J Musculoskelet Neuronal Interact 2018; 18(1):62-70

Journal of Musculoskeletal and Neuronal Interactions

Review Article

Muscular changes after minimally invasive versus open spinal stabilization of thoracolumbar fractures: A literature review

M. Pishnamaz[1], **U. Schemmann**[1], **C. Herren**[1], **K. Horst**[1], **P. Lichte**[1], **F. Hildebrand**[1], **H-C. Pape**[2], **P. Kobbe**[1]

[1]University of Aachen Medical Center, Department of Orthopaedic Trauma, Germany; [2]University of Zurich, Department of Trauma, Switzerland

Abstract

Purpose: This review addressed the question of whether minimally invasive surgery after traumatic thoracolumbar spine fractures can reduce paraspinal muscle injury, limit changes in muscular structure and function, and lead to better functional outcome. Special emphasis was given to studies using imaging techniques or electromyography to evaluate the lumbar multifidus muscle structure and function. **Methods:** The authors searched the literature in the PubMed/Medline, EMBASE, by cross-referencing and additional hand search. Included were comparative studies between conventional open and minimally invasive or percutaneous surgical approaches. Twelve studies were included. **Results and conclusions:** The literature review supports the assumption that minimally invasive surgery preserves muscles for the early post-operative period, even though the level of evidence is still low. The correlation of changes in muscular structure to pain, strength, disability, and quality of life remains ambiguous and should be addressed in further studies with a focus on the surgical approach.

Keywords: Paraspinal Muscle, Minimally Invasive, Percutaneous, Thoracolumbar Fracture, Functional Outcome

Introduction

Posterior spinal stabilization following traumatic thoracolumbar fractures aims at the recovery of spinal stability with optimal sagittal alignment and vertebral height. However, surgery is associated with additional iatrogenic soft tissue damage. One of the main affected structures is the lumbar multifidus muscle, which is a central component of the spinal stabilizing system[1-6]. Changes in the lumbar multifidus may cause persistent pain[4,7,8].

In the conventional open approach, the paraspinal musculature is dissected and retracted, which causes denervation, ischemia, and atrophy[7,9-17]. In contrast, by minimally invasive surgery, the detachment of the paraspinal muscles is avoided and the duration of retraction on nerves, vessels, and muscles is minimized[2,7,10,18-21]. Subsequent significantly lowered levels of serum enzymes and slighter systematic inflammatory response after minimally invasive surgery are reported[22-26]. Open spinal surgery leads to suppressed capillary perfusion, which alters the cell metabolism and yields muscle fiber degeneration[27,28]. Besides, the retraction pressure on muscle fibers causes interstitial edema, destruction of the sarcolemma, and mitochondrial changes implying musclar fiber necrosis[28-30]. Finally, altered use of the muscles after trauma and surgery due to healing, pain, deficiencies in motor function, or other factors leads to atrophy of muscle fiber cross sections.

However, the question of whether minimally invasive thoracolumbar spine surgery is able to minimize paraspinal muscle injury with an effect on clinical outcome after traumatic fractures is still not sufficiently answered.

This review aims at summarizing and discussing the literature regarding changes in structure and function of the concerned muscles subsequent to open surgery compared with minimally invasive posterior surgery of the spine. This review focusses on changes in the lumbar multifidus muscle by considering studies using imaging techniques or

---

The authors have no conflict of interest.

Corresponding author: Miguel Pishnamaz, MD, University of Aachen Medical Center, Department of Orthopaedic Trauma, Pauwelsstraße 30, 52074 Aachen
E-mail: mpishnamaz@ukaachen.de

Edited by: F. Rauch
Accepted 7 August 2017

Table 1. Studies comparing minimally invasive with conventionally open dorsal pedicle screw fixation in patients with traumatic thoracolumbar fractures.

Authors, Year Reference No	Study design Level of Evidence	AO Classification Level of fracture Neurological deficit Number Segment stabilized	Sample size	Assessment	Follow-up months ±SD (range)	Findings
Cawley et al. 2014 [63]	non-randomized prospective comparative LoE III	A3 L1-L5 no bi- or multisegmental	12	Needle EMG USI LM CSA	minimum 6 MIS: 25±12 CO: 12±5	more pronounced denervation in CO vs. MIS significant at adjacent levels
Grass et al. 2006 [66]	non-randomized prospective controlled clinical trial LoE IIa	A2/A3/B1/B2 T12-L4 no information mono- or bisegmental	57	Needle EMG	8.3 (4-18)	polyphasic potentials = drop-out of numerous motor units MIS < 20% vs. CO > 80%
Wild et al. 2007 [9]	non-randomized retrospective case control study LoE III	A1/A2/A3 T12-L2 no no information	21	Hannover Spine Score SF-36	67.9±8 (54-85)	MIS better Outcome CO in all dimensions but no significant differences
Ntilikina et al. 2017 [16]	non-random. retrospective comparative LoE III	A2/A3/B1/B2 T7-L5 no no information	92	MRI: CSA & signal intensity	12	Significant bigger CSA in the MIS group compared to CO

SD= standard deviation, MIS minimally invasive stabilization, CO conventionally open , USI= Ultrasound Imaging, EMG= Electromyography, LM= lumbar multifidus muscle, CSA= cross sectional area, SF-36= Short Form Health survey, LoE= Level of Evidence

electromyography of the lumbar multifidus and discusses the impact of conventional open vs. minimally invasive surgery on functional outcomes.

Literature review

To examine the existing evidence of post-operatively altered structure and function of the lumbar multifidus muscle, we searched the literature in the PubMed/Medline, EMBASE, by cross-referencing and additional hand search.

Main inclusion criteria were comparison of the open to minimally invasive or percutaneous surgical approaches, posterior spinal stabilization, pedicle screw fixation, and traumatic fractures of the thoracolumbar spine. Imaging techniques and clinical or functional outcomes concerning the lumbar multifidus were considered. English or German articles were included.

We found four studies related to traumatic thoracolumbar fractures that met these criteria (Table 1). To get a more substantial picture, we additionally included eight studies related to a diversity of degenerative disorders (Table 2). These degenerative disorders received posterior lumbar interbody fusion (PLIF) or transforaminal lumbar interbody fusion (TLIF). Minimally invasive or percutaneous surgical approaches included approaches with endoscope or tubular retractors, paramedian approach through the intermuscular cleavage, or the spinous process-splitting approach. All these surgical approaches aimed at preserving the lumbar multifidus muscle.

Results

Magnetic resonance imaging

Changes in muscle morphology can be visualized using magnetic resonance imaging (MRI)[6-8,15,16,31-33]. Axial MRI slides allow calculating the cross sectional area of the lumbar multifidus. A decrease in the cross sectional area points to muscle fiber atrophy. By using T2 weighted images, fibrotic and fatty infiltration of the muscle as well as edema or large extracellular fluid space can be visualized. Large extracellular fluid space could be explained by early increased capillary blood volume, later degeneration, or delayed regeneration of muscle fibers[34,35].

We found seven MRI studies on muscular change after minimally invasive surgery compared to open surgery. Wang HL et al.[26] compared 38 cases of open TLIF with 41 cases of minimally invasive TLIF in a prospective randomized study (RCT). Their patients suffered from single level degenerative disease of the lumbar spine (L2-S1). Follow up was performed at 3, 6, 12 and 24 months post-operatively. The authors found a higher T2 relaxation time for the lumbar multifidus muscle after open surgery compared to minimally invasive procedure at the surgical level three months post-operatively. Besides, the authors describe a better electrophysiological lumbar multifidus function after three months.

Fan et al.[22] conducted a prospective non-randomized study. The authors examined 16 patients with open PLIF and 16 patients with minimally invasive PLIF. They took images of the adjacent and operative levels (L3-S1) preoperative and at a mean follow-up of 14 months. Cross sectional area and T2 signal intensity of the lumbar multifidus were compared to the psoas muscle. The results revealed a decrease of the cross sectional area of the lumbar multifidus muscle in the conventional open-group at follow-up. Additionally they found a larger percentage change in T2 signal intensity ratio of the lumbar multifidus to the psoas muscle for the open-group at all levels compared to the minimal invasive-group. Furthermore, Fan et al.[22] report a correlation between T2 signal intensity ratio and the cross sectional area with pain

Table 2. Studies comparing minimally invasive with open dorsal pedicle screw fixation in patients with degenerative diseases.

Author, Year Reference No	Study design Level of Evidence	Surgery Level of surgery Number of level stabilized	Sample size	Assessment	Follow-up months (range)	Findings concerning lumbar multifidus muscle and functional outcome
Fan et al. 2010 [19]	non-random. prospective comparative LoE III	PLIF (MIS or CO) L3-S1, single level	32	MRI: CSA LM/ T2 ratio VAS back pain ODI Enzymes	6 & 14	MIS > CO significantly in all categories
Hyun et al. 2007 [56]	non-random. retrospective comparative LoE III	TLIF midline approach (CO) vs. paramedian interfascial approach (MIS) Lumbar, single level	26	CT: LM CSA, thickness, width	11 (6-18)	LM thickness decrease MIS < CO LM CSA & thickness pre/post CO sign. difference, MIS ns difference LM width pre/post no significant difference
Kim DY et al. 2005 [48]	non-random. comparative LoE III	MIS or CO pedicle screw fixation, with ALIF (n=13) L4-S1, single level	19	MRI: CSA LM,T2 ratio trunk extension strength VAS LBP	20	no between groups analysis reported LM CSA pre/post decrease CO=sign. T2 ns difference; Strength pre/post MIS & CO =sign.: VAS no difference
Mori et al. 2014 [50]	randomized comparative LoE III	PLF /TLIF (CO) vs. Spinous process- splitting (MIS) L3/4 & L4/5, single level	53	MRI: CSA LM atrophy ratio, T2 signal intensity VAS, JOA, RDQ Enzymes	12-36	MIS vs. CO CSA LM atrophy ratio: fused & caudal adj. level 1 & 3 y sign., cranial adj. level 1& 3 y ns T2 signal ns; VAS pain 1y sign., 3 y ns VAS discomfort 1 & 3 y sign; JOA & RDQ ns
Tsutsumimoto et al. 2009 [22]	non-random. retrospective comparative LoE III	PLIF (MIS or CO) L4-5, single level	20	MRI: CSA LM atrophy ratio, T2 ratio JAO; Enzymes	12	Atrophy ratio MIS sign. better L3 & L3/4, L5 & L5/S1 equivalent T2 pre-post ratio MIS significantly lower than CO
Wang HL et al. 2011 [23]	RCT LoE Ib	TLIF (MIS or CO) L2-S1	79	MRI: LM T2 relaxation time surface EMG Enzymes VAS, ODI	3, 6, 12 & 24	T2 relaxation time 3 months MIS better than CO Average discharge amplitude & mean frequency 3 months MIS better CO frequency/ mean amplitude ratio MIS & CO equivalent; VAS equivalent ODI MIS better 3 & 6 m, equivalent 12 & 24 m
Putzier M et al. 2016 [14]	RCT LoE Ib	TLIF (MIS) vs PLIF (CO) L4/L5 or L5/S1	50	CT: LM muscle tissue volume, relative fat VAS,ODI	Pre-OP 1 week 12 month	Atrophy and degeneration greater in PLIF (CO) Equal results for both groups in VAS & ODI
Bresnahan LE et al. 2017 [15]	non-random. retrospective comparative LoE III	Lumbar decompression CO vs microendoscopic	18	MRI: CSA	Pre-OP 16.3 -16.6	CSA decreased in CO-group and increased in the MIS -group

non-random.= non-randomized, sign.= significant, ns= non-significant, MRI= magnetic resonance imaging, MIS minimally invasive stabilization, CO conventionally open , EMG= Electromyography, LM= lumbar multifidus muscle, CSA= cross sectional area, y= year, m= months, LoE= Level of Evidence.

and disability. They conclude that patients benefit from minimal invasive surgery with less iatrogenic damage of the lumbar multifidus muscle.

Kim et al.[36] conducted a retrospective case selection study with prospective observation of 19 patients who underwent open or percutaneous pedicle screw fixation combined with PLIF or with anterior lumbar interbody fusion (ALIF) L4-S1. MRI slides of the adjacent levels were taken pre-operatively and at a mean follow-up of 20 months. Again, the authors calculated the cross sectional area and T2 signal intensity of the lumbar multifidus relative to the psoas muscle. Their results correspond to those of Fan et al.[22] regarding the decrease in the cross sectional area of the lumbar multifidus in the open-group. However, the results of Kim et al.[36] could not confirm a larger percentage change of the lumbar multifidus-psoas-ratio for the open-group.

In a retrospective non-randomized study, Tsutsumimoto et al.[25] compared two groups of ten patients with degenerative spondylolisthesis who underwent either a minimally invasive PLIF or conventional open PLIF (L4-5). They calculated the atrophy of the lumbar multifidus muscle and the lumbar multifidus signal intensity ratio pre- and 12 months post-operatively. In the open-group, T2 signal intensity increased caudal to the surgical level, whereas the atrophy ratio of the lumbar multifidus was higher cranial to the surgical level compared to the minimally invasive-group. The authors explain differences in T2 signal intensity by denervation of the medial branch nerve at the surgical level, whereas differences in atrophy ratio were explained by extended incision, detachment, and retraction above the surgical level. However, it is unclear how this explanation could account for the inconsistent data pattern.

A different minimally invasive surgical approach for posterior lumbar fusion or TLIF was used by Mori et al.[37]. Twenty-seven patients were treated with the spinous process-splitting approach following open pedicle screw fixation and fusion and 26 patients received the CO pedicle screw fixation. All 53 randomly assigned patients suffered from degenerative spondylolisthesis. Cross sectional area and T2-signal intensity of the lumbar multifidus muscle was analyzed pre-operative, one, and three years after surgery. The authors report less lumbar multifidus atrophy for the spinous-splitting approach-group at the fused and caudal adjacent levels one and three years after surgery compared to the open-group. The lower lumbar multifidus atrophy ratio correlated with the Visual Analog Scale (VAS) for discomfort. There was no significant difference in the lumbar multifidus atrophy ratio at the cranial adjacent level. T2-signal intensity revealed no difference between the groups. These results implicate that the spinous process-splitting approach is able to better prevent paraspinal muscles from iatrogenic damage.

Ntilikina et al.[16] performed an MRI follow up study to investigate the paravertebral muscles of patients treated by open or percutaneous instrumentation one year after implant removal. They found significant higher cross sectional areas of the entire spine for patients treated by percutaneous treatment compared to open. They also found less fat infiltration within the cross sectional area of patients with T-12 and L-1 fractures who received percutaneous compared to open surgery.

Bresnahan et al.[15] compared the cross sectional area of 18 patients after open or microendoscopic decompression of lumbar stenosis. MRI was performed pre- and 16 month postoperatively. They also report significantly less negative impact of the mircoendoscopic approach compared to the open performance and even found an increased cross sectional area in the endoscopic group 16 month post-operatively.

Computed tomography

Axial slides taken by computed tomography (CT) can provide information about thickness[38], cross sectional area, and density respectively fatty infiltration of the lumbar multifidus muscle. Therefore CT can indicate atrophy[39-43].

We detected two CT-studies that compared open and minimally invasive posterior surgical approaches concerning the morphology of the paraspinal muscles[14,44]. Hyun et al.[44] conducted a retrospective case selection study with 26 patients with degenerative disease of the lumbar spine. Patients received a unilateral TLIF with pedicle screw fixation via a traditional midline approach at the symptomatic side and a pedicle screw fixation via paramedian interfascial approach at the contralateral side. Lumbar multifidus, thickness, and width was calculated from axial CT scans at the supra and infra adjacent disc levels. The authors found a larger decrease of the cross sectional area of the lumbar multifidus muscle on the side where they performed the midline approach with muscle dissection after 11 months. The authors attributed an increase in muscle thickness early after surgery on the side with midline approach to edema resulting from iatrogenic muscle injury.

Putzier et al.[14] compared the size and texture of the lumbar multifidus and the longissimus muscle of patients after minimally invasive TLIF vs open PLIF of the segments L4/5 or L5/S1. They found an increased atrophy and fatty degeneration of the lumbar multifidus muscle at the index segment. At the adjacent level, no differences between the groups were found.

Ultrasound imaging

Ultrasound imaging is a valid and reliable technique for the assessment of the lumbar multifidus muscle[45,46]. Ultrasonography can deliver information about muscle thickness, cross sectional area, shape, symmetry, and consistency of the muscle. Measurements during static and dynamic tasks in different postures can be performed using ultrasonography[47]. There are few studies that analyzed signs of atrophy in the lumbar multifidus muscle in healthy subjects and persons with low back pain[48-50].

Cawley et al.[51] assessed the cross sectional area of the lumbar multifidus with ultrasonography of 12 patients after lumbar spine fractures (AO-Classification System type A). Patients were treated with bi- or multisegmental minimally invasive stabilization and kyphoplasty (n=6) or open stabilization (n=6). Cross sectional area was calculated for all instrumented levels and for the supra and infra adjacent levels. Additionally, needle EMG was conducted to detect neurogenic muscular changes of lumbar multifidus muscle. Mean follow-up periods were 12 months for the minimally invasive-group and 25 months for the convetional open-group. The authors' report a greater cross sectional area of the lumbar multifidus muscle at the adjacent levels for patients with minimally invasive compared to open surgery.

Electromyography

Needle electromyography (EMG) can measure muscular activity. Denervated musculature shows abnormal duration and amplitudes in motor unit action potentials during contraction or maximal contraction. Neurogenic damage can indirectly be quantified by the drop-out of motor units seen in polyphasic EMG signals[52]. Surface electromyography examinations display muscle activity and could give evidence about atrophy and dysfunction[53]. Studies demonstrated a reinnervation of the multifidus muscle after open posterior instrumentation and fusion 18 months postoperatively[17].

Cawley et al.[51] conducted eight different needle EMG measurements of the lumbar multifidus at rest and activation. Their study revealed more abnormal activation patterns at the adjacent levels in the open-group compared to the minimally invasive-group at final follow-up. The authors argue that minimal invasive surgery better preserves the medial branch nerve from traction or dissection and the lumbar multifidus from neurogenic atrophy than open surgery.

Grass et al.[54] performed electromyographic measurements after posterior stabilizations. In this prospective, non-randomized study, patients with thoracolumbar spine fractures (Th12-L4) were assessed with needle EMG (10 patients each for open and minimal invasive surgery). EMG signals of the lumbar multifidus muscle were taken at a mean follow-up period of eight months. The motor unit action potentials displayed over 80% polyphasic potentials in the open-group compared to less than 20% in the minimally invasive-group during maximal isometric contraction of the back extensor muscles. The high rate of polyphasic muscle potentials indicates denervation of the medial branch nerve after open surgery. This suggests a limited number of recruited motor units during muscle activation, probably resulting in reduced strength, but the authors also report signs of reinnervation of the lumbar multifidus muscle[54].

Wang HL et al.[26] used surface EMG of the sacrospinalis muscle. They assessed the discharge amplitude and frequency three months after surgery in minimally invasive TLIF and open TLIF and found higher amplitude and frequency for the minimally invasive surgery but equivalent frequency/mean amplitude ratio for both groups. The authors interpret their results as indicating reduced muscle damage in minimally invasive relative to open surgery.

Functional outcome assessment of back pain, disability, and quality of life

The prospective, non-randomized study of Wild et al.[13] assessed the disability and quality of life of patients after either minimally invasive or open posterior stabilization of thoracolumbar fractures. At a five years follow-up (67 months after implant removal) there was no significant difference in the Hannover-Spine-Score and the SF-36 between both groups. Yet, the authors concede that a clear conclusion is limited by the existence of inhomogeneity in age and severity of injury across the groups.

Fan et al.[22] compared 16 patients treated by minimally invasive-PLIF with 16 who underwent open-PLIF. The VAS and the ODI were used pre-operatively, as well as six and 14 month after surgery. The minimally invasive-group indicated in their ratings less pain and disability. The pain reduction and improvement in activities of daily living occurred in the first six months, whereas there was no significant change until the last follow-up for both groups. Both pain and disability correlate with changes in the cross sectional area of the lumbar multifidus muscle and density. Fan et al.[22] conclude that less back pain and disability is associated with less lumbar multifidus atrophy and fatty infiltration.

In contrast, Wang HL et al.[26] could not find any difference in pain between groups that had undergone open vs. minimally invasive TLIF after three, six, 12, or 24 months post-surgery. For the ODI scoring, Wang HL et al.[26] found better results for the minimally invasive group at three and six months follow-up, whereas results were equivalent for both groups after twelve to 24 months.

Kim et al.[36] present VAS data of 19 patients either with open or percutaneous posterior fusion. The data were collected pre-operatively and about 20 month post-operatively. The results showed no significant difference between the two groups in the pre- and post-operative pain scoring.

Putzier et al.[14] also found no differences in the VAS and ODI between fifty patients treated by minimally invasive PLIF compared to open PLIF one year postoperatively.

Discussion

This review addressed the question of whether minimally invasive surgery after traumatic thoracolumbar spine fractures can reduce paraspinal muscle injury and lead to better functional outcome.

Overall the literature supports evidence that the multifidus muscle is less severely injured by minimally invasive surgery compared to open approaches. Greater atrophic changes in the morphology of the muscle after open spinal surgery were demonstrated in all imaging studies up to three years postoperatively. Furthermore, MRI T2 signal intensity was increased after open surgery, caused by enlarged capillaries with increased blood volume and extracellular fluid, or by fibrous and fatty infiltrations. Soon after muscle denervation, muscle fibers degenerate and blood volume and extracellular fluid increase, resulting in postoperative edema. Consequently, fibrous and fatty infiltrations are indications of longer-lasting neurogenic muscular changes[28,34,43,55]. Neurogenic changes can be exposed by electromyographic recordings of muscular activity. Compared to healthy subjects, an altered EMG pattern of the paraspinal muscles became apparent more than five years after open dorsal stabilization of upper lumbar spine fractures[58]. All included studies showed markable differences in electromyographic parameters of paraspinal muscle between the open and the minimally invasive approach. But interestingly, in contrast to Grass et al.[54], Wang et al.[26] and Cawley et al.[51] found differences only for the adjacent levels but not for the instrumented levels. These results are unexpected and need further examination because of the segmental nerval supply of the multifidus muscle. All fascicles arising from one spinous process and running caudal as far as five segments are innervated by the medial branch nerve that exits below this spinous process[57]. Denervation and limited recruitment of motor units during muscular activation may result in reduced strength. Isokinetic or isometric measurement systems are widely-used for assessing trunk muscle strength[9,36,58]. There are findings that extensor muscle strength benefits from minimally invasive spine surgery and short retraction times[19,36]. Unfortunately, there are no studies comparing strength in MIS versus CO. In this regard it is helpful to consider the function of the lumbar multifidus muscle. According to its fiber type the main function of the muscle is segmental stabilization of the lumbar spine as well as proprioception and intersegmental mobility[59] with only about 25 % of maximal voluntary contraction[60]. Therefore, muscular function of the lumbar multifidus should not only be assessed during strength exercises but also during coordinative and stabilization exercises[60,61], focusing on the timing of muscular onset[62]. Studies that measure functional outcome after minimally invasive compared to open surgery report inconsistent results. Patients benefit in the early months from minimally invasive treatment especially concerning pain, disability, and quality of life. But more than 12 months postoperatively functional outcomes of minimally invasive and open surgery are equivalent. Yet, there is no clear correlation between changes in structural and functional muscular changes[6]. While some studies showed a positive correlation between muscular alterations and deficits in the clinical outcome[6,12,26], this causal relationship is not confirmed in other studies[8,14,26,36,51]. Further studies are necessary to clarify the relationship between muscular changes and clinical outcome[22].

Back-specific symptoms like pain may persist over years after traumatic thoracolumbar spine fractures[63,64]. In addition to physical factors, psycho-social, personal, and environmental factors help to understand the complex etiology and subjective perception of pain[65,66]. Nonetheless it may be important to take further physical aspects into account. The intervertebral disc plays an important role in pain generation[66]. The intervertebral disc in the adjacent levels of fusion is exposed to changed biomechanical loads[67], and the thoracolumbar fascia may be affected by remaining scares with consequences for the function of the deep musculo-fascial system[68]. Spinal biomechanics are also affected by kyphotic deformity and altered sagittal alignment after trauma and surgery of thoracolumbar fractures[64,65]. This may be reinforced by insufficient stabilization following post-surgical muscular changes. Chronic muscular changes may occur due to imbalance of muscular capacity and demands, too. All this may result in persisting pain and problems in daily activities.

Overall, however, functional outcome rated with ODI and SF-36 showed largely comparable results for minimally invasive and open surgery[13,24,26,69-73]. Long-term follow-up investigations after different approaches in surgery of traumatic thoracolumbar spine fractures likewise showed comparable functional outcomes.

Häkkinen et al.[74] observed that the largest extent of recovery occurs in the first months after surgery. This may explain why patients particularly benefit in early months from minimally invasive surgery especially concerning reduced changes in muscle structure and function. Imaging techniques, like MRI, CT, and Ultrasonography, offer useful insights in paraspinal muscle morphology and function[75-77] which offers additional insights in combination with functional tasks[49,78,79]. Unfortunately, there are only few studies addressing the muscular changes after surgical stabilization of traumatic fractures of the thoracic and lumbar spine.

Finally, we note some limitations to our review. Studies were included even if their conclusiveness was limited due to small samples. Moreover, comparative studies of thoracolumbar fractures and their surgical supply are lacking, and inclusion of studies with a diversity of disorders and surgical procedures limits comparison.

Conclusion

Our review supports the assumption that MIS preserves muscles for the early post-operative period, even though the level of evidence is still low. The correlation of changes in muscular structure to pain, strength, disability, and quality of life remains ambiguous and should be addressed in further studies with a focus on surgical approach, especially after traumatic thoracolumbar fractures.

References

1. McGill SM (2001). Low back stability: from formal description to issues for performance and rehabilitation. Exerc Sport Sci Rev 29:26-31.
2. Kim CW (2010). Scientific basis of minimally invasive spine surgery: prevention of multifidus muscle injury during posterior lumbar surgery. Spine 35:S281-6.
3. Panjabi M, Abumi K, Duranceau J, Oxland T (1989). Spinal stability and intersegmental muscle forces. A biomechanical model. Spine 14:194-200.
4. Richardson C, Hodges P, Hides J (2004). Therapeutic Exercise for Lumbopelvic Stabilization. A Motor Control Approach for the Treatment and Prevention of Low Back Pain. 2nd edn. Churchill Livingstone, Edinburgh.
5. Ward SR, Kim CW, Eng CM, Gottschalk LJ 4th, Tomiya A, Garfin SR, Lieber RL (2009). Architectural analysis and intraoperative measurements demonstrate the unique design of the multifidus muscle for lumbar spine stability. J Bone Joint Surg Am 91:176-85.
6. Zotti MG, Boas FV, Clifton T, Piche M, Yoon WW, Freeman BJ (2017). Does pre-operative magnetic resonance imaging of the lumbar multifidus muscle predict clinical outcomes following lumbar spinal decompression for symptomatic spinal stenosis? Eur Spine J. Feb 8. doi: 10.1007/s00586-017-4986-x. [Epub ahead of print].
7. Pourtaheri S, Issa K, Lord E, Ajiboye R, Drysch A, Hwang K, Faloon M, Sinha K, Emami A (2016). Paraspinal Muscle Atrophy After Lumbar Spine Surgery. Orthopedics 39(2):e209-14.
8. Gellhorn AC, Suri P, Rundell SD, Olafsen N, Carlson MJ, Johnson S, Fry A, Annaswamy TM, Gilligan C, Comstock B, Heagerty P, Friedly J, Jarvik JG (2017). Lumbar Muscle Cross-Sectional Areas Do Not Predict Clinical Outcomes in Adults With Spinal Stenosis: A Longitudinal Study. PM R. Jun;9(6):545-555.
9. Datta G, McGregor A, Medhi-Zadeh S, Khalil N, Hughes SP (2010). The impact of intermittent retraction on paraspinal muscle function during lumbar surgery. Spine 35:E1050-7.
10. Hu ZJ, Fang XQ, Fan SW (2014). Iatrogenic injury to the erector spinae during posterior lumbar spine surgery: underlying anatomical considerations, preventable root causes, and surgical tips and tricks. Eur J Orthop Surg Traumatol 24:127-35.
11. Regev GJ, Lee YP, Taylor WR, Garfin SR, Kim CW (2009). Nerve injury to the posterior rami medial branch during

the insertion of pedicle screws: comparison of mini-open versus percutaneous pedicle screw insertion techniques. Spine 34:1239-42.

12. Sihvonen T, Herno A, Paljarvi L, Airaksinen O, Partanen J, Tapaninaho A (1993). Local denervation atrophy of paraspinal muscles in postoperative failed back syndrome. Spine 18:575-81.
13. Wild MH, Glees M, Plieschnegger C, Wenda K (2007). Five-year follow-up examination after purely minimally invasive posterior stabilization of thoracolumbar fractures: a comparison of minimally invasive percutaneously and conventionally open treated patients. Arch Orthop Trauma Surg 127:335-43.
14. Putzier M, Hartwig T, Hoff EK, Streitparth F, Strube P (2016). Minimally invasive TLIF leads to increased muscle sparing of the multifidus muscle but not the longissimus muscle compared with conventional PLIF-a prospective randomized clinical trial. Spine J 16(7):811-9.
15. Bresnahan LE, Smith JS, Ogden AT, Quinn S, Cybulski GR, Simonian N, Natarajan RN, Fessler RD, Fessler RG (2017). Assessment of Paraspinal Muscle Cross-sectional Area After Lumbar Decompression: Minimally Invasive Versus Open Approaches. Clin Spine Surg 30(3):E162-E168.
16. Ntilikina Y, Bahlau D, Garnon J, Schuller S, Walter A, Schaeffer M, Steib JP, Charles YP (2017). Open versus percutaneous instrumentation in thoracolumbar fractures: magnetic resonance imaging comparison of paravertebral muscles after implant removal. J Neurosurg Spine 27(2):235-241.
17. Cha JR, Kim YC, Jang C, Yoo WK, Cui JH (2016). Pedicle screw fixation and posterior fusion for lumbar degenerative diseases: effects on individual paraspinal muscles and lower back pain; a single-center, prospective study. BMC Musculoskelet Disord 17:63.
18. Charles YP, Zairi F, Vincent C, Fuentes S, Bronsard N, Court C, Le Huec JC (2012). Minimally invasive posterior surgery for thoracolumbar fractures. New trends to decrease muscle damage. Eur J Orthop Surg Traumatol 22:1-7.
19. Gejo R, Matsui H, Kawaguchi Y, Ishihara H, Tsuji H (1999). Serial changes in trunk muscle performance after posterior lumbar surgery. Spine 24:1023-8.
20. Kobbe P, Pishnamaz M, Lange H, Pape H-C (2013). Minimally Invasive Dorsal Stabilization of Traumatic Thoracolumbar Instabilities. Oper Tech Orthop 23:13-8.
21. Taylor H, McGregor AH, Medhi-Zadeh S, Richards S, Kahn N, Zadeh JA, Hughes SP (2002). The impact of self-retaining retractors on the paraspinal muscles during posterior spinal surgery. Spine 27:2758-62.
22. Fan S, Hu Z, Zhao F, Zhao X, Huang Y, Fang X (2010). Multifidus muscle changes and clinical effects of one-level posterior lumbar interbody fusion: minimally invasive procedure versus conventional open approach. Eur Spine J 19:316-24.
23. Kim KT, Lee SH, Suk KS, Bae SC (2006). The quantitative analysis of tissue injury markers after mini-open lumbar fusion. Spine 31:712-6.
24. Shunwu F, Xing Z, Fengdong Z, Xiangqian F (2010). Minimally invasive transforaminal lumbar interbody fusion for the treatment of degenerative lumbar diseases. Spine 35:1615-20.
25. Tsutsumimoto T, Shimogata M, Ohta H, Misawa H (2009). Mini-open versus conventional open posterior lumbar interbody fusion for the treatment of lumbar degenerative spondylolisthesis: comparison of paraspinal muscle damage and slip reduction. Spine 34:1923-8.
26. Wang HL, Lu FZ, Jiang JY, Ma X, Xia XL, Wang LX (2011). Minimally invasive lumbar interbody fusion via MAST Quadrant retractor versus open surgery: a prospective randomized clinical trial. Chin Med J 124:3868-74.
27. Lu K, Liang CL, Cho CL, Chen HJ, Hsu HC, Yiin SJ, Chern CL, Chen YC, Lee TC (2002). Oxidative stress and heat shock protein response in human paraspinal muscles during retraction. J Neurosurg 97:75-81.
28. Shahidi B, Hubbard JC, Gibbons MC, Ruoss S, Zlomislic V, Allen RT, Garfin SR, Ward SR (2017). Lumbar multifidus muscle degenerates in individuals with chronic degenerative lumbar spine pathology. J Orthop Res May 8. doi: 10.1002/jor.23597. [Epub ahead of print].
29. Heffner RR, Barron SA (1978). The early effects of ischemia upon skeletal muscle mitochondria. J Neurol Sci 38:295-315.
30. Kawaguchi Y, Matsui H, Tsuji H (1994). Back muscle injury after posterior lumbar spine surgery. Part 2: Histologic and histochemical analyses in humans. Spine 19:2598-602.
31. Fleckenstein JL, Watumull D, Conner KE, Ezaki M, Greenlee RG Jr, Bryan WW, Chason DP, Parkey RW, Peshock RM, Purdy PD (1993). Denervated human skeletal muscle: MR imaging evaluation. Radiology 187:213-8.
32. Flicker PL, Fleckenstein JL, Ferry K, Payne J, Ward C, Mayer T, Parkey RW, Peshock RM (1993). Lumbar muscle usage in chronic low back pain. Magnetic resonance image evaluation. Spine 18:582-6.
33. Uetani M, Hayashi K, Matsunaga N, Imamura K, Ito N (1993). Denervated skeletal muscle: MR imaging. Work in progress. Radiology 189:511-5.
34. Bendszus M, Wessig C, Solymosi L, Reiners K, Koltzenburg M (2004). MRI of peripheral nerve degeneration and regeneration: correlation with electrophysiology and histology. Exp Neurol 188:171-7.
35. Wessig C, Koltzenburg M, Reiners K, Solymosi L, Bendszus M (2004). Muscle magnetic resonance imaging of denervation and reinnervation: correlation with electrophysiology and histology. Exp Neurol 185:254-61.
36. Kim DY, Lee SH, Chung SK, Lee HY (2005). Comparison of multifidus muscle atrophy and trunk extension muscle strength: percutaneous versus open pedicle screw fixation. Spine 30:123-9.
37. Mori E, Okada S, Ueta T, Itaru Y, Maeda T, Kawano O,

Shiba K (2012). Spinous process-splitting open pedicle screw fusion provides favorable results in patients with low back discomfort and pain compared to conventional open pedicle screw fixation over 1 year after surgery. Eur Spine J 21:745-53.

38. Suwa H, Hanakita J, Ohshita N, Gotoh K, Matsuoka N, Morizane A (2000). Postoperative changes in paraspinal muscle thickness after various lumbar back surgery procedures. Neurol Med Chir 40:151-4.
39. Danneels LA, Vanderstraeten GG, Cambier DC, Witvrouw EE, De Cuyper HJ (2000). CT imaging of trunk muscles in chronic low back pain patients and healthy control subjects. Eur Spine J 9:266-72.
40. Hu ZJ, He J, Zhao FD, Fang XQ, Zhou LN, Fan SW (2011). An assessment of the intra- and inter-reliability of the lumbar paraspinal muscle parameters using CT scan and magnetic resonance imaging. Spine 36:E868-74.
41. Kamaz M, Kiresi D, Oguz H, Emlik D, Levendoglu F (2007). CT measurement of trunk muscle areas in patients with chronic low back pain. Diagn Interv Radiol 13:144-8.
42. Mayer TG, Vanharanta H, Gatchel RJ, Mooney V, Barnes D, Judge L, Smith S, Terry A (1989). Comparison of CT scan muscle measurements and isokinetic trunk strength in postoperative patients. Spine 14:33-6.
43. Lee SH, Park SW, Kim YB, Nam TK, Lee YS (2017). The fatty degeneration of lumbar paraspinal muscles on computed tomography scan according to age and disc level. Spine J 17(1):81-87.
44. Hyun SJ, Kim YB, Kim YS, Park SW, Nam TK, Hong HJ, Kwon JT (2007). Postoperative changes in paraspinal muscle volume: comparison between paramedian interfascial and midline approaches for lumbar fusion. J Korean Med Sci 22:646-51.
45. Hebert JJ, Koppenhaver SL, Parent EC, Fritz JM (2009). A systematic review of the reliability of rehabilitative ultrasound imaging for the quantitative assessment of the abdominal and lumbar trunk muscles. Spine 34:E848-56.
46. Koppenhaver SL, Hebert JJ, Parent EC, Fritz JM (2009). Rehabilitative ultrasound imaging is a valid measure of trunk muscle size and activation during most isometric sub-maximal contractions: a systematic review. Aust J Physiother 55:153-69.
47. Whittaker JL, Stokes M (2011). Ultrasound imaging and muscle function. J Orthop Sports Phys Ther 41:572-80.
48. Hides J, Gilmore C, Stanton W, Bohlscheid E (2008). Multifidus size and symmetry among chronic LBP and healthy asymptomatic subjects. Man Ther 13:43-9.
49. Stokes M, Hides J, Elliott J, Kiesel K, Hodges P (2007). Rehabilitative ultrasound imaging of the posterior paraspinal muscles. J Orthop Sports Phys Ther 37:581-95.
50. Wallwork TL, Stanton WR, Freke M, Hides JA (2009). The effect of chronic low back pain on size and contraction of the lumbar multifidus muscle. Man Ther 14:496-500.
51. Cawley DT, Alexander M, Morris S (2014). Multifidus innervation and muscle assessment post-spinal surgery. Eur Spine J 23:320-7.
52. Röder R (1994). Elektromyografische Befunde bei Kompensations- und Regenerationsprozessen nach peripherer Nervenschädigung. Krankengymnastik 48:1346-53.
53. Dickx N, D'Hooge R, Cagnie B, Deschepper E, Verstraete K, Danneels L (2010). Magnetic resonance imaging and electromyography to measure lumbar back muscle activity. Spine 35:E836-42.
54. Grass R, Biewener A, Dickopf A, Rammelt S, Heineck J, Zwipp H (2006). [Percutaneous dorsal versus open instrumentation for fractures of the thoracolumbar border. A comparative, prospective study]. [Article in German] Unfallchirurg 109:297-305.
55. Kamath S, Venkatanarasimha N, Walsh MA, Hughes PM (2008). MRI appearance of muscle denervation. Skeletal Radiol 37:397-404.
56. Kramer M, Katzmaier P, Eisele R, Ebert V, Kinzl L, Hartwig E (2001). Surface electromyography-verified muscular damage associated with the open dorsal approach to the lumbar spine. Eur Spine J 10:414-20.
57. Macintosh JE, Valencia F, Bogduk N, Munro RR (1986). The morphology of the human lumbar multifidus. Clin Biomech 1:196-204.
58. Kramer M, Dehner C, Katzmaier P, Neuwirth F, Ebert V, Elbel M, Hartwig E (2005). Device-assisted muscle strengthening in the rehabilitation of patients after surgically stabilized vertebral fractures. Arch Phys Med Rehabil 86:558-64.
59. Lonnemann ME, Paris SV, Gorniak GC (2008). A morphological comparison of the human lumbar multifidus by chemical dissection. J Man Manip Ther 16:E84-92.
60. Borghuis J, Hof AL, Lemmink KA (2008). The importance of sensory-motor control in providing core stability: implications for measurement and training. Sports Med 38:893-916.
61. Danneels LA, Coorevits PL, Cools AM, Vanderstraeten GG, Cambier DC, Witvrouw EE, De CH (2002). Differences in electromyographic activity in the multifidus muscle and the iliocostalis lumborum between healthy subjects and patients with sub-acute and chronic low back pain. Eur Spine J 11:13-9.
62. Vasseljen O, Dahl HH, Mork PJ, Torp HG (2006). Muscle activity onset in the lumbar multifidus muscle recorded simultaneously by ultrasound imaging and intramuscular electromyography. Clin Biomech 21:905-13.
63. Briem D, Behechtnejad A, Ouchmaev A, Morfeld M, Schermelleh-Engel K, Amling M, Rueger JM (2007). Pain regulation and health-related quality of life after thoracolumbar fractures of the spine. Eur Spine J 16:1925-33.
64. Reinhold M, Knop C, Beisse R, Audige L, Kandziora F, Pizanis A, Pranzl R, Gercek E, Schultheiss M, Weckbach A, Bühren V, Blauth M (2010). Operative treatment of

733 patients with acute thoracolumbar spinal injuries: comprehensive results from the second, prospective, Internet-based multicenter study of the Spine Study Group of the German Association of Trauma Surgery. Eur Spine J 19:1657-76.

65. Chaleat-Valayer E, Mac-Thiong JM, Paquet J, Berthonnaud E, Siani F, Roussouly P (2011). Sagittal spino-pelvic alignment in chronic low back pain. Eur Spine J 20:634-40.
66. Salzberg L (2012). The physiology of low back pain. Prim Care 39:487-98.
67. Helgeson MD, Bevevino AJ, Hilibrand AS (2013). Update on the evidence for adjacent segment degeneration and disease. Spine J 13:342-51.
68. Vleeming A (2012). The thoracolumbar fascia. An integrated functional view of the anatomy of the TLF and coupled structures. In: Schleip R, Findley TW, Chaitow L, Huijing PA (ed) Fascia: The Tensional Network of the Human Body. Elsevier, Edinburgh, pp 37-43.
69. Peng CW, Yue WM, Poh SY, Yeo W, Tan S (2009). Clinical and radiological outcomes of minimally invasive versus open transforaminal lumbar interbody fusion. Spine 34:1385-9.
70. Rodriguez-Vela J, Lobo-Escolar A, Joven-Aliaga E, Herrera A, Vicente J, Suñén E, Loste A, Tabuenca A (2009). Perioperative and short-term advantages of mini-open approach for lumbar spinal fusion. Eur Spine J 18:1194-201.
71. Schizas C, Tzinieris N, Tsiridis E, Kosmopoulos V (2009). Minimally invasive versus open transforaminal lumbar interbody fusion: evaluating initial experience. Int Orthop 33:1683-8.
72. Wang J, Zhou Y, Zhang ZF, Li CQ, Zheng WJ, Liu J (2010). Comparison of one-level minimally invasive and open transforaminal lumbar interbody fusion in degenerative and isthmic spondylolisthesis grades 1 and 2. Eur Spine J 19:1780-4.
73. Pishnamaz M, Oikonomidis S, Knobe M, Horst K, Pape HC, Kobbe P (2015). Open versus Percutaneous Stabilization of Thoracolumbar Spine Fractures: A Short-Term Functional and Radiological Follow-up. Acta Chir Orthop Traumatol Cech 82(4):274-81.
74. Hakkinen A, Ylinen J, Kautiainen H, Airaksinen O, Herno A, Kiviranta I (2003). Does the outcome 2 months after lumbar disc surgery predict the outcome 12 months later? Disabil Rehabil 25:968-72.
75. Demoulin C, Crielaard JM, Vanderthommen M (2007). Spinal muscle evaluation in healthy individuals and low-back-pain patients: a literature review. Joint Bone Spine 74:9-13.
76. Gold GE (2003). Dynamic and functional imaging of the musculoskeletal system. Semin Musculoskelet Radiol 7:245-8.
77. Whittaker JL, Teyhen DS, Elliott JM, Cook K, Langevin HM, Dahl HH, Stokes M (2007). Rehabilitative ultrasound imaging: understanding the technology and its applications. J Orthop Sports Phys Ther 37:434-49.
78. Shek KL, Dietz HP (2013). Pelvic floor ultrasonography: an update. Minerva Ginecol 65:1-20.
79. Teyhen DS, Gill NW, Whittaker JL, Henry SM, Hides JA, Hodges P (2007). Rehabilitative ultrasound imaging of the abdominal muscles. J Orthop Sports Phys Ther 37:450-66.