Evidence of Reduced Muscle Trauma Through a Minimally Invasive Anterolateral Approach by Means of MRI

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Abstract

Background Minimally invasive techniques in THA are intended to minimize periarticular muscle trauma. The lateral approach has a risk of partial gluteal insufficiency, while the anterolateral approach carries the risk of damaging the tensor fasciae latae through intermuscular nerve and compression injury.

Questions/purposes We assessed the surgical influence of the anterolateral minimally invasive approach and the modified direct lateral approach on the tensor fasciae latae and gluteus medius.

Methods We prospectively randomized 44 patients with primary coxarthrosis to receive a cementless THA via the anterolateral minimally invasive approach or the modified direct lateral approach. We performed clinical and MRI examinations preoperatively and 3 and 12 months postoperatively, including Harris hip and pain scores. MRI analysis included assessment of the tensor fasciae latae and

gluteus medius with regard to fatty atrophy and changes in the muscle cross-sectional area.

Results Clinical scores were similar in the two groups but a low-grade Trendelenburg sign was observed more frequently in the lateral group. MRI showed a pronounced, postoperative fatty atrophy of the anterior part of the gluteus medius more often; and a compensatory hypertrophy of the tensor fasciae latae occurred. Higher-grade atrophy of the tensor fasciae latae and gluteus medius did not occur with the anterolateral approach.

Conclusions We found no increased damage to the tensor fasciae latae with the anterolateral approach. The lateral approach was associated with increased partial gluteus atrophy and a compensatory hypertrophy of the tensor fasciae latae. Based on fewer structural changes in the musculature, we recommend the anterolateral minimally invasive approach.

Introduction

A major aim of minimally invasive hip surgery is to minimize damage to the periarticular muscles. To achieve this aim, standard approaches have been modified [10, 15, 32, 39, 47] and new minimally invasive techniques have been developed over the past few years [5–7, 12]. Currently, none of the approaches to the hip can be considered superior; but the trend is toward minimally invasive approaches, as it is generally accepted that muscle trauma should be reduced. However, some authors are critical of minimally invasive hip arthroplasty because of added potential risks, such as increased problems with wound-healing, implant malpositioning, additional nerve and vessel injury, and inadequate visualization during surgery [33, 48]. Cadaver investigations demonstrate substantial

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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damage to the periarticular musculature with a minimally invasive approach [27, 30, 34].

In the anterolateral minimally invasive (ALMI) approach, the dissection of the hip is performed intermuscularly between the tensor fasciae latae (TFL) and the gluteus medius, without incising or detaching muscles and tendons [7]. Possible risks of the approach involve an injury to intermuscular nerve branches of the superior gluteal nerve or muscle compression of the TFL caused by the retractor [46, 50]. In the modified direct lateral (mDL) approach, the gluteus medius is incised distally to a maximum of 3 cm and the ventral part is detached from the trochanter, resulting in a clear approach to the hip and minimizing tissue trauma [11, 15, 32, 39] compared with the lateral standard approach according to Bauer et al. [3] and Hardinge [16]. As a result of the incision and the detachment of the tendon, however, there is still a risk of partial, postoperative gluteal damage or insufficiency [36, 42], the extent of which is unknown.

Most assessments of muscle damage are based on muscle function tests (eg, gait analysis, EMG), which only allow indirect and nonspecific conclusions about muscle trauma [1, 4, 9, 20, 31, 37, 40, 46], or on cadaver investigations in which only the traumatized muscle tissue can be evaluated and not nerve damage, compression damage, or in particular the regenerative capacity of the muscles [27, 30].

Recently, MRI has been successfully used to image the periarticular musculature and analyze the damage to the abductor muscle associated with different surgical approaches [2, 35]. The use of nonferromagnetic titanium prostheses and ceramic balls instead of metal heads, as well as the observances of some technical features, eg, the orientation of the frequency-encoding gradient of the MR system, enables high-quality MRI of patients with THA. The changes in muscle cross-sectional area (CSA) and fatty atrophy of the muscle that can thus be visualized reflect the muscle damage and correlate with muscle function [28, 29].

Using MRI to investigate the structural changes in the TFL and gluteus medius after the mDL and ALMI approaches, we addressed the following questions: (1) Is there an increased risk of damage to the TFL when the ALMI approach is taken? (2) Is there an increased risk of damage to the gluteus medius after the mDL approach? (3) Does choice of approach influence muscle CSA? And (4) are the approach-related MR findings reflected in the clinical scores?

Patients and Methods

We prospectively enrolled all 44 patients (24 female, 20 male) with primary coxarthrosis meeting our criteria and

scheduled for THA between June 2006 and July 2007. An a priori power analysis was performed to estimate the required number of patients for each study-group. A minimum power of 0.8 had to be achieved. With a given alpha of 0.05, an effect size of 1.0, and the required power of 0.8, the sample size of 16 per group had been calculated. The defined effect size of 1.0 was based upon the presumption of a remarkable muscle-sparing effect of the MIS approach compared to the lateral approach. The power analysis was performed by means of statistical computer software (G-Power 3.1, University Düsseldorf, Germany). We included patients with primary coxarthrosis and between 35 and 80 years of age. Exclusion criteria were higher-grade dysplastic coxarthroses (> Crowe Type I), fractures, the need for osteotomies, previous hip operations, rheumatoid arthritis, muscle diseases, or the presence of a joint implant on the contralateral side, as well as any type of physical or mental disability. Criteria evaluation was preoperatively performed through a detailed anamnesis, a radiographic examination (AP pelvic and axial view), and a blood test.

The patients were randomized into two groups with regard to the surgical approach: the mDL approach ($n = 20$) and the ALMI approach ($n = 24$). Randomization was by means of 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. Of the 44 patients, 37 (mDL [$n = 16$] and ALMI [$n = 21$]) were followed for up to 12 months postoperatively, resulting in a dropout rate of 16% (Table 1). The most common reason for dropout was claustrophobia ($n = 5$). One patient failed to appear for followup examinations and another patient withdrew consent without giving a reason. Age, gender, and body mass index were homogeneously distributed between the patient groups (Table 1). The average Harris hip score was 55 in both groups preoperatively. The study was approved by the institutional review board (EA 1/068/06) and registered with the clinical trial register (GCTR, Registry Number:

Table 1. Demographic data on the patients, body mass index, and side

	ALMI	mDL	P-value
Number of hips (n)	24	20	
Drop out	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*

Mann-Whitney U-test, *Chi-square test.

DRKS00000152). Written consent was obtained from all patients.

All operations were performed by two surgeons (ST, CP), who had implanted more than 1500 prostheses using the two approaches. The mDL approach was a modified form [32] of the direct lateral approach described by Bauer et al. [3] and Hardinge [16]. The gluteus medius and minimus were incised to a maximum length of 3 cm and detached ventrally from the trochanter major. Extension of incision into the vastus lateralis was strictly avoided. Skin incision was minimized to approximately 10 cm. After implantation, the tendons were reattached with tight transperiosteal sutures (2-0 Ethibond®; Ethicon, Inc, Somerville, NJ). The ALMI approach was a modified Watson-Jones approach [7], in which the approach to the hip is achieved without incision or detachment of muscles between the TFL and the anterior edge of the gluteus medius. A cementless titanium straight stem (Alloclassic-SL®; Zimmer, Inc, Warsaw, USA) and a press-fit cup (Allofit®; Zimmer) were implanted.

All patients experienced the same standardized postoperative care and the same rehabilitation. Physical therapy started on the first postoperative day. The goals of therapy were to enable the patients to independently transfer, ambulate with full weightbearing 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, including exercises for the entire lower extremity, the ankle, the knee, and all the muscles surrounding the hip. The goals for the patients were to regain full ROM/flexibility, strength and endurance, and nearly all proprioception. Crutches were used for at least 6 weeks, depending on the preoperative muscular condition of each patient. No further therapy was provided after the rehabilitation program.

The patients underwent a clinical examination preoperatively and 3 and 12 months postoperatively, in which the Harris hip score [41], and a pain score using a NRS of 0 to 10 (0 = no pain, 10 = maximum pain) were recorded [43, 44]. Trendelenburg 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). All clinical data were collected by the same single observer (MM), who was blinded to the patient's approach.

MRI was performed preoperatively and 3 and 12 months postoperatively on all patients. The MRI was performed on a 1.5-T MR tomograph (Symphony; Siemens Medical Solutions, Erlangen, Germany) according to a standard protocol, using a flexible phased-array coil and clinically established MRI sequences at our department of

radiology, including (1) a coronal T1-weighted turbo spin-echo (TSE; repetition time [TR]/echo time [TE] of 667/12 ms, 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), (2) a transverse T1-weighted TSE sequence (667/12 ms [TR/TE], 6-mm section thickness, 420- × 275.52-mm FOV, 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), (3) a 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), (4) a 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 (5) a 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). The frequency-encoding gradient was always parallel to the longitudinal axis of the prosthesis (craniocaudal direction).

The fatty atrophy and the muscle CSA of the gluteus medius and the TFL were assessed at the respective examination times. The graduation of the fatty atrophy was performed on axial T1-weighted MR images. All MR images were independently analyzed by two radiologists (MD, IS, with 10 and 4 years experience, respectively). The readers were blinded to whether the patients were in the anterolateral or lateral group. The gluteus medius was assessed at the level of the lower third of the connecting line between the iliac crest and the trochanter tip (Fig. 1) [35]. The anterior, medial, and posterior thirds of the gluteus medius were evaluated separately from each other [35]. The degree of fatty atrophy and the muscle CSA of the TFL were assessed at the level of the greater trochanter, directly at the tendon attachment of the lateral medius tendon (Fig. 1). To guarantee the same transverse evaluation level at each time point, the anatomically correct height was adjusted on the coronal planes in the scout at the MRI workstation, where the greater trochanter, iliac crest, and lower third of the medius muscle were always exactly identifiable (Fig. 1). The graduation system for fatty atrophy was based on the classification system for assessing the rotator cuff [14]: Grade 0, no fat; Grade 1, slight fatty streaks; Grade 2, fat visible but less than muscle; Grade 3, fat and muscle present in equal amounts; and Grade 4, considerably more fat than muscle. The respective muscle

CSAs were determined directly on the MR workstation by manual rendering. The interobserver agreement in the assessment of fatty atrophy as determined by the kappa statistic was 0.51 to 0.89.

We compared pre- and postoperative continuously and normally distributed variables (CSA) within the two groups using Student's *t* test. The nonnormally distributed variables (Harris hip and pain scores) were compared with the

Wilcoxon test. Similar tests were used to compare the same variables between the groups. For nominal variables (frequency distribution of fatty atrophy and Trendelenburg sign), the chi square test was used. If the values were less than the expected contingent of 5, the Fisher-Yates test was used. For measurement of the strength of linear dependence between two variables (CSA, fatty atrophy) the Pearson product-moment correlation coefficient was used. Statistical analysis was performed with the aid of SPSS® (Version 15; SPSS Inc, Chicago, IL).

Results

Changes of fatty atrophy of the TFL were similar in the two groups (Table 2). Specifically, a higher grade of atrophy of the TFL was not seen postoperatively when the ALMI approach was used.

More pathologic changes of the gluteus medius were evident after the mDL approach. Compared with the ALMI approach group, the mDL approach group showed more fatty atrophy of the anterior part of the gluteus medius after both 3 months ($p = 0.04$) and 12 months ($p = 0.007$) (Fig. 2). A post hoc power of 0.92 was calculated for the significant increase of the fatty atrophy in the mDL group after 12 months using an alpha of 0.05, the corresponding sample size, and a calculated effect size of 0.9.

We observed an increase ($p = 0.03$) in the muscle CSA for the TFL in the mDL approach group 12 months postoperatively (Table 3) while in the ALMI approach group we observed no such increase. For the gluteus medius, a change in muscle CSA was not observed in either group. An increase in the muscle CSA of the TFL from

Fig. 1A–C (A) A T1-weighted coronal MR image shows the height of the transverse evaluation slices for the gluteus medius muscle (lower third of the connecting line between the iliac crest and the trochanter tip shown by the dotted line) and the TFL (at the height of the greater trochanter shown by dashed line). (B) A T1-weighted transverse MR image shows the gluteus medius (arrowheads) separated into the anterior, medial, and posterior portions by the short dotted lines. (C) A T1-weighted transverse MR image shows the height of the greater trochanter for evaluation of the TFL.

Table 2. Fatty atrophy of gluteus medius and tensor fasciae latae

		Gluteus medius		*P value	TFL		*P value
Number		ALMI Mean $\pm$ SD	Direct lateral Mean $\pm$ SD		ALMI Mean $\pm$ SD	Direct lateral Mean $\pm$ SD	
Number		21	16		21	16	
Fatty atrophy	preoperatively	0.15 $\pm$.4	0.16 $\pm$.3	0.75	1.13 $\pm$.7	0.95 $\pm$.8	0.6
(total value)	3 months	0.76 $\pm$ 1.0	1.29 $\pm$ 1.4	0.08	1.15 $\pm$.7	0.9 $\pm$.7	0.32
	12 months	0.69 $\pm$.9	1.29 $\pm$ 1.5	0.00	1.18 $\pm$.6	0.8 $\pm$.6	0.19
dFatty Atrophy (Difference)	d3 Difference of 3 months to preoperatively						
	posterior	0.29 $\pm$.5	0.5 $\pm$ 0.8	0.85			
	middle	0.66 $\pm$.6	1.3 $\pm$ 1.1	0.18	−0.05	0.02	—
	anterior	0.87 $\pm$.6	1.5 $\pm$ 1.3	0.04			
	d12 Difference of 12 months to preoperatively						
	posterior	0.29 $\pm$.5	0.4 $\pm$ 0.9	0.55			
	middle	0.47 $\pm$.5	1.2 $\pm$ 1.2	0.05	−0.15	0.05	—
	anterior	0.75 $\pm$.7	1.5 $\pm$ 1.5	0.00			

* χ^2 -test.

preoperatively (4.2 cm^2) to 12 months postoperatively (5.2 cm^2) in a patient with the mDL approach is shown on axial T1-weighted MR images (Fig. 3). A post hoc power analysis has been performed to calculate the achieved power of the significant increase of the CSA of the TFL in the mDL group. With the given means ($5.1/7.2$) and standard deviations ($2/2.9$) of the CSA of the mDL group preoperatively and 12 months postoperatively, an effect size of 0.83 was calculated. Using this effect size with an

alpha of 0.05, and the corresponding sample size of 16, a statistical power of 0.94 could be achieved.

The increase in the fatty atrophy of the anterior part of the gluteus medius muscle correlated with ($r = 0.76$, $r^2 = 0.58$, $p < 0.001$) the increase in the muscle CSA of the TFL after 12 months in the mDL group (Fig. 4). For

Fig. 2 Graphs show the percentage distribution of the degrees of fatty atrophy of the anterior part of the gluteus medius according to approach and examination time.

Fig. 4 A graph illustrates the correlative connection between the change in grade of fatty atrophy (dFatty Atrophy) of the anterior part of the gluteus medius muscle and the increase in the muscle cross section of the TFL (dCSA) after 12 months in the mDL approach group. The more pronounced the fatty atrophy of the gluteus medius is, the greater is the increase in the muscle cross section of the TFL ($r = 0.76$, $r^2 = 0.58$, $p < 0.001$).

Table 3. Muscle cross-sectional area (CSA) preoperatively, 3 and 12 months postoperatively for the TFL and gluteus medius muscle.

		Gluteus medius		TFL	
		ALMI	mDL	ALMI	mDL
Number	N	21	16	21	16
CSA (cm^2)	preoperatively	31.7 ± 6.7	32.6 ± 8.8	6.6 ± 2.5	5.1 ± 2
	3 months	31.5 ± 7.7	31.6 ± 7.5	7.2 ± 2.6	6.7 ± 2.5
	12 months	32.8 ± 7.7	31.8 ± 7.1	7.5 ± 3.0	7.2 ± 2.9
Diff. CSA (cm^2)	Delta 3 months	$\downarrow -0.2 \pm 1.0$ $p = 0.9$	$\downarrow -1 \pm 1.3$ $p = 0.7$	$\uparrow 0.6 \pm 1.1$ $*p = 0.4$	$\uparrow 1.5 \pm 1.9$ $*p = 0.06$
	Delta 12 months	$\uparrow 1.0 \pm 1.1$ $p = 0.7$	$\downarrow -0.8 \pm 1.5$ $p = 0.8$	$\uparrow 0.9 \pm 1.4$ $*p = 0.3$	$\uparrow 2.1 \pm 2.1$ $*p = 0.03$

* T-test.

Fig. 3A–C (A) Preoperative, (B) 3-month postoperative, and (C) 12-month postoperative axial T1-weighted MR images at the level of the trochanter major show muscle cross sections of the TFL of a patient with the mDL approach.

Fig. 5A–D Axial T1-weighted MR images at the level of the trochanter major (Tr.) and acetabulum of a patient with the mDL approach are shown. (A) Compared with preoperatively, (B) a postoperative increase in the CSA of the TFL can be seen. In addition, (C) compared with the preoperative values, (D) the gluteus medius (Glu.me.) (arrowheads) shows a Grade 4 atrophy of the anterior part (arrows) 12 months postoperatively. * = gluteus minimus.

Table 4. Harris Hip and pain scores

	ALMI	mDL	Significance (p*)
Harris Hip Score			
3 months	80.5 ± 14	76.2 ± 19	0.53
12 months	87.3 ± 7	80.4 ± 17	0.39
Pain score (0–10)			
3 months	1.4 ± 1.2	2.6 ± 3	0.51
12 months	1.9 ± 1.5	2.4 ± 2.7	0.42

* Mann Whitney U-test.

the ALMI approach group, we observed no such correlation ($r = 0.33$, $r^2 = 0.111$, $p = 0.151$). An increase in the CSA of the TFL and a marked Grade 4 atrophy of the anterior part of the gluteus medius in a patient with the mDL approach are shown in axial T1-weighted MR images (Fig. 5).

At 12 months, the Harris hip score and pain score were similar in the ALMI and mDL approach groups (Table 4). The mDL approach group showed a higher ($p = 0.01$) incidence of a low-grade (unsteady single-leg stance) positive Trendelenburg sign than the ALMI approach group (six [38%] versus one [5%], respectively) after 12 months. We found no instances of a pronounced Trendelenburg sign in either group after 12 months.

Discussion

Minimally invasive THA has been widely established in orthopaedic surgery because of the supposed reduction of soft tissue trauma. However, the visualized proof of the reduced muscle trauma and investigations of additional risks of nerve or muscle damage by compression forces or increased retractor pull are still lacking. Therefore, we analyzed the muscle trauma of the TFL and the gluteus medius associated with the ALMI and mDL approaches by means of MRI. In particular, we investigated whether there was an increased risk of TFL trauma with the ALMI approach and a higher gluteus medius trauma with the mDL approach and whether changes in CSA were related to the approach.

Readers should be aware of the limitations of this study. First, the small patient cohort may limit the generalizability of the study, although we had adequate power to identify statistically significant findings. Second is the relatively short followup time. Further studies are necessary to investigate the long-term influences of both approaches. Nevertheless, there are several basic reports in the literature providing strong evidence that muscular regenerative processes take place within the first weeks after injury [8, 19, 45], and hence, our MR findings are not jeopardized by the followup time of 12 months. Wagers et al. report that adult skeletal muscle possesses remarkable regenerative

capacity, and that a large number of new myotubes normally are formed in only a few days after acute muscle damage [45]. Järvinen et al. described a three-phase regeneration process of 21 days after muscle injury, which either results in normal muscle or fibrous scar tissue [18]. Similar results were obtained by Chargé et al. which demonstrate that the return to a morphologically and histochemically normal mature muscle is seen at three to four weeks after injury [8]. These references reinforce the fact of a muscular-regeneration process taking place within the time frame of our followup. Nevertheless, potential regenerative changes of injured muscular tissue beyond that time period remain unclear.

We were able to find neither pronounced destruction nor fatty atrophy in the TFL or the gluteus medius after the ALMI approach. We could not confirm the potential risks of the approach described in the literature, such as injury to the superior gluteal nerve, compression, and dissection injuries caused by retractors and rasps [17, 31, 50]. In contrast, the comparative group with the mDL approach showed a higher postoperative fatty atrophy of the gluteus medius, particularly of the anterior part. Interestingly, an increase in the CSA of the TFL was also demonstrated in this group after 12 months. We saw a higher-grade degeneration of the gluteus medius in the mDL approach group in connection with surgery-related denervation of the anterior part of the muscle [17, 40]. The incision can cause damage to the lower branches of the superior gluteal nerve, which runs between the gluteus medius and minimus, while a lack of reintegration of the gluteal tendon accompanied by atrophy is also possible [13, 17]. The postoperative changes to the gluteus medius visualized by MRI in this study have been previously indirectly postulated in other studies using EMG measurements [1, 20, 36, 40]. We did not observe damage of the TFL in the mDL approach group; rather, the damage to the anterior part of the gluteus medius was clearly accompanied by a compensatory hypertrophy of the TFL, reflecting a complex interplay of the individual muscle groups of the hip. Using two-dimensional vector analysis, cadaver investigations, and biomechanics models, a synergistic interaction of the gluteal musculature and the TFL in a certain force relationship has been previously described [13, 21, 26, 38]. Potential compensation mechanisms among the respective abductors are not known.

Despite the postoperative morphologic differences existing between the approaches, the clinical scores were similar between the patient groups. This might be explained by either the small patient group or by the followup time, since most beneficial effects of minimally invasive surgery are reported for the early rehabilitation period [9, 24]. However, several studies suggest there are no substantial clinical benefits of minimally invasive THA [12, 33, 48].

Compared to the postoperative Harris hip scores of this study, some authors have reported scores in the 90 s in their minimally invasive operated patients [25, 49]. We did not make any preselection of our patients; therefore, we did not exclude patients with higher age, higher body mass index, higher American Society of Anesthesiology score, or with further orthopaedic diseases such as degenerative spine diseases, arthritis of the contralateral hip or the knees. This may explain why the scores in our study were not as high as those reported in other studies. The only clinical difference between the groups was a higher incidence of a low-grade Trendelenburg sign in the mDL group 12 months postoperatively. This is most likely in connection with the partial atrophy of the gluteus medius and is in accordance with reports in the literature [1, 40].

We found MRI could demonstrate approach-related effects on the TFL and gluteus medius, similar to Pfirrmann et al. [35], who showed MRI could identify muscular causes in patients with a painful THA. By determining the muscle CSA and the degree of fatty atrophy, the effects of surgery-related trauma could be demonstrated directly and precisely. This immediate in vivo evidence represents a major benefit in the evaluation of the invasiveness of surgical approaches and of implantation techniques. Our observations suggest the hip abductors can be spared by using the ALMI approach. Increased muscle damage, especially for the TFL, could not be confirmed. In contrast, the use of the mDL approach led to increased surgical trauma because of the incision and partial detachment of musculature. For the mDL approach, the data suggest a partial atrophy of the gluteus medius and a compensatory hypertrophy of the TFL, which underlines the complex interaction of the hip abductors. In light of the lesser structural damage we observed, we recommend the use of the ALMI approach, with the conditions that surgical experience with the more demanding minimally invasive technique is required and the associated intraoperative visibility is reduced compared with the mDL approach [22, 23].

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