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Biomechanical considerations of the posterior surgical approach to the lumbar spine

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Abstract

BACKGROUND CONTEXT: The effect of the posterior midline approach to the lumbar spine, relevance of inter- and supraspinous ligament (ISL&SSL) sparing, and potential of different wound closure techniques are largely unknown despite their common use.

PURPOSE: The aim of this study was to quantify the effect of the posterior approach, ISL&SSL resection, and different suture techniques.

STUDY DESIGN: Biomechanical cadaveric study.

METHODS: Five fresh frozen human torsi were stabilized at the pelvis in the erect position. The torsi were passively loaded into the forward bending position and the sagittal angulation of the sacrum, L4 and T12 were measured after a level-wise posterior surgical approach from L5/S1 to T12/L1 and after a level-wise ISL&SSL dissection of the same sequence. The measurements were repeated after the surgical closure of the thoracolumbar fascia with and without suturing the fascia to the spinous processes.

RESULTS: Passive spinal flexion was increased by 0.8±0.3° with every spinal level accessed by the posterior approach. With each additional ISL&SSL resection, a total increase of 1.6±0.4° was recorded. Suturing of the thoracolumbar fascia reduced this loss of resistance against lumbar flexion by 70%. If the ISL&SSL were resected, fascial closure reduced the lumbar flexion by 40% only. In both settings, suturing the fascia to the spinous processes did not result in a significantly different result (p=.523 and p=.730 respectively).

CONCLUSION: Each level accessed by a posterior midline approach is directly related to a loss of resistance against passive spinal flexion. Additional resection of ISL&SSL multiplies it by a factor of two.

CLINICAL SIGNIFICANCE: The surgical closure of the thoracolumbar fascia can reduce the above mentioned loss of resistance partially. Suturing the fascia to the spinal processes does not result in improved passive stability.

Keywords: Fascia closure; Interspinous ligament; Lumbar spine; Posterior midline approach to the spine; Posterior ligamentous complex; Spinal structures; Supraspinous ligament; Transection study

FDA device/drug status: Not applicable

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Introduction

Surgical access to the spine can be achieved through a multitude of different approaches. One of the most common is the dorsal midline approach, in which the thoracolumbar fascia is split along its centerline and the erector spina musculature is dissected bilaterally from the posterior aspects of the vertebrae [1]. The dorsal midline approach is therefore inevitably related to iatrogenic damage of these anatomical structures, which is more pronounced in larger surgical interventions [2]. Iatrogenic muscle damage [3] can impact the spinal balance [4], the loading conditions on adjacent segments [5] and the passive stability of the spine in general [6]. Similarly, the thoracolumbar fascia is believed to be an important stabilizer of the spine [7,8]. By surrounding the erector spinae, it is hypothesized to provide an additional hydrostatic stabilizing effect [9−11].

To achieve certain surgical objectives, the inter- and supraspinous ligaments (ISL&SSL), which help stabilize the spinal column especially in end-range flexion [12−14], have to be removed as well [15].

After surgery, the access to the operation site is typically closed by cross-stitching the thoracolumbar fascia [16,17]. Besides, the goal of the wound closure to help the healing processes [18], a positive side effect could be achieved when the pre-operative state of the thoracolumbar fascia can be reestablished to a large extent [16,17]. An interrupted cross stitching technique was proposed for dural tears as it showed improved water tightness compared with continuous sutures or single stitches [19]. However, there is no consensus on the best technique for fascial closure [20]. The STITCH trial proved that herniation of abdominal viscera occurs less with small bites (5mm distance from incision and from stitch to stich) compared with large bites (1 cm each) [21]. However, the applicability of these findings to spine surgery is questionable as incisional hernia is not a common complication in spine surgery [2]. One approach for fascial closure of the posterior access to the spine is to include the spinous processes into the fascial closure with the idea to reduce the size of wound cavity [7] and to improve the postoperative biomechanical integrity by reconstructing the anatomy to a higher degree [16]. Although the latter hypothesis is plausible, there is no clear evidence so far.

In summary, the biomechanical effects of the longitudinal incision of the thoracolumbar fascia, the dissection of the erector spina musculature and incision/resection of the ISL&SSL performed during the dorsal midline approach on the spinal column has not been quantified. Likewise, the biomechanical effect of fascial closure techniques has not been analyzed hitherto. The aims of this study were to investigate the biomechanical impact of the dorsal midline approach and fascia closure techniques.

Methods

Five fresh frozen cadavers (three males, two females, age 58−86 years) were used for this study (Science Care, Phoenix, AZ, USA). Ethical approval was obtained by the local authorities (Kantonale Ethikkommission, BASEC Nr. 2021-00207). A 3T MRI scan (Magnetom Prisma, Siemens Medical Solutions, Erlangen, Germany) acquiring sagittal T2w turbo spin-echo (TSE) dixon images, including water only sequences was performed to evaluate intervertebral disc (IVD)-degeneration based on the Pfirrmann classification [22]. The mean degeneration of the lumbar discs was Pfirrmann Stage III ± I Grade.

CT scans of all specimens were acquired to exclude spinal deformity. The thoracolumbar fascia was further scanned with an ultrasound probe to exclude defects or abnormal thickenings. Ultrasonic measurements of fascial thickness were performed at level Th12/L1 and at L4/5 on each side. The superficial fascial layer showed a mean thickness of 0.12±0.06 mm and the deep layer 0.07±0.03mm.

Test setup

The specimens were rigidly fixed in a neutral “standing position” with S1 screws laterally, supraacetabular iliopectineal screws from anteriorly and sacral screws posteriorly. To prevent axial rotation, the torso was further stabilized with a transglenoidal bar, which was fixed to a rectangular radiolucent frame restricting all movement to the sagittal plane. The frame was able to rotate freely to allow for flexion-extension and the bar was able to move up- and down on the frame to compensate for translational movement (Fig. 1). The spinous processes of S1, L4, and Th12 were identified using fluoroscopy (Ziehm Vision FD, Ziehm Imaging GmbH, Nürnberg, Germany) and short skin incisions were performed at these locations to attach digital angle measurement devices (ELV, 360° Bevel Box, 068773) (Fig. 1).

Test protocol

The specimens were brought in a forward bending position and a forward directed force of 50N was attached to the radiolucent frame for 20 minutes to achieve a stable position and prevent later posture changes during the

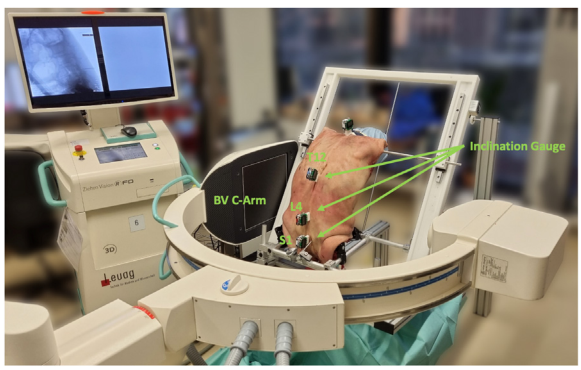

Fig. 1. Experiment setup with image intensifier, stabilizing frame and the inclination gauges in place.

experiments. After preloading, the angular position in the sagittal plane of the Sacrum, L4 and Th12 were recorded and served as reference for the later intervention steps. (Fig. 2)

As illustrated in Fig. 2, the posterior midline approach was first conducted at S1−L5 and extended cranially in level-wise steps up to L1-Th12. After each intervention, the angular positions of the Sacrum, L4 and Th12 were measured. With the surgical approach being completed covering the whole lumbar spine (Th12−S1), the torsi were brought into an upright position to allow for fascial closure with crossed interrupted sutures (Fig. 3). After bringing the torsi back into the forward bending position, the angular position prior and after cutting the sutures was recorded and the difference was used to evaluate the effect of the suturing. The fascial closure was repeated with the same technique but with the inclusion of the spinous processes into the fascial closure. A wiggling motion was used for advancement of the needle through the bone. With this technique fracturing of the spinous process was avoided. In a next step, the ISL&SSL were incised in a level-wise manner starting at S1/L5 and ending at L1/Th12. Then, the same fascial closure technique with and without suturing to the spinous processes was repeated.

Lumbar angulation was defined as the angular difference between Th12 and S1. Lower lumbar angulation was defined as the angular difference between L4 and S1. The difference of these flexion angles was a surrogate for loss of resistance (LoR) against passive flexion.

Statistics

Matlab (Matlab R2019a, Mathworks Inc.) was used for data processing and statistical analysis. According to the

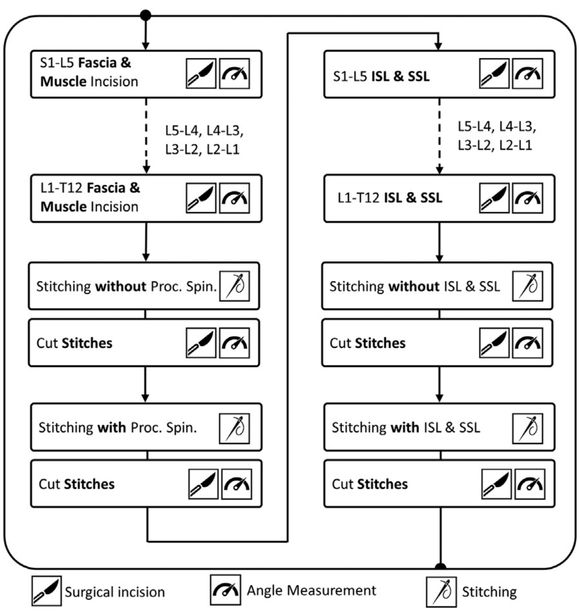

Fig. 2. Experiment workflow.

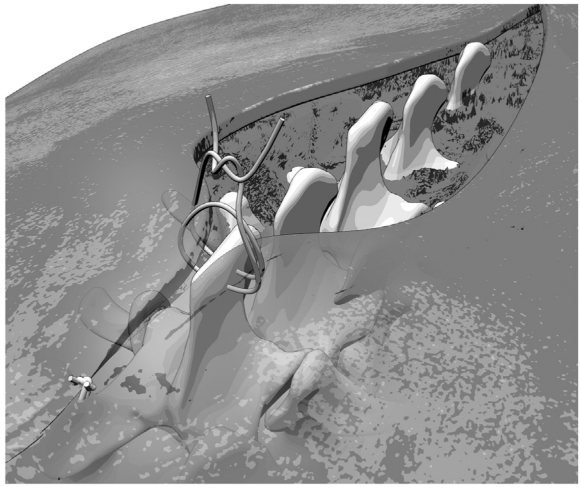

Fig. 3. Schematic drawing of the interrupted cross stitches including the spinous process used for fascial closure.

Shapiro-Wilk parametric hypothesis tests of composite normality (α=0.05), not all values were normally distributed. Therefore, the Mann-Whitney *U* test was used for the statistical evaluation with a significance level of α=0.05.

Results

Fig. 4 illustrates the change in lumbar angulation (Th12−S1) after the level-wise dorsal midline approach, after the additional incision of the ISL&SSL compared with the reference position and the effect of the different fascial closures. By every additional level accessed with the dorsal midline approach, the lumbar angulation (mean ± std) was increased by an average of 0.8±0.3°. The incision of the ISL&SSL further increased passive lumbar flexion to 1.6±0.4° per spinal level.

With intact ISL&SSL, suturing restored the lumbar angulation by 2.5±1.2° without spinous process inclusion and by 3.7±3.1° with inclusion of the spinous processes. This corresponds to 54% and 80% of initial resistance

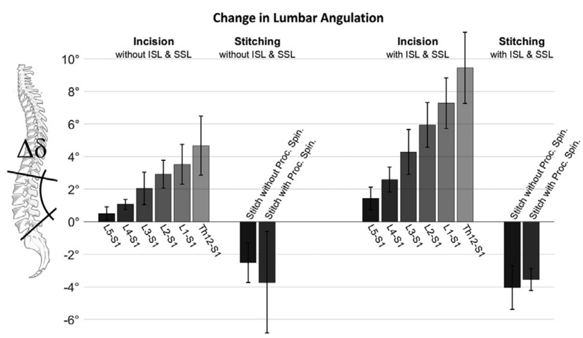

Fig. 4. Change in lumbar angulation (T12−S1) for each level of incision differentiating between incision of the thoracolumbar fascia with dissection of the muscle and ISL/ISS resection. Resistance against passive lumbar flexion after suturing is presented with negative values in separate columns and for the whole lumbar spine.

Table
Change of lumbar and lower lumbar angulation

	Change of lumbar angulation Th12 - S1-Angle			Change of lower lumbar angulation L4 − S1-Angle		
	Incision Th12 - S1	Restoration without Spinous Proc.	Restoration with Spinous Proc.	Incision Th12 - S1	Restoration without Spinous Proc.	Restoration with Spinous Proc.
Intact ISL&SSL	4.7±1.8°	−2.5±1.2°	−3.7±3.1°	3.5±1.7°	−0.9±0.7°	−1.6±1.4°
Incised ISL&SSL	9.4±2.2°	−4.0±1.3°	−3.5±0.7°	5.4±-0.9°	−1.3±0.5°	−1.9±1.1°

ISL, interspinous ligament; Proc., process; SSL, supraspinous ligament.

against passive lumbar flexion caused by the dorsal midline approach from S1 to Th12 (Table).

After ISL&SSL incision, the lumbar angulation was decreased by 4.0±1.3° (without spinous processes) and by 3.5±1.7° (with spinous processes) by suturing, which corresponds to 42% and 38% of initial resistance against passive lumbar flexion, respectively.

The difference between fascial closure with and without spinous process inclusion did not reach statistical significance (p> .05) for both cases (prior and after ISL&SSL incision).

Fig. 5 illustrates the effect of the level-wise dorsal midline approach on the lower lumbar angulation (S1−L4). It was increased by an average of 0.6±0.2° per level without ISL&SSL incision. With ISL&SSL incision, the increase in angulation was not linear and measured 2.3±1.0° for L5−S1 and 4.8±1.3° at L4−S1 and dropped to 4.1±0.8° at L3−S1. For the remaining levels it increased approximately linearly with 0.5°±0.1°.

Suturing the lumbar fascia with incised ISL&SSL restored the lower lumbar angulation by 1.3±0.5° (without spinous process) and by 1.9±1.1° (with spinous process). This corresponds to 24% and 34% of LoR against lower lumbar flexion, which can be restored with fascial closure (Table).

Discussion

Despite its frequent use, the biomechanical effect of the posterior midline approach to the lumbar spine and the restorative potential of the fascial closure is unknown. The purpose of this study was to quantify this using a experimental setup on human cadavers. The change in lumbar angulation during passive forward bending was used as a surrogate for stability of the posterior structures of the spine. We found that the posterior midline approach reduces the resistance of the spine to passive forward flexion. The resistance decreases at each step of incision of the fascia with an approximately linear relationship. The increase in angulation is around 0.8° per level. Interestingly, the additional incision of the ISL&SSL has almost the same effect resulting in a total angulation for all dissected structures of 1.6° per level. This emphasizes the essential role of the ISL&SSL in providing end of range stability, which has also been hypothesized in previous biomechanical studies [14]. It implicates that midline-decompression with the resection of the ISL&SSL, has a far greater effect on spinal stability compared with unilateral decompression without ISL&SSL-incision. However, this destabilizing effect appears to affect mainly the fully flexed position and is less severe in movements close to the neutral position of the spine where the ISL&SSL contribute only marginally [14].

As opposed to the ISL&SSL, the thoracolumbar fascia and the muscles were not dissected but only incised longitudinally. Nevertheless, considerable loss of stability following their incision was observed. This indicates that the thoracolumbar fascia and the muscles are also important contributors in providing passive stability to the spine, concordant to previous reports [6,23,24].

Measurements of the S1−L4-angle revealed a greater increase in angulation with the ISL&SSL incision from S1−L4 compared with the incision from S1−L3 (Fig. 5). This seems counterintuitive at first. However, during the experiments, we found that releasing the tension at the L3−L4 ISL&SSL interrupts the load (torque) transfer from the upper lumbar spine to the lower lumbar spine (Fig. 5). This results in derotation of the lower vertebra (L4 and L5) which eventually leads to regression of the lower lumbar flexion when L3/4 ISL&SSL were incised.

It is further notable that LoR against passive lumbar flexion (L1−S1) was lower compared with LoR against passive lower lumbar flexion (L4−S1) when incising the ISL&SSL at the levels S1−L4. This may be explained by the mobility of the other structures of the spine [14,25]. It seems like the

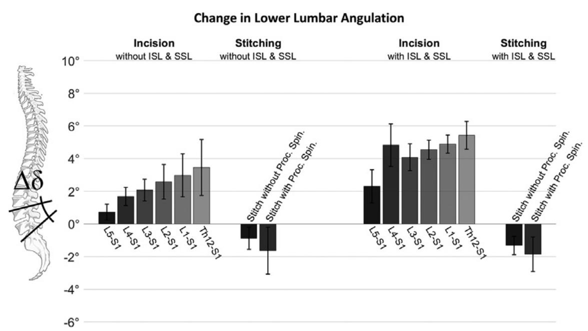

Fig. 5. Change in lower lumbar angulation (L4−S1) for each level of incision differentiating between incision of the thoracolumbar fascia with dissection of the muscle and ISL&SSL resection. Resistance against passive lower lumbar flexion after suturing is presented with negative values in separate columns and for the lower lumbar spine from L4 to S1.

segments from L4 to Th12 compensate for the loss of sagittal stability in the lower two segments even in a postmortem model [4]. As the fascia and the musculature are dissected laterally, the incised spine may also translate posteriorly as it was observed visually.

Anatomical reconstruction is important for rehabilitation and postoperative recovery [25,26]. Similarly, recreating spinal balance is a major goal in spine surgery [4]. Restoring spinal stability to the best possible extend can benefit both aspects. Our study shows that ~65% of resistance to lumbar flexion can be restored by the surgical closure of the thoracolumbar fascia. The relative effect of the fascial closure is markedly smaller, when spinous ligaments have been incised or resected as well. In this case, the restorative potential was around ~40%. In the lower lumbar area this restoration was even less effective. These results imply that despite surgical closure of the thoracolumbar fascia, 35-60% resistance in lumbar flexion is not restored, which indicates that the consequence of spinal surgery on the structural stability could be even more important than generally thought [4].

As an attempt to further improve postoperative reconstruction, inclusion of the spinous process is oftentimes performed in the clinical routine. Our study showed however, that this measure did not increase the primary passive stability to a significant degree. While based on this biomechanical study, spinous process inclusion appears not obligatory, it could still be beneficial for other reasons such as for example reduction of “dead”-space for seroma or faster postoperative rehabilitation [26].

Limitations

The cadaveric setting of our experiment comes with some limitations. Axial rotation was restricted to ensure reproducibility of the flexion-extension motion. Although, real flexion could come along with some coupled axial movement, this inaccuracy was evaluated to be negligible. Furthermore, we could only evaluate passive effects of the structures around the spine and these structures were not standardized. No dynamic evaluation has been performed. To get a statistical mean we did use five different torsos for testing to approximate best possible to the real truth although these numbers are low.

A further limitation of this study is that passive stability was assessed by the increase of angulation. With increasing flexion, the center of mass of the torso is shifting forward and consequently increases its lever arm. The effect of the incision at the upper lumbar level might therefor be slightly overestimated compared with the lower ones. Nevertheless, this may be often the case as well in patients with severe sagittal imbalance.

Furthermore, the fascia closure was difficult to be performed around the inclination gauges and experimental setup also required the operator to perform the stiches in an unusual position, as the torso was erect. Nevertheless, the stiches were performed by a surgeon used to the approach to overcome this limitation.

Conclusion

Each level accessed by a posterior midline approach is directly related to a loss of resistance against passive spinal flexion. Additional resection of ISL&SSL multiplies it by a factor of two. The surgical closure of the thoracolumbar fascia can reduce this effect only partially and suturing the fascia back to the spinal processes does not result in increased resistance to passive flexion.

Declarations of competing interests

None of the authors, their immediate family, and any research foundation, with which they are affiliated, received any financial payments or other benefits from any commercial entity related to the subject of this article.

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