ORIGINAL PAPER/PŮVODNÍ PRÁCE

Comparison of MRI of Paraspinal Muscles in Patients after Open and Minimally Invasive Percutaneous Stabilisation of Thoracic and Lumbar Spine Fractures

Srovnání MRI paraspinálních svalů u pacientů po otevřené a miniminvazivní perkutánní stabilizaci zlomenin hrudní a bederní páteře

TOMÁŠ MATĚJKA[1], JIŘÍ MATĚJKA[1], JAROSLAV ZEMAN[1], JAROSLAV BELATKA[1], MARTIN SALÁŠEK[1,2]

[1] Department of Orthopaedics and Trauma of Locomotive Apparatus, University hospital and Faculty of Medicine in Plzeň, Charles University, Czech Republic

[2] New Technologies for Information Society, University of West Bohemia, Plzeň, Czech Republic

Corresponding author:

MUDr. Martin Salášek, Ph.D.
Klinika ortopedie a traumatologie pohybového ústrojí
LF UK a FN Plzeň
Alej Svobody 80, 304 60 Plzeň

salasekm@fnplzen.cz
salasek@ntis.zcu.cz

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ABSTRACT

Purpose of the study

Magnetic resonance imaging (MRI) was used to evaluate paraspinal muscle damage after classic open surgery (OPEN) and minimally invasive spine surgery (MISS) after injury. In a randomised prospective study, we evaluated our hypothesis that MISS would result in a lower extent of atrophy and fibrosis as detected by MRI.

Material and Methods

MRI was performed after the injury and not earlier than 3 months after the removal of implants. 16 OPEN and 16 MISS patients underwent the final follow-up. Both atrophy and muscle fibrosis were assessed based on the progression of the condition after the surgery from the pre-operative state. Atrophy was assessed using T2-weighted axial scans based on the progression of fat tissue growth in the muscle and muscle tissue regression, while muscle fibrosis was assessed using T1-weighted scans before and after the administration of a contrast agent.

Results

Mean fibrotic changes were found to be higher in the OPEN group than in the MISS group, but insignificantly ($p = 0.1100$). Muscular atrophy was higher in the MISS group ($p = 0.2099$).
Occurrence of fibrosis correlated positively with muscular atrophy only in the MISS group ($R = 0.617$ (0.174–0.852), $p = 0.0094$).

Discussion

Minimally invasive percutaneous methods of spinal stabilization and other types of less invasive spinal surgeries are more gentle to the paraspinal muscles than standard OPEN approaches. Their importance is clear despite certain disadvantages such as longer duration of surgery and higher radiation exposure (in case of insertion without robotic assistance or 3D CT guidance). The condition of the paraspinal muscles is more suitable for the follow-up physiotherapy, enabling easier and quicker recovery. In the long term, the muscles are more capable of maintaining spinal balance and allowing for a wider range of movement, despite in this study is a mild controversy in the higher percentage of muscle atrophy in MISS procedures.

Conclusions

MISS procedures are more gentle to the paraspinal muscles than OPEN procedures. The condition of muscles is better for physiotherapy, enabling easier and quicker recovery.

Key words: spine, fracture, rehabilitation, muscles, minimally invasive spine surgery, magnetic resonance imaging, fibrosis, muscular atrophy.

INTRODUCTION

Minimally invasive methods of spine surgery are becoming more popular and widespread. One of the factors is the impression of minor injury to the muscular corset of the spine. The open method (OPEN) approaches the spine via skeletisation, retraction the muscle wall to the sides. In the mini-invasive method (MISS), the instruments are inserted percutaneously from stab incisions using special instrumentation. Both methods have their pros and cons. The OPEN method leads to higher blood loss and higher postoperative pain. Even strict subperiosteal skeletisation is associated with muscular denervation, decreases blood supply and contusions caused by retractors which results in long-term changes in muscle structure. Minimally invasive high-quality posterolateral fusion is not possible, fractures are more difficult to reduce but there should be no chronic muscle damage. However, screw tubular extensions can cause local muscular contusion at the insertion site.

Our prospective randomised study, previously approved by the institutional review board, investigated the extent of changes in the paraspinal muscles namely the *multifidus* muscle using magnetic resonance imaging (MRI) in order to determine whether minimally invasive techniques, which are increasingly used in the management of injuries and degenerative changes of the spine, are beneficial in this respect. Introduction of minimally invasive approaches into the portfolio of spinal surgery techniques is supposed to result in substantially smaller muscle damage and to protect the original quality of muscular tissue, thus enabling for quicker and more intensive rehabilitation, promoting a better long-term outcome (9,13).

In our previous projects, we investigated biochemical parameters during primary surgery in traumatic indications and on implant removal (7). In another phase of the same study we evaluated the histochemical and histological changes of the spinal muscles (the *erector spinae* muscle) (5, 6). We hypothesised that open surgery would lead to much more pronounced long-term damage of the muscles than minimally invasive spinal surgery.

Similarly, this phase of the study was designed to assess the hypothesis on a lower extent of damage of paravertebral muscles in MISS procedures by assessing changes of the muscles through a comparison of the development of fibrotic and atrophic alterations as detected by MRI. The primary source was spinal MRI acquisition immediately after the injury and before the surgery and its comparison with patterns found no earlier than 15 months after the surgery and no earlier than 3 months after implants removal.

MATERIAL AND METHODS

This study was approved by the local institutional review board (IRB) and informed consent was obtained from each patient prior the enrolment to this trial. The patients and their families were informed that anonymised data on their condition would be submitted for publication and gave their consent.

The study included a group of 38 patients with single type A or B of AOSpine Knowledge forum classification fracture of the thoracic or lumbar spine without neurological impairment (12). 19 fractures were managed in both the OPEN and MISS approaches.

Inclusion criteria: Age 18 to 70, A or B type fracture, no neurological deficit or concomitant injury or history of spinal surgery, informed consent signed

Exclusion criteria: Any myopathy, any other injury, use of anabolic steroids, general contraindications for spinal surgery, more than 48 hours delay between the injury and surgery, injury of the spinal cord or history of previous spinal surgery

All patients underwent plain radiograph, MRI and CT scans and were indicated for spinal stabilization. Each patient was assigned to one of the groups using random number generator.

Group of patients: Out of the 38 subjects primarily included in the study who had undergone the surgery, 32 patients (16 OPEN and 16 MISS) came back for the final MRI acquisition, performed no earlier than 15 months after the injury. The mean age of the evaluated group was 45.4 years (18–68), 44.8 (18–66) in the MISS group and 46.9 (19–68) in the OPEN group. BMI in the OPEN group was 25.9 and in the MISS 23.4. The whole cohort included 21 males and 11 females. All the patients were in very good physical condition, active individuals.

Surgery: All spine stabilizations were performed by the experienced senior spine surgeon, within 24 hours after trauma. All the patients were operated on the next day after injury at 8 in the morning. The USS Fracture (DePuy-Synthes, Switzerland) instruments was used for the open method of stabilization and the USS Fracture MIS (DePuy-Synthes, Switzerland) was used for the minimally invasive percutaneous procedure. Two segments were fixed in all patients in both groups. In OPEN we approached the spine via longitudinal incision above the spinous processes managed with instruments and the injured vertebra, protecting the supra- and interspinous ligaments. The muscles were carefully dissected and retracted laterally in the best feasible and subperiostal way and two self retaining retractors were used to maintain their position.

Screws were inserted under the control of one C-arm in the lateral view and, after insertion, they were also checked in the PA projection. After the instrumentation was completed, the sutures of the muscular fascia and the muscles to the spinous processes, the subcutaneous tissue and the skin closure was performed. The wound was drained using two vacuum drains. In MISS four longitudinal skin incisions, circa 2 cm long, were made about 3 cm from the median line. Instruments were used for blunt penetration to the entry points for mini-invasive stabilization, for the insertion of the bolts; the control

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was performed using two fluoroscopic devices simultaneously in the lateral and PA view. After the insertion of the screws, connectors were inserted and rods tunnelled through muscles and fixed to the connectors. Every step was performed through instrumentation tubes. These small incisions were not drained and fascia, subcutaneous tissue and skin sutures were performed. On the first day, the patients were monitored at the intensive care unit and were mobilized the next day after the transfer to the standard ward and started rehabilitation to strengthen the paraspinal muscles. Only weight lifting and rotation of the trunk was restricted. The NSAID´s were used for pain management minimally for two days.

During implant removal, which was indicated at the earliest 12 months after the primary stabilization due to the injury, we proceeded in a similar way in both methods, i.e. careful and gentle skeletisation in the open method and percutaneous extraction in the minimally invasive method.

MRI investigation: A Magnetom SKYRA 3T scanner (Siemens Healthcare GmbH, Erlangen, Germany) was used for the MRI examination. The contrast medium was gadoteridol (Prohance, Bracco Imaging, Colleretto Giacosa, Italy) 0.1 mmol/kg means 0.2 ml/kg. The implants were removed no earlier than 12 months after the primary injury-related surgery. Follow up MRI after instruments removal was performed no earlier than 3 months after their extraction.

Muscle quality assessment using MRI: The increase in the muscle atrophy and fibrosis in the treated segments before the injury-related surgery and after the removal of the implants was assessed by an independent imaging specialist – musculoskeletal radiologist.

Muscle atrophy was evaluated as the progression of the condition after the surgery to condition before the surgery. The evaluation used a 5-level scale ranging from the absence of post-operative atrophy (0 points) to very serious atrophy (4 points), enabling the use of intermediate steps (0.5 points). T2-weighted sequences acquired in the axial plane were used for the evaluation, which was based on the growth of the T2-hypersignal fat tissue in the muscle (hyposignal). The result was assigned a score from 0 (condition without alterations) to 4 (dominance of fat tissue with minimal muscle tissue residues – trabeculae).

Atrophy: 0 – no atrophy (0 %), 1 – mild atrophy (1–24 %), 2 – moderate atrophy (25–49 %) , 3 – severe atrophy (50–74 %), 4 – very severe atrophy (75–100 %).

Muscle fibrosis was assessed for the two treatment methods, specifically the T1-weighted sequences before and after the administration of the contrast agent. These protocols visualise fibrotic changes and enable evaluation of the extent of fibrotic alterations in the muscle on axial images (i.e. the area of muscle alteration), again in 5 grades with intermediate steps. The scale ranged from the condition with no fibrosis (score 0) to very serious fibrosis (score 4) affecting the whole muscle area. Fibrosis was characterised by a lower T1-weighted signal with post-contrast enhancement, increasing the signal intensity.

Fibrosis: 0 – no fibrosis (0 %), 1 – mild fibrosis (1–24 %), 2 – moderate (25–49 %), 3 – severe (50–74 %), 4 – very severe fibrosis (75–100 %).

The atrophy and fibrosis scores were then converted to percentage values expressing the amount of atrophy or fibrosis of the inner spinal extensors.

Statistical analysis was performed in MS Excel 2019, using add in Realstat. The categorical variables were evaluated by Fisher exact test and in case of ordered grading also by nominal ordered analysis (via Kruskal-Wallis test). The parametric quantitative data (e.g. percentage of fibrosis) were analysed using the Mann-Whitney-Wilcoxon exact test. The dependence of fibrosis on atrophy and type of surgical approach was quantified via multiple linear regression analysis. The dependence of OPEN approach probability on fibrosis and muscular atrophy was assessed by logistic regression. Data normality was screened by Shapiro Wilk test.

The test result with $p < 0.05$ was considered as statistically significant.

RESULTS

The paraspinal muscle quality in MRI scans was assessed for both treatment methods. The percentages are provided in Tables 1 and 2, Chart 1.

Table 1. **Paraspinal muscle alterations in MR scans in the groups of patients**

ATROPHY – MISS (%)	FIBROSIS – MISS (%)	ATROPHY – OPEN (%)	FIBROSIS – OPEN (%)
62.5	75	25	25
25	62.5	75	50
62.5	62.5	37.5	75
37.5	25	25	50
37.5	37.5	37.5	37.5
25	12.5	0	12.5
12.5	12.5	37.5	50
37.5	62.5	0	62.5
25	12.5	37.5	75
75	62.5	25	62.5
75	62.5	87.5	75
25	25	0	50
25	25	25	62.5
62.5	25	0	37.5
25	50	50	62.5
37.5	25	12.5	62.5

Table 2. **Results of statistical evaluation of MR scans for the OPEN and MISS approaches**

PERCENTAGE	ATROPHY		FIBROSIS	
	MISS	OPEN	MISS	OPEN
Mean	40.63	29.69	39.84	53.13
Median	37.50	25.00	31.25	56.25
95% CI lower	30.75	17.06	29.07	44.32
95% CI upper	50.50	42.31	50.62	61.93
MWW exact	p = 0.2099		p = 0.1100	

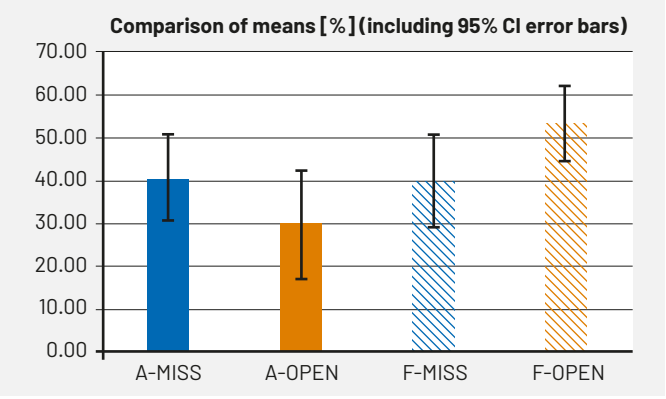

Chart 1. **Comparison of percentual rating of muscular fibrosis (F) and atrophy (A) between groups according to surgical approach.**

The mean percentage (95% CI) of muscular atrophy was 40.63 (30.75–50.50) in the MISS group, but only 29.69 (17.06–42.31) in OPEN group, p = 0.2099.

The mean percentage (95% CI) of fibrous changes (fibrosis) in MISS group was 39.84 (29.07–50.62), in the OPEN group the percentual rate of fibrosis was insignificantly higher – 53.13 (44.32–61.93), p = 0.1100.

There were no significant differences in comparison either of muscular atrophy grading (p = 0.2945 (Fisher 5×2); p = 0.1228 (nominal ordered analysis)), or fibrosis grading (p = 0.3873 (Fisher 5×2), p = 0.0633 (nominal ordered analysis)).

The correlation of fibrosis occurrence and muscular atrophy was different in both group: in the MISS group, fibrosis correlated positively with the presence of atrophy – R = 0.617 (0.174–0.852), **p = 0.0094;** in the OPEN one, there was no significant correlation (R = 0.436 (-0.098–0.775), p = 0.1053), Chart 2 and 3.

Logistic regression analysis (probability of OPEN approach) revealed this odds ratios:

for muscular atrophy OR = 0.955 (95% CI 0.916-0.996), **p = 0.0331,** this corresponds to the odds decrease by 4,5% in case of 1% elevation of muscular atrophy. The OR lower than 1 is concordant with more frequent atrophy in the MISS group.

For fibrosis analysis, OR = 1.059 (95% 1.011-1.110), **p = 0.0160**; the odds is increased by 5,9% in case of 1% elevation of fibrosis. Fibrous changes were more often viewed in the OPEN group, that is in concordance with the mean percentage of fibrosis.

We demostrate on the figures 1, 2, 3 the MRI findings at the patients with minimal or severe changes of the muscles after the OPEN or MISS procedures.

DISCUSSION

We hypothesised that the MISS approach will lead to a lower extent of damage in spinal fracture stabilisation than the

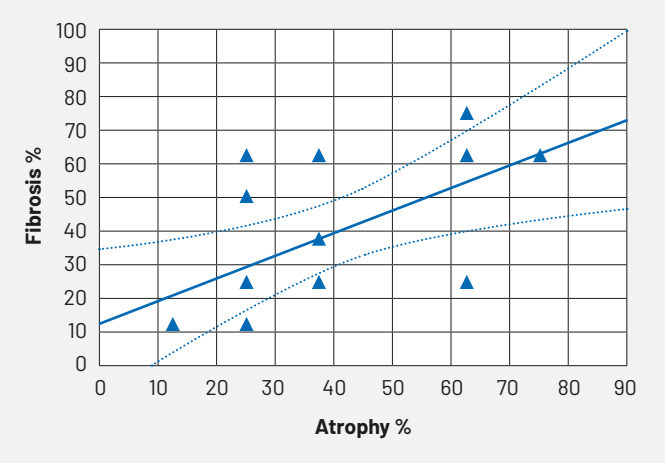

Chart 2. **Dependence of fibrosis on atrophy in MISS group, R = 0.617 (0.174–0.852), p = 0.0094.**

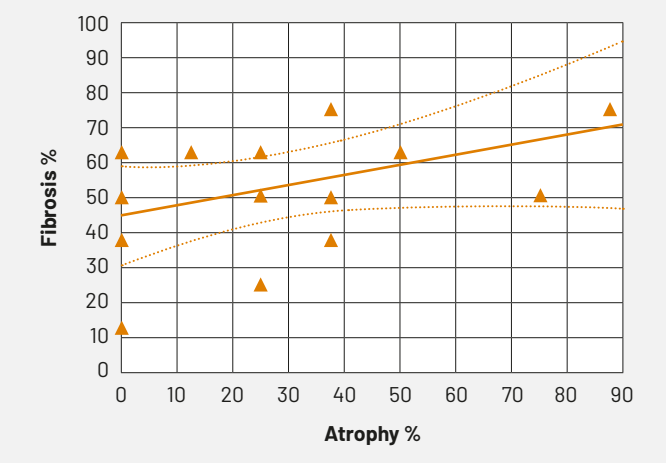

Chart 3. **Dependence of fibrosis on atrophy in OPEN group, R = 0.436 (-0.098–0.775), p = 0.1053.**

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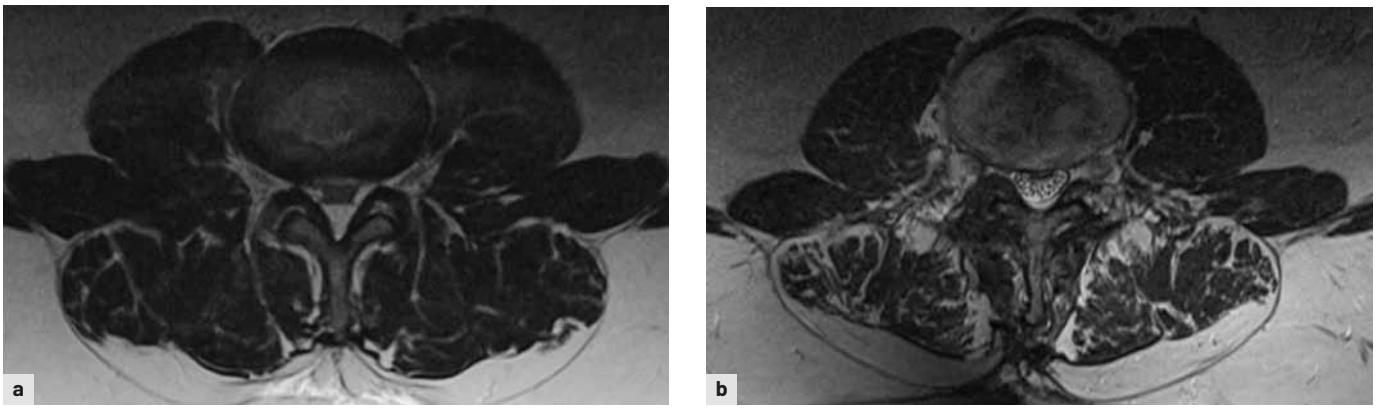

Fig. 1. **Severe changes in muscle quality. The atrophy is higher in the OPEN procedure after the implant removal (b) in comparison with the findings before primary procedure (a) in T2-weighted sequences.**

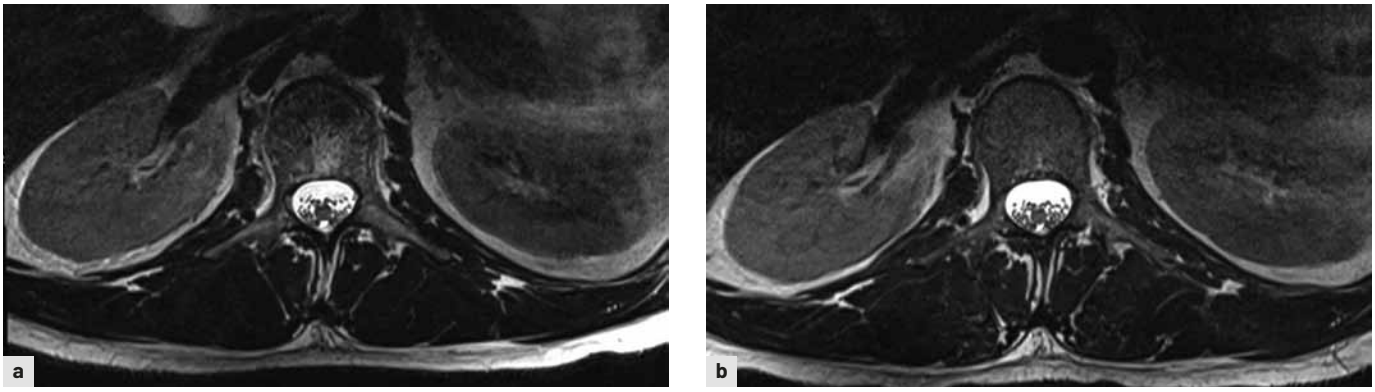

Fig. 2. **Minimal changes in muscle atrophy in the MISS procedure after the implant removal (b) in comparison with the findings before primary procedure (a) in T2-weighted sequences.**

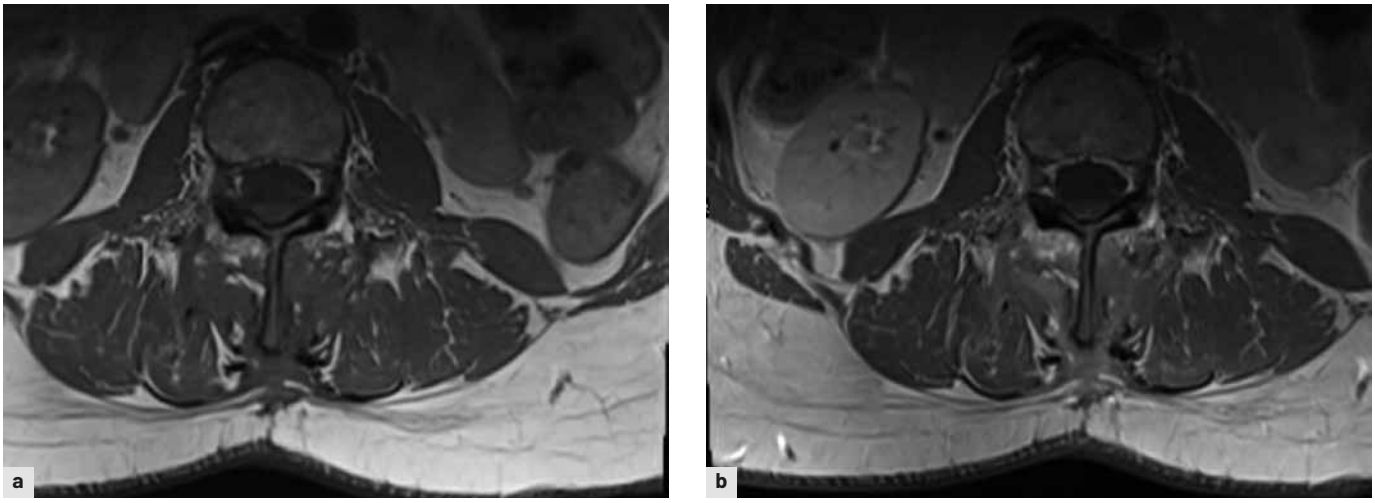

Fig. 3. **The MRI demonstrate in T1-weighted sequences before (a) and after (b) the administration of the contrast media, the changes in the signal with post-contrast enhancement, increasing the signal intensity.**

OPEN approach. Among the ways to prove this was evaluation of muscle atrophy and fibrosis based on MRI signal alterations. We were able to confirm this hypothesis only partly. Muscle fibrotic changes were statistically more significant but muscle atrophy was not. This was actually lower after OPEN. Our results also corroborate our previous studies showing statistically significant alterations in fibrosis intensity in the OPEN approach vs. the MISS approach in histology and histochemistry-derived parameters (5). On the other hand, Fan compared creatine kinase (CK) immediately after MISS (28 patients) and after OPEN (31 patients) with the condition of muscles as detected by MRI one year after the surgery and was unable to find such difference (2). While Fan found an association between the less increased CK level and muscle fibrosis in MRI in MISS procedures, we detected significantly higher CK and myoglobin (MYO) levels after the primary procedure in MISS than in OPEN. Our groups were smaller but we monitored the enzyme level for a much longer time, until their return to the normal range, which occurred on Day 3 (MYO) and Day 5 (CK) after the surgery. Jun-hui compared the condition of the muscles after an open posterior procedure and after the more gentle Wiltse approach and showed that in this case, too, the more gentle surgical approach significantly decreased atrophy and fibrosis in MRI 12 months after the surgery (4).

An experimental New Zealand white rabbit study performed by Zhi-Jun (16) compared MRI (similarly to our study) and histological results in the OPEN and MISS approaches provided findings similar to those of our studies (5, 7).

Another study published by Ghiasi examined muscle alterations in MRI in a group of 6 patients after open posterior surgery for degenerative spinal disease and compared the findings with a group of 6 healthy volunteers (3). We believe that our cohorts of patients confirm our hypothesis with a higher degree of validity. Ntikilina et al. compared a group of 27 OPEN patients with 65 MISS patients (8). MRI was scanned at least 1 year after removal of the implants and, once again, confirmed a statistically significant difference in fibrosis and atrophy between the OPEN and MISS approaches, with significantly lower values in the MISS group than in the OPEN group. Other authors compared other types of surgical procedures and diagnoses and concluded that minimally invasive spinal surgery in any form decreases the extent of atrophy of paraspinal muscles in MRI (1,10,11,14,15).

The reason for higher muscular atrophy rate in the MISS group could by associated with the soft tissue contusion during tunnelling of the connecting rods, but for verification of this hypothesis we do not have sufficient data. The *erector spinae* muscle is not only biomechanically active, but also produces several endocrine, paracrine and autocrine substances (myokines), which could be associated both with fibrosis and adjacent atrophy of the spinal muscles. Myokines proteomic and metabolomic analysis was not included in the current study.

CONCLUSIONS

Minimally invasive percutaneous methods of spinal stabilization and other types of less invasive spinal surgeries are more gentle to the paraspinal muscles than standard OPEN approaches. Their importance is clear despite certain disadvantages such as longer duration of surgery and higher radiation exposure. The condition of the paraspinal muscles is more suitable for the follow-up physiotherapy, enabling easier and quicker recovery. In the long term, the muscles are more capable of maintaining spinal balance and allowing for a wider range of movement, despite in this study is a mild controversy in the higher percentage of muscle atrophy in MISS procedures. ■

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Ethical standard statement

Our study has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments (in 2024). Our research was approved by the institutional review board of the authors' affiliated institutions. Data acquisition and analysis were concordant with the STROBE protocol. Written informed consent was gained prior to enrollment in this clinical trial. Written informed consent was gained prior to the publication of clinical data.

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