 mm section thickness, FA of 150°, 400 × 400 mm FOV, 512 × 256 matrix, 130 Hz/Px BW, 0.8 × 1.6 × 6.0 mm³ voxel size, 15 ETL, 7:35 min:s AT, 23 slices], transverse TIRM sequence [5260/59/150 ms (TR/TE/inversion time), 6 mm section thickness, 360 × 270 mm FOV, 512 × 154 matrix, 130 Hz/Px BW, 0.7 × 1.8 × 6.0 mm³ voxel size, 15 ETL, 7:55 min:s AT, 39 slices] and coronal T2-weighted fast spin echo [6040/30/150 ms (TR/TE/inversion time), 6 mm section thickness, FA of 150°, 400 × 400 mm FOV, 512 × 256 matrix, 300 Hz/Px BW, 2.0 × 3.3 × 5.0 mm³ voxel size, 6 ETL, 0:28 min:s AT, 30 slices] MR images were obtained. The frequency encoding gradient was always parallel to the long axis of the prosthesis (craniocaudal direction).

Image analysis

All MR images were independently analyzed by a radiologist (M.D.) and a research assistant (I.S.). The readers were blinded to whether the patients were in the minimally invasive or standard group. After the independent readings, intraobserver differences were resolved by consensus.

Fatty atrophy of the abductor muscles was assessed on the transverse T1-weighted MR images using the following grading system. Grade 0 indicated that no intramuscular fat was present; grade 1: that some fat streaks were present; grade 2: that fat was evident, but there was less fat than muscle tissue; grade 3: that there were equal amounts of fat and muscle tissue; and grade 4: that there was more fat than muscle tissue. This grading system has already been introduced in the evaluation of gluteus muscle and corresponds to a classification system that is commonly used to categorize the rotator cuff muscles [14, 28]. Fatty atrophy was assessed on transverse T1-weighted MR images at the lower one-third of the distance between the iliac crest and the tip of the greater trochanter. The anterior, middle and posterior portions of the gluteus medius and gluteus minimus muscles were evaluated separately.

Tendon defects were evaluated for the gluteus minimus tendon, the lateral part of the gluteus medius tendon and the superior–posterior part of the gluteus medius separately. Tendon tears or detachments were defined as hyperintense signals on images obtained with fluid-sensitive sequences. Tendon signal intensity was graded on the T1-weighted MR images as normal (hypointense) or abnormal (increased signal intensity) compared with the signal intensity of a normal tendon. Bursal fluid collections were documented as absent or present using fluid-sensitive MR imaging.

Statistics

SPSS (version 15, SPSS Inc., Chicago, USA) was used for statistical analysis. In testing for statistically significant differences in the frequencies of findings between two patient groups, χ^2 analysis was used and an exact Fischer–Yates test when the expected theoretical figures were lower than 5 (e.g. tendon defects, fatty atrophy, Trendelenburg's sign). Pre- and postoperative continuously and normally distributed variables were compared with a Student's *t* test (e.g. age, BMI). In the event that the variables were not normally distributed between the two groups, the Mann–Whitney *U* test was used (e.g. Harris Hip, satisfaction and pain score, abduction strength and blood parameters). A *P* value of 0.05 was considered to indicate a significant difference. Kappa (κ) statistics were calculated for interobserver agreement according to the method of Landis and Koch [19].

Results

Clinical assessment

In general, the patients of the minimally invasive group attained higher Harris Hip Scores, better satisfaction scores and lower pain scores at both 3 and 12 months (Table 2). But this was not statistically significant.

A statistically significant difference was seen concerning Trendelenburg's sign. At 12 months, there was a significantly higher rate of positive Trendelenburg's signs in the mDL group, compared to the ALMI group ($P < 0.05$, χ^2) (Table 3).

Abduction strength

Higher values of abduction strength of the affected hip, measured preoperatively and at 3 and 12 months were obtained in the ALMI group [ALMI: pre/3/12Mo: $7.9 \pm 2.7/8.1 \pm 2.8/8.9 \pm 2.5$ (Nm); mDL: pre/3/12Mo: $7.8 \pm 3.4/7.0 \pm 2.5/7.9 \pm 2.2$ (Nm)], but without statistical significance (3 Mo: $P = 0.23$; 12Mo: $P = 0.24$; Mann–Whitney *U* test).

Table 2 Clinical scores preoperatively and after 3 and 12 months

	mDL	ALMI	Sig. (<i>P</i> *)
Harris hip score			
Preoperatively	55.6 ± 12	55.9 ± 8	0.939
3 months	76.2 ± 19	80.5 ± 14	0.530
12 months	80.4 ± 17	87.3 ± 7	0.399
Pain score (0–10)			
3 months	2.6 ± 3	1.4 ± 1.2	0.519
12 months	2.4 ± 2.7	1.9 ± 1.5	0.427
Satisfaction score (1–6)			
3 months	2.4 ± 1.3	1.7 ± 0.7	0.083
12 months	2.3 ± 1.6	1.6 ± 0.7	0.225

* Mann–Whitney *U* test

Table 3 Trendelenburg's sign preoperatively and after 3 and 12 months

Trendelenburg's sign	Preoperatively	3 months	12 months
mDL			
None	14 (87.5%)	10 (62.5%)	10 (62.5%)
Slight	2 (12.5%)	4 (25%)	6 (37.5%)
Severe	0	2 (12.5%)	0
ALMI			
None	18 (86%)	18 (86%)	20 (95%)
Slight	2 (9.5%)	2 (9.5%)	1 (4.7%)
Severe	1 (4.7%)	1 (4.7%)	0
<i>P</i> (Chi-Square)	1.0	0.13	0.029
(ALMI:mDL)			

Fig. 1 Serum myoglobin concentration (a) and creatine kinase activity (b). Higher serum myoglobin concentration was measured 6 and 24 h postoperatively in the mDL group ($P > 0.05$, MWU). No differences in the creatine kinase activity were seen between the two groups

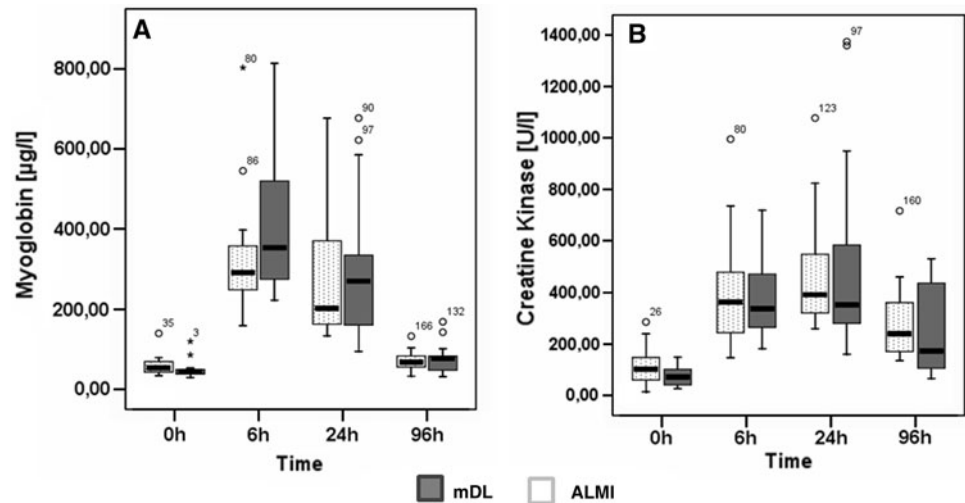


Table 4 Mean rating of the fatty atrophy

	Gluteus medius muscle			Gluteus minimus muscle		
	mDL Mean ± SD	ALMI Mean ± SD	Significance (P) [#]	mDL Mean ± SD	ALMI Mean ± SD	Significance (P) [#]
Preoperatively						
Posterior	0.06 ± 0.2	0.04 ± 0.2	0.951	0.4 ± 0.6	0.43 ± 0.6	0.963
Middle	0.18 ± 0.4	0.19 ± 0.4	0.97	0.29 ± 0.5	0.47 ± 0.6	0.491
Anterior	0.25 ± 0.3	0.23 ± 0.4	0.958	0.29 ± 0.5	0.43 ± 0.6	0.541
3 months						
Posterior	0.56 ± 1	0.33 ± 0.7	0.852	1.7 ± 1	1.7 ± 1.2	0.416
Middle	1.56 ± 1.5	0.85 ± 1	0.184	1.9 ± 1.1	1.76 ± 1.4	0.594
Anterior	1.75 ± 1.6	1.1 ± 1	0.041	2 ± 1.1	1.47 ± 1.4	0.496
12 months						
Posterior	0.5 ± 1.1	0.33 ± 0.7	0.553	2.3 ± 1.4	1.9 ± 1.2	0.381
Middle	1.62 ± 1.6	0.76 ± 0.9	0.053	2.2 ± 1.4	1.9 ± 1.4	0.483
Anterior	1.75 ± 1.8	0.98 ± 1.1	0.007	1.7 ± 1.3	1.5 ± 1.3	0.626

[#] Mann–Whitney U test

Blood parameters

A higher serum myoglobin concentration was measured 6 and 24 h postoperatively in the mDL group (6 h: $403 \pm 168 \mu\text{g/l}$; 24 h: $304 \pm 182 \mu\text{g/l}$) compared to the ALMI group (6 h: $331 \pm 143 \mu\text{g/l}$; 24 h: $268 \pm 145 \mu\text{g/l}$), but without statistical significance. No differences of the creatine kinase activity were seen between the two groups (Fig. 1).

Image analysis

Interobserver agreement for assessment of the fatty atrophy and tendon defects was moderate to excellent (kappa, 0.51–0.89).

Fatty atrophy

The means and the standard deviation for the rated fatty atrophy of the gluteus medius muscle are shown in Table 4. Significantly more fatty atrophy was found in the anterior part of the gluteus medius muscle at 3 and 12 months for the direct lateral approach ($P = 0.007$, χ^2). Table 5 gives a detailed overview of the ratings for each approach. Figure 2 shows axial T1 FSE-MR images of a patient with a direct lateral approach and from a patient with a minimally invasive anterolateral approach. A grade 4 atrophy was seen in the anterior part of the gluteus medius in the patient with the mDL approach. We did not see any changes between the fatty atrophy at 3 and 12 months. The preoperative fatty atrophy was significantly less in both

Table 5 Mean fatty atrophy (FA) of the anterior part of the gluteus medius muscle at 3 and 12 months

Fatty atrophy	FA grade				
	0: no fat	1: some fat	2: fat < muscle	3: fat = muscle	4: fat > muscle
At 3 months [count (%)]					
mDL	5 (31.3)	4 (25.0)	0 (0.0)	4 (25.0)	3 (18.8)
ALMI	8 (38.1)	5 (23.8)	6 (28.6)	2 (9.5)	0 (0.0)
At 12 months [count (%)]					
mDL	8 (50.0)	0 (0.0)	0 (0.0)	4 (25.0)	4 (25.0)
ALMI	8 (38.1)	7 (33.3)	4 (19.0)	1 (4.8)	1 (4.8)
Statistic	Value	df	Asymp. Sig. (2-sided)		
At 3 months					
Pearson's Chi-square	9.977	4	0.041		
Likelihood ratio	13.288	4	0.010		
At 12 months					
Pearson's Chi-square	14.183	4	0.007		
Likelihood ratio	18.426	4	0.001		

Fig. 2 MRI axial T1 TSE image sections of patients with an mDL approach (**a, b**) and a minimally invasive anterolateral approach (**c, d**), preoperatively (**a, c**) and 12 months postoperatively (**b, d**). The gluteus medius muscle (*short black arrows*) clearly shows fatty atrophy, grade 4, in the anterior part (**b**, *long black arrow*) in the patient with an mDL approach after 12 months. In contrast, the gluteus medius muscle of the patient with an ALMI approach was completely intact without any sign of atrophy (**d**). Also, the gluteus minimus muscle (*white star*) clearly shows fatty atrophy in the patient with an mDL approach, while the minimus in the minimally invasive anterolateral patient is completely uninjured

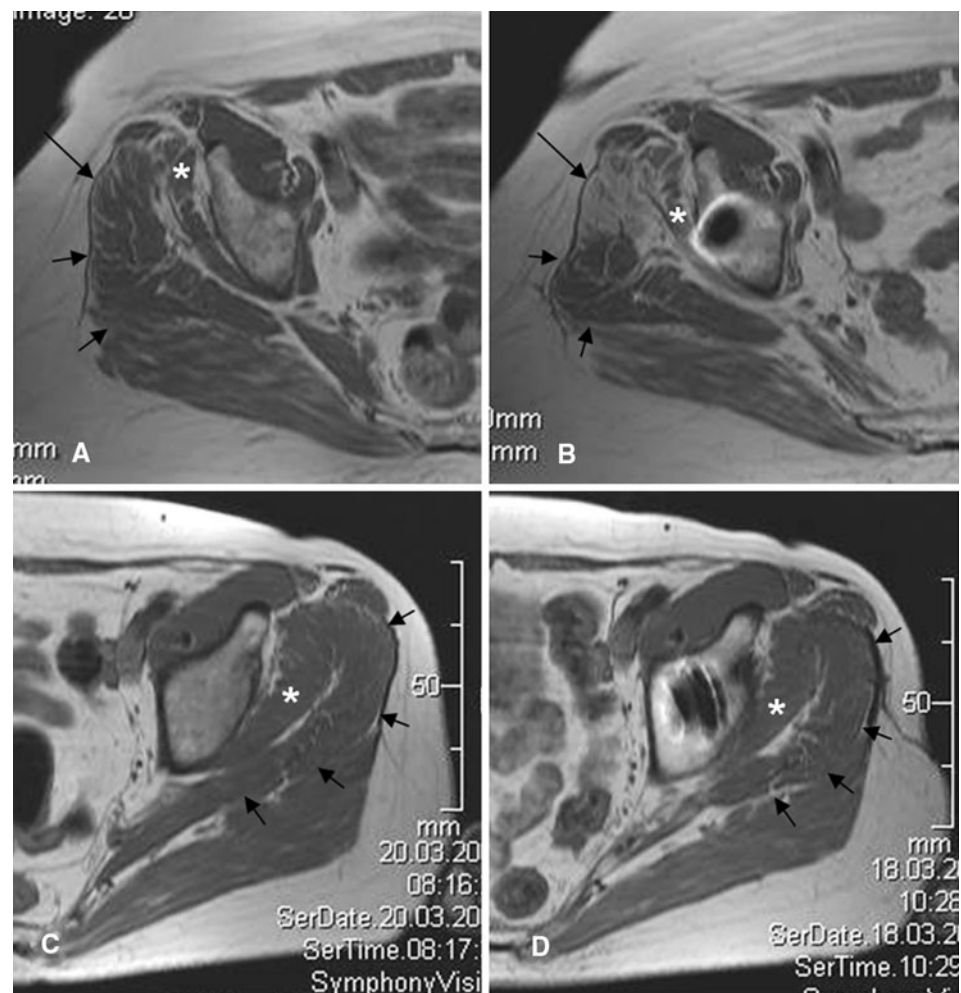


Table 6 Tendon defects

	Gluteus medius muscle			Gluteus minimus muscle		
	mDL (<i>n</i> = 16)	ALMI (<i>n</i> = 21)	<i>P</i> (χ^2)	mDL (<i>n</i> = 16)	ALMI (<i>n</i> = 21)	<i>P</i> (χ^2)
Preoperatively						
Absent	16	21		16	21	
Present	–	–		–	–	
3 month						
Absent	10 (62%)	18 (86%)	0.13	6 (37%)	8 (37%)	0.76
Present	6 (37%)	3 (14%)		10 (62%)	13 (63%)	
12 month						
Absent	12 (75%)	19 (91%)	0.37	8 (50%)	11 (48%)	0.8
Present	4 (25%)	2 (9%)		8 (50%)	10 (52%)	

groups and only a few patients showed some fat between the muscle fibers.

The fatty atrophy of the gluteus minimus muscle was rated higher than for the gluteus medius muscle in both groups (Table 4). There were no significant differences between the two patients groups.

Tendon defects

More lateral gluteal tendon defects were seen in the mDL group than in the minimally invasive group concerning the gluteus medius muscle ($P = 0.13$, χ^2), (Table 6). The tendon at the posterior–superior trochanter region was almost intact in both groups. In terms of the gluteus minimus tendon, defects were equally distributed, without any difference between the two techniques. In both groups, a recovery of the tendon defects was recognizable at 12 months.

Figure 3 shows coronal T1-weighted FSE and fluid-sensitive IR-MR images of a patient who underwent the direct lateral technique and of a patient who underwent minimally invasive surgery.

Figure 4 shows the coronal and axial preoperative and postoperative (3 months) MR images of a patient who underwent THA via a minimally invasive anterolateral approach. A tendon defect of the gluteus minimus tendon and corresponding fatty atrophy are depicted.

Bursal fluid

Of the 16 patients in the mDL group, 5 (31%) showed a clear trochanteric bursitis at 3 months ($P = 0.009$, χ^2). Two of these five patients still had a bursa at 12 months ($P = 0.171$, χ^2). In no patient of the ALMI group was a bursa evident.

Incision length

The median incision length was 10.4 cm (range 8–13.5 cm) for the direct lateral approach and 8.0 cm

(range 7–12.5 cm) for the minimally invasive anterolateral approach ($P = 0.043$, Mann–Whitney *U* test).

Discussion

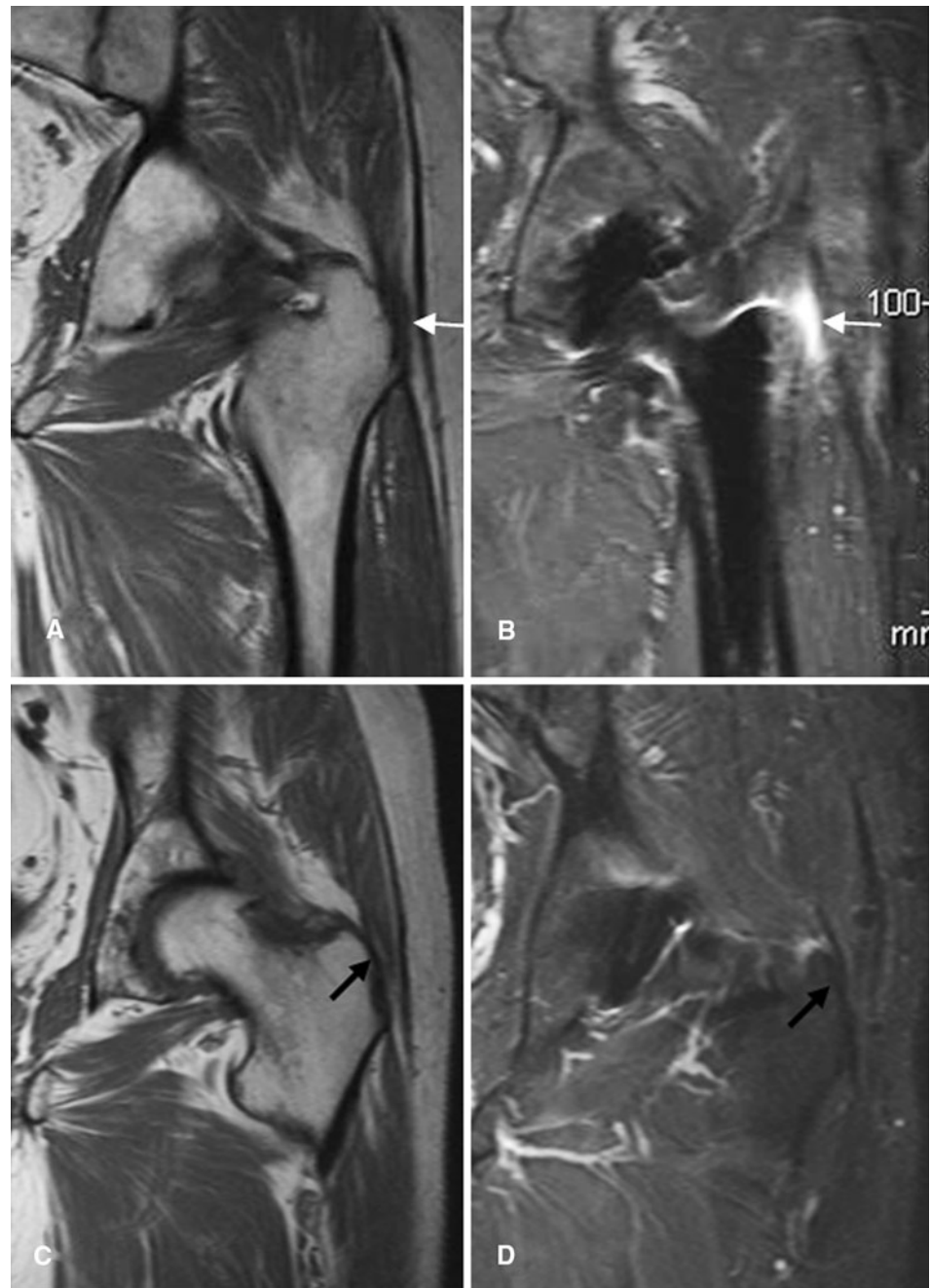
The results of this study demonstrate that there is a trend, with higher and better values, in scoring systems, muscle enzyme analysis and in abduction test, for the mini-invasive approach. However, these tests may not be sufficiently sensitive to detect statistical significant differences between the two techniques. The results may be limited by the relatively small number of patients.

In contrast, the MRI turns out to be the most sensitive method in the depiction of differences in the contributory effects of surgical approach on muscle damage.

The results of MRI evaluation demonstrate that abductor muscle and tendon damage occur in both the ALMI approach and the mDL approach, but significantly more pathological findings for the gluteus medius muscle were found in patients with the mDL approach. The gluteus minimus muscle was damaged equally in both groups.

In particular, tendon defects and fatty atrophy in the anterior part of the gluteus medius muscle were more evident in the mDL group. In other words, the gluteus medius can be spared more effectively via the minimally invasive anterolateral approach, while the lateral approach is associated with an increased risk of tendon and muscle damage. The higher rate of gluteus medius muscle and tendon damage via the mDL approach is obviously caused by the partial dissection and detachment of the gluteus medius muscle and tendon from the greater trochanter during the initial preparation. The partially detached tendon was always reattached to the greater trochanter with sutures, but this does not seem to guarantee stable ingrowth in all cases. A persistent tendon defect and lack of integrity in association with fatty muscle atrophy may result. Unfavorable effects of the lateral approach on the

Fig. 3 Coronal MR images showing the greater trochanter region at the level of the insertion of the lateral gluteus medius tendon, preoperatively and 12 months postoperatively in two different patients with an mDL approach (**a, b**) and ALMI approach (**c, d**), respectively. Images **a** and **c** are T1-weighted TSE sequences; **b** and **d** are fluid-sensitive IR sequences. In the postoperative image **b**, a tendon defect is visible (*white arrow*). In image **D**, the patient with an ALMI approach shows the same anatomical situation as preoperatively, without any damage



postoperative integrity of the gluteus medius tendon have also been described in a radiographical analysis, where metal markers were placed in the tendon for measurements of tendon separation [33].

Furthermore, the pathological findings are correlated with the clinical outcome, because significantly more positive Trendelenburg signs were found in the mDL patient group. The depicted gluteus medius damage seems also to be reflected in gait pattern, pain and satisfaction of the patient, and therefore appears to be clinically relevant, at least in the early rehabilitation period. Patients with the

minimally invasive anterolateral approach had a slightly better clinical outcome, higher clinical scores and lower rate of Trendelenburg signs, corresponding to significantly fewer muscle and tendon defects. Concerning this matter, in an MRI study of the abductor muscle and tendon in symptomatic and asymptomatic patients after THA, it was shown that abductor tendon defects and fatty atrophy of the gluteus medius muscle are more common in symptomatic patients and also most frequently found after lateral THA [28]. A more frequent occurrence of a positive Trendelenburg test after a direct lateral approach to the hip is

Fig. 4 Coronal and axial preoperative (a, c) and postoperative (b, d) (3 months) MR images in a patient who underwent THA via a minimally invasive anterolateral approach. Defect (arrow) of the gluteus minimus tendon and corresponding fatty atrophy of the minimus muscle (asterisk) are clearly depicted



described by several authors and attributed to either injuries of the superior gluteal nerve or muscle and tendon damage [1, 17, 29, 33]. Because we have strictly limited the division of the gluteus medius to the safe zone of 3–5 cm proximal to the greater trochanter tip, the possibility of superior gluteal nerve injury was minimized [9, 12]. Therefore, we see the direct relationship between the poorer clinical outcome of the lateral group and the MRI findings of muscle and tendon damage. Nearly all patients had completely recovered after 12 months and there were no significant differences between the two groups. In six patients of the lateral group, a slight positive Trendelenburg sign was apparent, but without any restrictions on gait pattern (limping). This is consistent with other studies where a reduction of the initial Trendelenburg sign after lateral THA was also described [1, 33]. We attribute this to the time-dependent compensation of other muscles and muscle units of the abductor muscle. We saw a recovery of the abductor tendon in some cases, but this was not statistically significant. A regression of fatty atrophy between

3 and 12 months was not seen. The longer recovery time of standard patients may be explained by the beneficial effects of rapid rehabilitation in the early postoperative period in patients undergoing minimally invasive total hip arthroplasty [4, 7, 10]. The rehabilitation time by itself could not be focused on in this study, since the study protocol was the same for both study groups.

In contrast to the gluteus medius muscle, no significant differences between the two approaches were seen for the gluteus minimus muscle. Although a certain number of minimally invasive anterolateral patients showed a lower rate of fatty atrophy compared to the standard group, the percentage of rating score 3 and 4 was nearly equally distributed between the two groups. Also, there were no apparent differences in the occurrence of tendon defects. In general, the gluteus minimus muscle showed the highest rate of fatty atrophy in both groups, compared to the gluteus medius muscle. Similar findings were reported in literature [23].

This higher rate of minimus muscle damage seems to be a result of the stem-related implantation technique, which

has to be done from the most lateral femur side. We used a tapered, rectangular, uncemented straight Zweymüller stem in this study. For adequate placement of this stem model, the femur cut surface has to be well prepared, especially from the lateral side so that femoral preparation can begin in direct line with the shaft of the femur, to avoid varus or valgus malposition. During this preparation, the minimus muscle and tendon are at the highest risk of damage in the anterolateral and lateral approach.

The results of the MRI evaluation support and verify the presumption that minimally invasive THA causes less muscle damage. Because there is a variety of traditional and MIS approaches, the results of this study have to be seen rather as a specific comparison between the minimally invasive anterolateral and the lateral approach. We selected these approaches because the lateral approach is a well-established, traditional approach, while the minimally invasive anterolateral approach is consistent with the demands of an MIS technique: approaching the hip without detachment and dissection of muscles. Despite the clear advantage of minimization of muscle trauma via the ALMI approach, the associated possible risk of peroperative complications such as fractures of the greater trochanter or varus malalignment of the more demanding ALMI-technique have to be taken into account [5, 18].

Because myoglobin and creatine kinase are found in skeletal muscle and are released into the circulation when muscle is damaged, the measurement may allow for an objective evaluation of the potential difference among minimally invasive and standard THA techniques. The use of minimally invasive approach theoretically disrupts less of the muscle surrounding the hip and thus may have less of an effect on these serum markers. We found peak values of CK and myoglobin 6 h postoperatively for both approaches and observed a measurable trend in serum myoglobin level relating to the approach. However, the difference was not sufficiently great to reach statistical significance. The higher myoglobin level for the standard approach at 6 h may be justified with the different amount of skeletal muscle damage. In a recent investigation, different muscle enzyme levels were measured, also dependent on the respective THA technique and the associated muscle trauma. The mean myoglobin level at 6 h for the ALMI ($331 \pm 143 \mu\text{g/l}$) was similar to that at 8 h reported by Cohen et al. [11] for the same approach ($346 \pm 144 \mu\text{g/l}$). This supports the reliability of the measurements of this study. It is interesting that the level of myoglobin in the mDL group at 6 h ($403 \pm 168 \mu\text{g/l}$) was as high as that in the MIS-II incision group (427.6 ± 247.3) in the study of Cohen et al. at 8 h.

In conclusion, the present study has demonstrated that damage to the abductor muscles and tendons is significantly less in minimally invasive total hip arthroplasty than

when using a direct lateral approach. More fatty atrophy, tendon defects and bursal fluid collection concerning the gluteus medius muscle were observed when using the direct lateral approach, compared to the minimally invasive anterolateral approach. These findings are in line with the clinical outcome, although not reflected with the same significance. MRI emerges as an important imaging modality in the evaluation of patients with total hip arthroplasties. The minimization of muscle trauma in THA can be achieved best by going through the intermuscular plane, without any detachment or dissection of muscles and tendons.

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