

## Review Article

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

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## 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<sup>1-6</sup>. Changes in the lumbar multifidus may cause persistent pain<sup>4,7,8</sup>.

In the conventional open approach, the paraspinal musculature is dissected and retracted, which causes denervation, ischemia, and atrophy<sup>7,9-17</sup>. 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<sup>2,7,10,18-21</sup>. Subsequent significantly lowered levels of serum enzymes and slighter systematic inflammatory response after minimally invasive surgery are reported<sup>22-26</sup>. Open spinal surgery leads to suppressed capillary perfusion, which alters the cell metabolism and yields muscle fiber degeneration<sup>27,28</sup>. Besides, the retraction pressure on muscle fibers causes interstitial edema, destruction of the sarcolemma, and mitochondrial changes implying muscular fiber necrosis<sup>28-30</sup>. 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.

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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 $\pm$ 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 $\pm$ 12 CO: 12 $\pm$ 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 $\pm$ 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)<sup>6-8,15,16,31-33</sup>. 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<sup>34,35</sup>.

We found seven MRI studies on muscular change after minimally invasive surgery compared to open surgery. Wang HL et al.<sup>26</sup> 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.<sup>22</sup> 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.<sup>22</sup> 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
Tsutomimoto 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.<sup>36</sup> 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.<sup>22</sup> regarding the decrease in the cross sectional area of the lumbar multifidus in the open-group. However, the results of Kim et al.<sup>36</sup> could not confirm a larger percentage change of the lumbar multifidus-psoas-ratio for the open-group.

In a retrospective non-randomized study, Tsutomimoto et al.<sup>25</sup> 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.<sup>37</sup>. 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.<sup>16</sup> 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.<sup>15</sup> 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 microendoscopic 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<sup>38</sup>, cross sectional area, and density respectively fatty infiltration of the lumbar multifidus muscle. Therefore CT can indicate atrophy<sup>39-43</sup>.

We detected two CT-studies that compared open and minimally invasive posterior surgical approaches concerning the morphology of the paraspinal muscles<sup>14,44</sup>. Hyun et al.<sup>44</sup> 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.<sup>14</sup> 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<sup>45,46</sup>. 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<sup>47</sup>. There are few studies that analyzed signs of atrophy in the lumbar multifidus muscle in healthy subjects and persons with low back pain<sup>48-50</sup>.

Cawley et al.<sup>51</sup> 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 conventional 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<sup>52</sup>. Surface electromyography examinations display muscle activity and could give evidence about atrophy and dysfunction<sup>53</sup>. Studies demonstrated a reinnervation of the multifidus muscle after open posterior instrumentation and fusion 18 months postoperatively<sup>17</sup>.

Cawley et al.<sup>51</sup> 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.<sup>54</sup> 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<sup>54</sup>.

Wang HL et al.<sup>26</sup> 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.<sup>13</sup> 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.<sup>22</sup> 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.<sup>22</sup> conclude that less back pain and disability is associated with less lumbar multifidus atrophy and fatty infiltration.

In contrast, Wang HL et al.<sup>26</sup> 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.<sup>26</sup> 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.<sup>36</sup> 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.<sup>14</sup> 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<sup>28,34,43,55</sup>. 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<sup>58</sup>. 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.<sup>54</sup>, Wang et al.<sup>26</sup> and Cawley et al.<sup>51</sup> 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 neural 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<sup>57</sup>. 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<sup>9,36,58</sup>. There are findings that extensor muscle strength benefits from minimally invasive spine surgery and short retraction times<sup>19,36</sup>. 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<sup>59</sup> with only about 25 % of maximal voluntary contraction<sup>60</sup>. Therefore, muscular function of the lumbar multifidus should not only be assessed during strength exercises but also during

coordinative and stabilization exercises<sup>60,61</sup>, focusing on the timing of muscular onset<sup>62</sup>. 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<sup>6</sup>. While some studies showed a positive correlation between muscular alterations and deficits in the clinical outcome<sup>6,12,26</sup>, this causal relationship is not confirmed in other studies<sup>8,14,26,36,51</sup>. Further studies are necessary to clarify the relationship between muscular changes and clinical outcome<sup>22</sup>.

Back-specific symptoms like pain may persist over years after traumatic thoracolumbar spine fractures<sup>63,64</sup>. In addition to physical factors, psycho-social, personal, and environmental factors help to understand the complex etiology and subjective perception of pain<sup>65,66</sup>. Nonetheless it may be important to take further physical aspects into account. The intervertebral disc plays an important role in pain generation<sup>66</sup>. The intervertebral disc in the adjacent levels of fusion is exposed to changed biomechanical loads<sup>67</sup>, and the thoracolumbar fascia may be affected by remaining scars with consequences for the function of the deep musculo-fascial system<sup>68</sup>. Spinal biomechanics are also affected by kyphotic deformity and altered sagittal alignment after trauma and surgery of thoracolumbar fractures<sup>64,65</sup>. 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<sup>13,24,26,69-73</sup>. Long-term follow-up investigations after different approaches in surgery of traumatic thoracolumbar spine fractures likewise showed comparable functional outcomes.

Häkkinen et al.<sup>74</sup> 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<sup>75-77</sup> which offers additional insights in combination with functional tasks<sup>49,78,79</sup>. 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.

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