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ORIGINAL ARTICLE

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Influence of surgical intervention at the level of the dorsal spinous processes on the biomechanics of the equine thoracolumbar spine

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Abstract

Background: Surgical treatment options for horses with overriding dorsal spinous processes include interspinous ligament desmotomy and partial spinous process ostectomy. The impact of spinal surgery on the three-dimensional biomechanics of the equine thoracolumbar spine and the epaxial musculature is unclear.

Objectives: To investigate the influence of interspinous ligament desmotomy and cranial wedge ostectomy on the biomechanics of the equine thoracolumbar spine and the paraspinal Musculi multifidi.

Study design: Ex-vivo experiments.

Methods: Twelve equine thoracolumbar spine specimens were mounted in a custom-made mechanical test rig. Based on computed tomographic imaging, distances between dorsal spinous processes and the spinal range of motion (lateral bending, axial rotation, flexion, extension) were compared before and after desmotomy and cranial wedge ostectomy performed at two or five surgical sites. Anatomical dissection was subsequently conducted to document surgical trauma to the Musculi multifidi following desmotomy.

Results: The distance between spinous processes in neutral position did not increase significantly after desmotomy (median preoperative = 7.2 mm, interquartile range [IQR] = 3.6 mm; median postoperative = 7.4 mm, IQR = 3.7 mm; $p = 0.09$), but increased significantly after ostectomy (median preoperative = 8.8 mm, IQR = 4.2 mm; median postoperative = 13 mm, IQR = 6.1 mm; $p < 0.001$). Both surgical procedures significantly increased the rotational spinal range of motion ($p = 0.001$), particularly at the level T14/T15 (median preoperative = 6.4°, IQR = 3.2°; median postoperative = 8.2°, IQR = 3.5°; increase = 28.1%; $p = 0.02$). Musculi multifidi injury was evident at all desmotomy sites.

Main limitations: Ex-vivo study with limited sample size.

Conclusions: Neither interspinous ligament desmotomy nor cranial wedge ostectomy resulted in an increased range of motion during flexion, extension or lateral bending but both procedures influenced the rotational component of the equine thoracolumbar spinal mobility.

KEYWORDS
biomechanics, desmotomy, dorsal spinous process, horse, multifidus, ostectomy

1 | INTRODUCTION

Impinging or overriding dorsal spinous processes (ORDSP) are a common radiographic finding in the equine thoracolumbar spine.[1–4] The condition is defined as narrowing of the interspinous space between dorsal spinous processes (DSPs) to less than 4 mm.[5] Affected horses may show behavioural changes, pain on palpation or gait abnormalities; however, affected horses may also be asymptomatic.[6–8] The severity of ORDSP radiographic findings does not necessarily correlate with the severity of clinical signs.[3,4]

A variety of conservative as well as surgical options are available for the treatment of ORDSP in horses.[9,10] Surgical methods include desmotomy of the interspinous ligament and subtotal or total ostectomy of affected DSPs.[11–22] The desmotomy involves transection of the interspinous ligament. For the subtotal ostectomy, the supraspinous ligament is divided longitudinally and the interspinous ligament is cut to facilitate partial DSP removal.[12,16,20]

The biomechanics of the equine spine have been studied in anatomical specimens and in vivo.[23–28] It was demonstrated that the spinal range of motion (ROM) varies depending on the direction of motion (lateral bending, axial rotation or dorsoventral movement) and the individual spinal segment.[23–29] Whilst the influence of the desmotomy on the dorsoventral spinal mobility has been investigated, the impact of the desmotomy and ostectomy on the three-dimensional spinal ROM including lateral bending and axial rotation remains unclear.[30]

Anatomical dissection of the equine interspinous ligament identified an oblique, crossing fibre arrangement, suggesting that the interspinous ligaments serve to resist distractive and rotational forces in horses.[31] Thus, desmotomy or ostectomy may reduce the vertebral columns' resistance to internal forces, potentially resulting in altered spinal mobility and stability.

In addition to the ligaments, the Musculi (Mm.) multifidi have been shown to provide intersegmental stabilisation of the equine thoracolumbar spine.[32–35] These muscles course in a craniomedial to caudolateral direction adjacent to the DSPs and consist of several fascicles spanning two to four intervertebral segments.[32,36] The epaxial muscles, including the Mm. multifidi, are sharply dissected off the affected DSPs under visual control during ostectomy.[21,22] To the best of the authors' knowledge, the impact of the desmotomy on the Mm. multifidi has not been analysed.

The aim of this study was to investigate the impact of spinal surgery on the three-dimensional ROM of the equine thoracolumbar spine and to assess the extent of iatrogenic Mm. multifidus injury following desmotomy. The authors hypothesised that both desmotomy and ostectomy would result in significant alterations of the spinal mobility and that desmotomy would traumatise the Mm. multifidi.

2 | MATERIALS AND METHODS

2.1 | Animals and samples

Twelve horses, euthanised due to conditions unrelated to spinal pathology, were included in the study. Thoracolumbar spine specimens were obtained from nine geldings, two mares and one stallion. The breeds represented are Warmblood ($n = 7$), Arabian ($n = 1$), Haflinger ($n = 1$), Icelandic horse ($n = 1$), Pony ($n = 1$) and Welsh Cob ($n = 1$). Thoracolumbar spine specimens were excised between the seventh and eighth thoracic (T) and the fourth and fifth lumbar (L) vertebra with the ribs transected at the level of the rib angle. The attached soft tissues including musculature and skin were left intact. Specimens weighed 25.2–38.6 kg (median [Md.]: 30.9 kg). The time between euthanasia and excision of specimens was 12–24 h with 48 h between excision and examination. Tissues were stored at 4°C prior to biomechanical testing.

2.2 | Experimental protocol

The thoracolumbar spine specimens were mounted in a previously described custom-made mechanical test rig that was constructed to obtain cross-sectional images during biomechanical testing in a large bore (900 mm) computed tomography (CT) scanner (Canon Medical Systems, 32-slice detector) (Figure 1).[29] CT parameters were as follows: 135 kV, 370 mA, 1 mm slice thickness, field of view 40–70 cm.

Initially, a reference CT scan was obtained for each specimen in a neutral position to be examined for significant spinal pathology. Specimens with ORDSP > grade 4 or other spinal pathologies (e.g., spondylosis) were excluded from the study.[5]

Specimens were randomly assigned to a desmotomy ($n = 6$) or ostectomy group ($n = 6$). Biomechanical analysis was performed following a set order based on a previously described protocol.[29] After the reference CT scan, lateral (left and right) deflection, axial (left and right) rotation, as well as dorsoventral (flexion and extension) deflection, were consecutively achieved by applying a torque of 60 Newton metres (Nm). To achieve a constant torque, that acts equally on every spinal segment, the torque was applied to the cranial and caudal aspect of the specimen for lateral and dorsoventral deflection. For axial rotation torque was applied to the cranial aspect with the caudal part of the specimen in a fixed position. A torque of 60 Nm was selected as it resulted in maximum spinal deflection in all directions. To account for soft tissue relaxation, the torque of 60 Nm was constantly readjusted manually for 5 s before the self-locking state. CT imaging was performed for each motion pattern with a neutral position scan obtained in between.

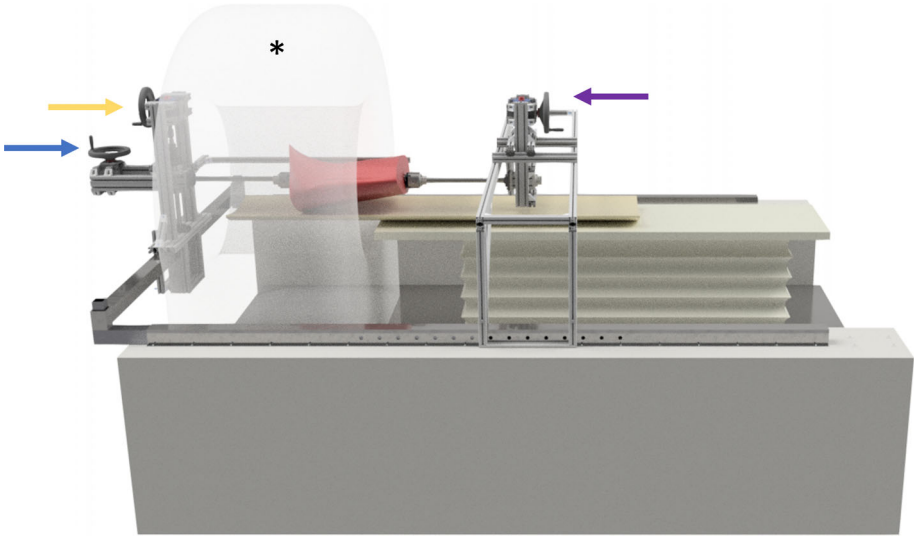

FIGURE 1 Mechanical test rig for deflection of equine spine specimen (indicated in red) during computed tomographic imaging. Cranial part (left side of the image) with handwheels for lateral bending/dorsoventral movement (yellow arrow) and rotation (blue arrow). Caudal part (right side of the image) with handwheel for lateral bending and dorsoventral movement (purple arrow). For dorsoventral movement, the specimen was positioned at 90° to the sagittal plane. Qalibra CT-system equipped with a Canon Large Bore (white transparent, marked with black asterisk).

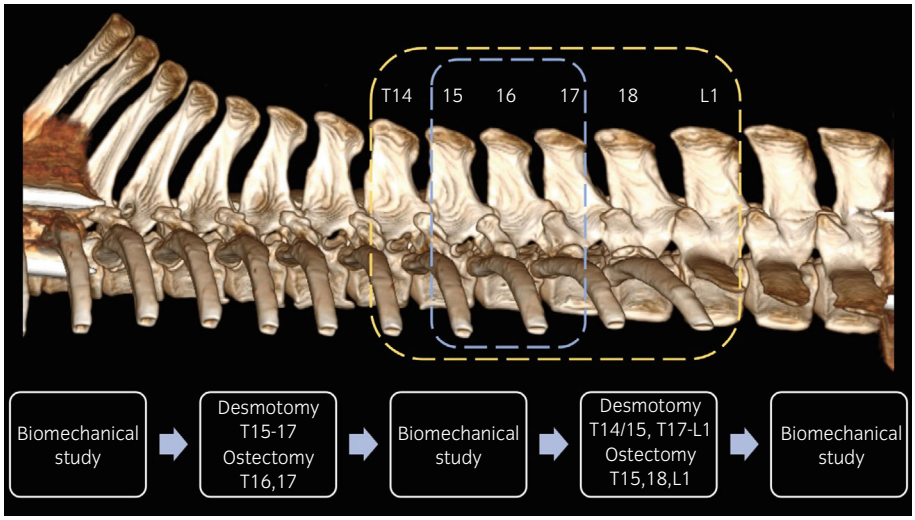

FIGURE 2 Illustration of surgical areas and experimental protocol. During the first part of the study, either interspinous ligament desmotomy in the interspinous spaces between T15/T16 and T16/T17, or partial dorsal spinous process (DSP) ostectomy of the T16 and T17 DSPs was performed (area marked in blue). In the second part, desmotomy between T14/T15, T17/T18 and T18/L1 or ostectomy of the T15, T18 and L1 DSPs (marked in yellow) was added in the same specimens. L, lumbar vertebra; T, thoracic vertebra.

A constant moment along the entire spinal specimen was achieved as specimens were supported by the CT couch during biomechanical testing, making the applied movement independent of gravitational forces. For lateral bending, the hand wheels on both sides of the specimen (Figure 1) were used with rotational movement mechanically enabled to facilitate coupled motion.[29] Coupled motion results are documented in a previously published paper.[29] Axial rotation was applied by using the cranial handwheel, with the caudal aspect of the specimen remaining in a fixed position. For flexion-extension, specimens were positioned at a 90° angle to the sagittal plane and torque was applied with the handwheels as used for lateral movement.[29]

Surgery was subsequently performed with the specimens in neutral position within the test rig. All surgical procedures were performed by the same operator (N.B.) under supervision of an ECVS boarded equine surgeon (A.E.). Interspinous ligament desmotomy was conducted in the interspinous spaces between T15/T16 and T16/T17.[16] Subtotal cranial wedge ostectomy was performed on the T16 and T17 DSPs (Figure 2).[12] After surgery biomechanical analysis, including all described motion patterns, was repeated with the same torque (60 Nm) applied (Figure 2).

Additional surgery was performed in the same specimens in the interspinous spaces T14/T15, T17/T18 and T18/L1 in the desmotomy group and on the DSPs T15, T18 and L1 in the ostectomy group. Biomechanical analysis was again repeated as described (Figure 2).

2.3 | Computed tomographic image analysis

Philips IntelliSpace Portal© (2020, Koninklijke Philips N.V.) was used to perform CT measurements. The detailed analysis of the spinal ROM before and after surgical intervention was based on a previously described protocol (Figure 3).[29] Where significant changes in ROM were identified, the non-surgical area (T9–T14, L1–L3) served as a control. Since the mobility of spinal segments differs along the length of the spine, values of the control segments were not directly compared with those of the surgical area. Control values (ROM of T9–T14, L1–L3) were compared between the initial biomechanical

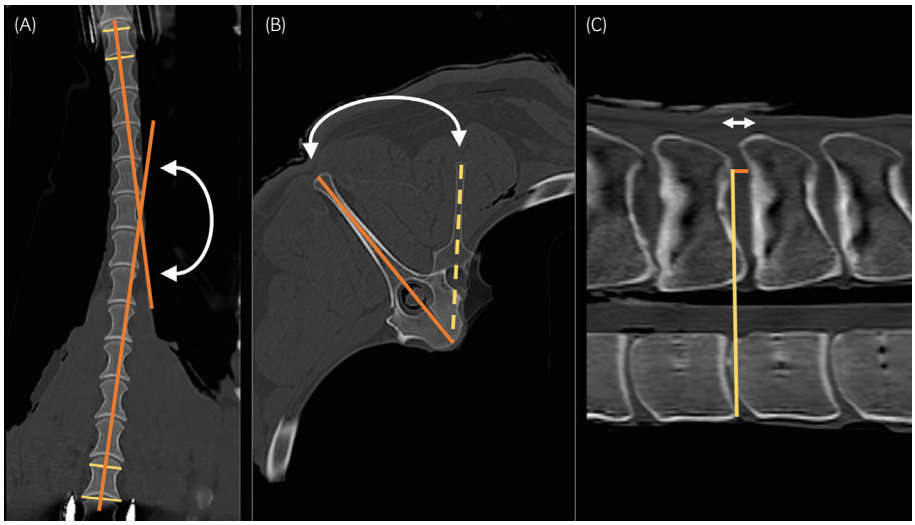

FIGURE 3 Illustration of measurements acquired, based on CT imaging of the equine thoracic spine in different deflections. (A) Measurement of lateral bending: The midline of the vertebral bodies of the ninth thoracic and the third lumbar vertebrae (yellow and orange lines) was used to determine the lateral bending angle (white arrow). (B) Measurement of rotation: The third lumbar vertebra (transparent) served as a reference point (yellow line) which provided the baseline to which other vertebrae were compared. The angle deviation (white arrow) from the vertical baseline to every vertebra (orange line) was measured. (C) Measurement of the interspinous distance in neutral position, flexion and extension: A line (yellow line) was inserted between the most caudoventral aspect of the cranial vertebral body and the caudal aspect of the corresponding dorsal spinous process. A perpendicular line (orange line) was drawn to identify the width of the interspinous space (white arrow).[38]

study and the biomechanical tests after spinal surgery was performed. Results were used to determine whether an increased ROM occurred along the entire length of the spinal specimen (surgical and non-surgical area) or if only the surgical area was affected.

2.3.1 | Absolute values

At the level where surgery was performed (Figure 2), the postoperative increase of the interspinous space width (mm) was determined in neutral position for both groups (desmotomy/ostectomy). To account for anatomical variations, values of lateral bending and axial rotation were first subtracted from the neutral position values. The degree of lateral bending or rotation to the left and right were subsequently added up, resulting in a total spinal ROM between T9 and L3 for lateral bending and a total ROM of the individual spinal segments for rotation.

The pre- and postoperative distance (mm) between adjacent DSPs in neutral position, flexion and extension was analysed and a median calculated considering the entire spinal specimen (T9–L3).[30] The analysis of absolute values for interspinous distance (mm) for dorsoventral deflection was omitted in the ostectomy group as the removal of bone leads to an increased distance between the DSPs.

2.3.2 | Relative values

For the detailed assessment of the individual inter-segmental dorsoventral ROM, relative values were calculated for flexion and extension in both the desmotomy and the ostectomy group. The percentage increase or decrease of the interspinous spaces width during flexion and extension was calculated by dividing the distance between adjacent DSPs during deflection by the values obtained in neutral position.

2.4 | Anatomical dissection

After the postoperative biomechanical analysis, anatomical dissection was performed. The epaxial musculature was removed to expose the Multifidus layers and inspect the degree of postoperative trauma. For documentation purposes, the described Multifidus fascicles were divided into dorsal (lateral spinous process fascicle, dorsocaudal spinous process fascicle), intermediate (middle spinous process fascicle) and deep (deep spinous process fascicle, lamina fascicle) sections.[32] For each operated interspinous space, the proportion of the fascicle section (dorsal, intermediate, deep) that was cut in a vertical direction was assessed. It was documented whether a fascicle section was cut by one-quarter (1/4), one-third (1/3), half (1/2), two-thirds (2/3), three-quarters (3/4) or severed completely.

2.5 | Data analysis

Data were recorded in Excel© (Version 2211, Microsoft Inc.) and statistical analysis was performed using SPSS© (IBM SPSS Statistics for Windows, Version 28.0). Descriptive analysis included the horses' age, the weight of the specimen, and the surgical injury to the Mm. multifidi.

Data were visually inspected for normal distribution. To identify differences in the pre- and postoperative spinal ROM in the surgical

area, independent of the surgical site and surgical method applied, a paired *t*-test was performed for normally distributed data and a Wilcoxon signed-rank test for non-normal data distribution. A *p*-value <0.05 was considered statistically significant. To assess the influence of the location where surgery was performed, the vertebral segments T14–T18 were compared with the least mobile vertebral segment T18/L1 using a linear mixed model. A linear mixed model was also used to evaluate whether the surgical method would impact the spinal ROM. Surgical location and method were selected as fixed effects and the horse as a random effect. Residuals were visually analysed for normal distribution.

3 | RESULTS

3.1 | Two surgical sites (T15–T17)

In neutral position, the distance between adjacent DSPs did not change significantly after desmotomy (Md. preoperative [preop.] = 6.5 mm, interquartile range [IQR] = 3.7 mm; Md. postoperative [postop.] = 6.0 mm, IQR = 3.8 mm; $p = 0.7$). Ostectomy increased the distance between DSPs significantly (Md. preop. = 8.7 mm, IQR = 4.0 mm; Md. postop. = 13.7 mm, IQR = 7.6 mm; $p = 0.003$). Regardless of the surgical site and surgical method used, no significant differences between pre- and postoperative lateral bending (Md. preop. = 8.4°, IQR = 8.3°; Md. postop. = 8.7°, IQR = 10.7°; $p = 0.6$), axial rotation (Md. preop. = 4.3°, IQR = 2.4°; Md. postop. = 4.3°, IQR = 3°; $p = 0.2$), flexion (Md. preop. = 10.2%, IQR = 16.6%; Md. postop. = 6.7%, IQR = 13.3%; $p = 0.6$) or extension ROM (Md. preop. = −8.1%, IQR = 11.1%; Md. postop. = −8.8%, IQR = 10.2%; $p > 0.999$) were identified.

3.2 | Five surgical sites (T14–L1)

3.2.1 | Absolute values

Analysing the surgical area (T14–L1) in neutral position, the distance between DSPs did not increase significantly after desmotomy ($p = 0.09$) but increased significantly after ostectomy (Md. preop. = 8.8 mm; Md. postop. = 13 mm; $p < 0.001$) (Table 1; Figure 4).

The lateral bending analysis (T9–L3) did not identify a significant increase in lateral spinal mobility after surgery ($p = 0.5$) (Table 1). In the surgical area (T14–L1), the overall axial rotation ROM increased significantly from a median of 3.2° to 3.4° ($p = 0.001$) (Table 1). Spinal segments where no surgery was performed (T9–T14, L1–L3) were used for comparison. Here, no significant change in rotational ROM was detected postoperatively ($p = 0.3$) (Table 2).

Considering the entire length of the spinal specimen (T9–L3), a significant increase of the interspinous space width was observed postoperatively in neutral position as well as in flexion following desmotomy. In neutral position, the median interspinous space width was 7.45 mm preoperatively (IQR = 4.2 mm) and 7.6 mm postoperatively (IQR = 3.9 mm) ($p = 0.01$). In flexion, a preoperative median width of 8.5 mm (IQR = 3.8 mm) and a postoperative median width of 8.6 mm (IQR = 3.5 mm) were identified ($p = 0.04$). Pre- and postoperative extension values (T9–L3) did not differ significantly (Md. preop. = 6.55 mm, IQR = 4.0 mm; Md. postop. = 6.65 mm, IQR = 4.0 mm; $p = 0.6$).

TABLE 1 Influence of surgery, surgical method and surgical site on the range of motion (ROM) after performing surgery on five interspinous spaces (T14–L1). A *p*-value <0.05 was considered statistically significant.

Investigated motion	Surgery	Md. preop.	IQR preop.	Md. postop.	IQR postop.	*p*-Value
DSP distance/ROM						
Distance between DSPs	Desmotomy	7.2 mm	3.6 mm	7.4 mm	3.7 mm	0.09
	Ostectomy	8.8 mm	4.2 mm	13.0 mm	6.1 mm	**<0.001**
Lateral bending	Desmotomy/Ostectomy	8.4°	8.3°	8.4°	10.3°	0.5
Axial rotation		3.2°	3.5°	3.4°	4.3°	**0.001**
Flexion		12.8%	20.0%	8.2%	17.0%	0.1
Extension		−7.9%	13.2%	−6.0%	10.1%	0.3
Influence of surgical method						
Lateral bending	Desmotomy versus Ostectomy	NA		NA		0.1
Axial rotation						0.5
Flexion						0.4
Extension						0.7
Influence of surgical site						
Lateral bending	Desmotomy/Ostectomy	NA		NA		0.1
Axial rotation						**0.02**
Flexion						0.2
Extension						0.6

Abbreviations: Md, median; Postop., postoperative; Preop., preoperative.

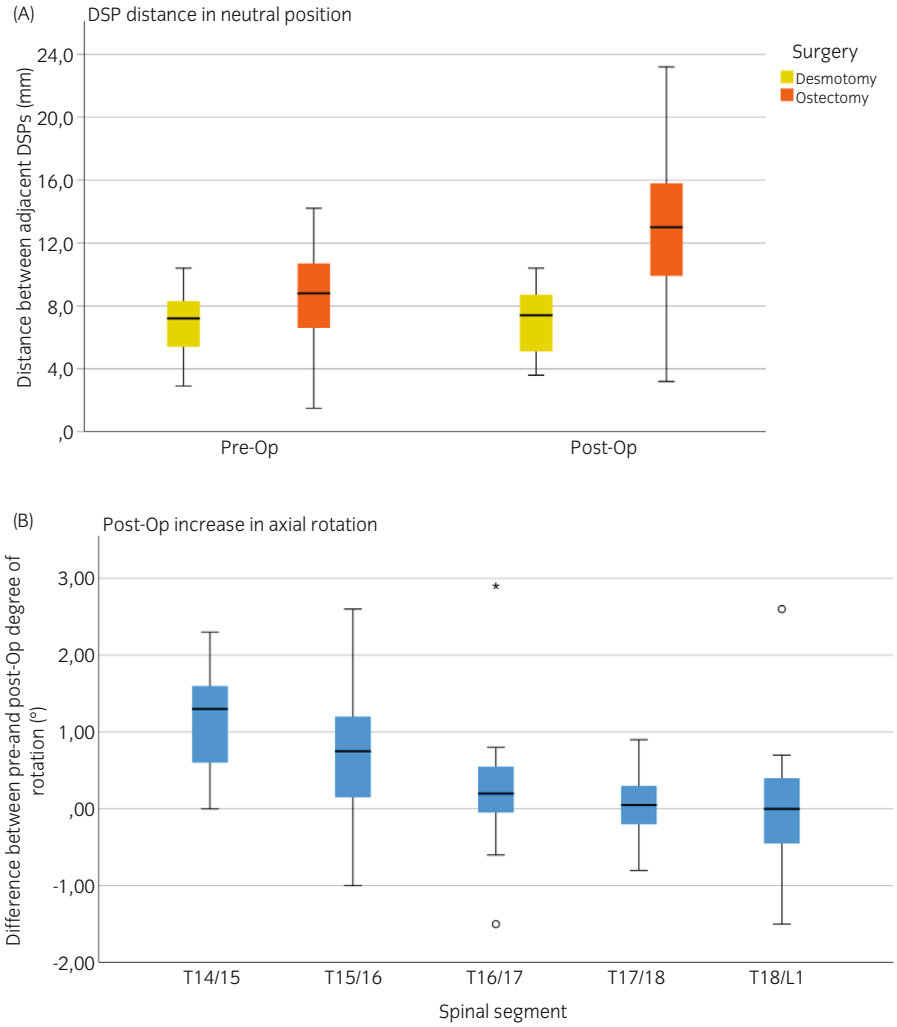

FIGURE 4 (A) Box plots representing comparison between pre- and postoperative interspinous space width following desmotomy or ostectomy in neutral position. Black lines represent the median. Whiskers indicate values outside the interquartile range. (B) Box plots illustrating difference between the pre- and postoperative degree of axial rotation independent of the surgical method. Black lines represent the median. Whiskers represent values outside the interquartile range. Extreme values are indicated by asterisks (*) and circles (°). DSPs, dorsal spinous processes.

3.2.2 | Relative values

Comparing the relative values for flexion ($p = 0.1$) and extension ($p = 0.3$) in the surgical area (T14–L1), there were no significant differences in the pre- and postoperative ROM regardless of the surgical location or method employed (Table 1).

3.2.3 | Influence of surgical method

Based on the linear mixed model, the choice of surgical method had no significant effect on the ROM during lateral bending ($p = 0.1$), axial rotation ($p = 0.5$), flexion ($p = 0.4$) or extension ($p = 0.7$) (Table 1).

3.2.4 | Influence of surgical site

The influence of surgery on the ROM during lateral bending ($p = 0.1$), flexion ($p = 0.2$) or extension ($p = 0.6$) did not differ between the anatomical regions. However, the difference in the degree of rotation before and after surgery was significantly associated with the location of the surgical site ($p = 0.02$) (Table 1). The difference in the pre- and postoperative degree of rotation for the spinal segment T14/T15 was on average 1.0° (95% confidence interval [CI] = 0.3°–1.8°) higher than that of the spinal segment T18/L1 ($p = 0.008$) (Figure 4). The pre- and postoperative rotational values of T15/T16, T16/T17 and T17/T18 were not significantly different from the pre- and postoperative values of T18/L1 ($p = 0.1$; 0.6; 0.9) (Figure 4). During axial rotation T14/T15 showed a median ROM of 6.4° (IQR 3.2°) before surgery and 8.2° (IQR 3.5°) after surgery, representing an increase in rotational ROM of 28.1%, whereas T18/L1 showed a median ROM of 1.2° (IQR 0.7°) before surgery and 1.3° (IQR 0.5°) after surgery, representing an increase of 8.3%.

3.3 | Dissection of Mm. multifidi

Anatomical dissection of the M. multifidus fascicles following desmotomy identified iatrogenic damage to the dorsal fascicles in 100% of surgical sites (Figure 5). In 5% of the dorsal fascicles, 1/4 of the muscular tissue was affected. One-half of the dorsal fascicles were transected in 10% of cases and complete transection occurred in 85% of cases. The intermediate section was affected to 1/2 in 20% of

TABLE 2 Increase in axial rotation in the surgical (surgery performed at five surgical sites) and non-surgical area regardless of the surgical method used.

	Surgical area T14–L1	Non-surgical area T9–T14, L1–L3
Md. preop.°	3.2	5.5
Md. postop.°	3.4	5.7
Increase %	6.3	3.6
p-Value	0.001	0.3

Abbreviations: Md, median; Postop., postoperative; Preop., preoperative.

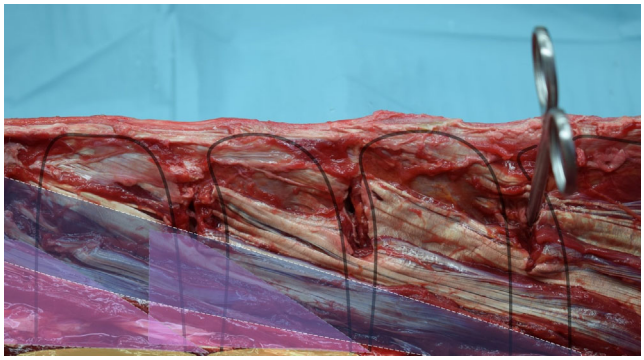

FIGURE 5 Anatomical dissection of the paravertebral Multifidus musculature following desmotomy. Spinous processes are sketched for clarification. To the right of the picture, scissors are inserted to illustrate placement for an interspinous ligament desmotomy. There is evidence of trauma to the dorsal (transparent blue) and intermediate fascicles (transparent pink) of the Musculi multifidi. Deep fascicles (transparent yellow) were not injured.

specimens, 1/3 was transected in 10% and 1/4 in 5% of specimens. Sixty-five per cent of the intermediate fascicles were preserved. Injury to the deep multifidus sections was not observed.

4 | DISCUSSION

This study of the equine thoracolumbar mobility before and after spinal surgery confirmed a significant increase in rotational ROM, particularly in the area of the caudal thoracic spine, following desmotomy and subtotal (cranial wedge) ostectomy performed at five surgical sites. Additionally, compromise of the Mm. multifidi was identified following minimally invasive interspinous ligament desmotomy.

In agreement with a recent report, desmotomy resulted in a significant increase of the spinal ROM (T9–L3) during dorsoventral flexion with widening of the interspinous space in neutral position.[30] Biedrzycki and Elane (2022) excised spinal specimens between T11 and L1 and performed desmotomy in all interspinous spaces ($n = 8$).[30] However, when only the spinal segments where surgery was performed (T14–L1) were considered in the current study, a significant difference in flexion ROM after desmotomy was not observed. Widening of the interspinous space in neutral position in both the surgical and non-surgical area (T9–L3: Md. preop. = 7.45 mm; Md. postop. = 7.6 mm) and the general tendency for the measured values to increase postoperatively is most likely related to soft tissue relaxation during multiple biomechanical examinations. Therefore, results were only considered statistically significant when there was an increase in ROM after surgery that was not observed in the non-operated spinal segments in the current report. Additionally, absolute values are subject to potential errors, as they may be influenced by factors like the spinal length. Relative values were calculated to avoid misinterpretation in the current study.

Coomer et al. (2012) reported a widening of the interspinous space after desmotomy in vivo.[16] As it is not entirely clear to what extent a standardised protocol was used for pre- and postoperative radiographic examination of the thoracolumbar spine, the head and neck position as well as the x-ray beam angle might have influenced the determined interspinous space width in the in vivo report.[16,37,38] The results of the current study support the hypothesis, that pain relief results more from a reduction in tension on the nociceptive receptors within the interspinous ligament rather than from actual widening of the interspinous space.[16,39]

A significant increase of the rotational ROM was observed postoperatively in the area where surgery (desmotomy or ostectomy) was performed. A similar increase in rotational ROM was not evident in the non-surgical area, indicating a rise in rotational spinal mobility due to surgical intervention at five surgical sites. Spinal segments located further cranially (T14/T15) showed a greater increase in rotational ROM when compared with the caudal segments (T18/L1). Since the rotational ROM is naturally higher in the thoracic spine when compared with the thoracolumbar segment, surgical intervention exaggerates this effect.[27,29,40]

ROM results following desmotomy did not differ significantly from those after subtotal ostectomy at five sites. During desmotomy, the interspinous ligament is transected. For the ostectomy, the supraspinous ligament is additionally incised longitudinally and DSPs are resected. The common characteristic of both surgeries is the transverse transection of the interspinous ligament. This could imply that the transection of the interspinous ligament has the greatest influence on spinal biomechanics and the longitudinal transection of the supraspinous ligament plays a minor role.

During ostectomy, the paravertebral muscles are dissected under visual control whereas iatrogenic trauma to the epaxial musculature remains undetected when minimally invasive interspinous ligament desmotomy is performed.[21,22] Inadvertent trauma to the dorsal multifidus fascicles as a consequence of desmotomy was observed at all surgical sites in this study. The authors further hypothesise that more trauma likely occurs when desmotomy is performed in clinical ORDSP cases where it often poses a challenge to drive the scissors in between affected DSPs upon first attempt. Unilateral neurogenic atrophy of the epaxial muscles was additionally described contralateral to the site where the scissor was inserted for desmotomy in clinical cases.[17] It is hypothesised that the atrophy may be due to the horizontal angle of the inserted

instrument, resulting in damage to the middle branch of the dorsal spinal nerves.[17,41]

An investigation in rabbits compared two techniques for the surgical approach performing lumbar spinal surgery.[42] In one group, an incision was made in the skin and lumbodorsal fascia only (Group C), and in the other group the Mm. multifidi were additionally incised bilaterally (Group S). Significantly more necrosis, inflammation, fibrosis and fatty degeneration of the Mm. multifidi were identified postoperatively in group S. Additionally, degeneration of neuromuscular junctions was present during all follow-up time points (3, 6, 9, 24 weeks) for group S, with a significant increase in the number of degenerated junctions over time.[42] Similarly, in human spinal surgery, injury to the Mm. multifidi was significantly associated with long-term muscle atrophy and fatty infiltration.[43] A minimally invasive approach, using two wires to pierce the Mm. multifidi bilaterally and then creating surgical corridors with serial dilators, resulted in fewer changes in the Mm. multifidi with less postoperative back pain and functional disability in human patients.[43] In equine surgery, a minimally invasive approach under endoscopic control has been described for subtotal ostectomy.[11,16] A paramedian incision is created as for the interspinous ligament desmotomy. The endoscope is however only inserted once the paravertebral muscles are dissected and retracted to free the affected DSP. It is therefore unlikely that this approach as it is described would significantly reduce the local soft tissue trauma when compared with the desmotomy approach.[11]

An increase in the M. multifidus cross-sectional area has been associated with improved equine spinal health and postural stability in several studies.[44,45] In one study, an increase in the multifidus cross-sectional area was shown after a mean of 56 days following desmotomy for the treatment of horses with ORDSP.[44] Horses were however following a specific plan tailored to train the epaxial musculature and particularly the Mm. multifidi post-surgery.[35] The composition and more importantly the functionality of the epaxial soft tissues after spinal surgery in horses remains unclear.

Limitations of the presented research include the small sample size and the ex vivo character of the study without separate controls. As the spinal specimens lack muscle tone, spinal biomechanics in the living animal may vary. Additionally, only spines with an ORDSP grade of less than four were included in the current study. Surgery performed on more severely affected or fused DSPs might result in a more significant change in the thoracolumbar spinal biomechanics. This study did not consider the movement of the vertebral bodies in other directions than the one currently being investigated. A surgically induced lateral tilt of the vertebrae during flexion, for example, would remain undetected.

In summary, this is the first study investigating the influence of both interspinous ligament desmotomy and subtotal DSP ostectomy on the ROM of the equine thoracolumbar spine. Both surgeries resulted in a significant increase of the rotational spinal ROM, particularly in the area of the caudal thoracic spine when performed at five surgical sites. Injury to the Mm. multifidi was detected in all specimens following minimally invasive desmotomy. Most movements of the horse involve a rotational component of the thoracolumbar spine in vivo.[23–25] How the findings of the current study impact the biomechanics of equine motion in vivo, and whether or to what degree the increased postoperative mobility during axial rotation results in instability of the equine spine, remains unclear at this stage. Future studies including in vivo biomechanical investigations focusing on the long-term consequences of spinal surgery in horses as well as the histopathological assessment of the M. multifidus recovery post-surgery would be of great interest.

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CONFLICT OF INTEREST STATEMENT

The authors have declared no conflicting interests.

AUTHOR CONTRIBUTIONS

Natalie Baudisch: Conceptualization; investigation; funding acquisition; writing – original draft; writing – review and editing; visualization; validation; methodology; software; formal analysis; project administration; resources; data curation; supervision. **Ellen Singer:** Conceptualization; writing – review and editing; methodology. **Katharina Charlotte Jensen:** Formal analysis; software; writing – review and editing; methodology; validation; data curation. **Fabienne Eichler:** Writing – review and editing; methodology; investigation. **Henning Jürgen Meyer:** Methodology; writing – review and editing; supervision; conceptualization. **Christoph Lischer:** Supervision; conceptualization; methodology; resources; writing – review and editing. **Anna Ehrle:** Supervision; writing – review and editing; methodology; conceptualization; investigation; validation; resources; visualization.

DATA INTEGRITY STATEMENT

Natalie Baudisch had access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

ETHICAL ANIMAL RESEARCH

The study was approved by the local research ethics committee 'Landesamt für Gesundheit und Soziales Berlin' (IVC1Schr-StN010/20; 29.04.2020).

INFORMED CONSENT

Informed owner consent forms for tissue retention were obtained.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in 'figshare' at http://doi.org/10.6084/m9.figshare.24970182.

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