Phase-Resolved Computed Tomographic Evaluation of Equine T11–L1 Mobility after Interspinous Ligament Desmotomy

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Abstract: ISLD is performed on horses with impinging or overriding dorsal spinous processes, however, the mechanical effect of such surgery cannot be easily identified from rest radiographic appearance. This project investigates computed tomography measurements of seven equine thoracolumbar spine sections from T11 to L1 in seven normal horses prior to and following ISLD at eight interspinous levels, quantifying interspinous distance, total section length, L1 translation, and L1 rotation. The study aim is to identify the primary mechanical effect of ISLD through rest interspinous distance, loaded interspinous aperture, range of adjacent interspace motion, or L1 end position during loading. There were four Quarter Horses, one Thoroughbred, one Warmblood, and one Spotted Saddle Horse, including four mares and three geldings, aged 16.3 ± 3.3 years and weighing 461 ± 46.6 kg. Rest interspinous distance was not affected by ISLD surgery (39.89 ± 2.84 mm to 39.90 ± 2.84 mm, $p = 0.98$), but there was a significant increase in total rest length from 310.0 ± 13.9 mm to 313.9 ± 11.8 mm ($p = 0.03$). Loaded measurements were significantly more affected by ISLD surgery. Interspinous distance during flexion significantly increased from 34.3 ± 17.4 mm to 44.4 ± 10.6 mm ($p = 0.046$). The range of motion of adjacent interspaces during flexion also significantly increased from 17.9 ± 3.0 mm to 23.5 ± 4.0 mm ($p = 0.02$). In addition, L1 dorsoventral excursion significantly increased from 32.6 ± 10.8 mm to 48.0 ± 14.0 mm ($p = 0.01$), L1 craniocaudal translation significantly increased from 22.9 ± 10.8 mm to 29.8 ± 10.9 mm ($p = 0.03$), and median rotation of L1 during flexion significantly increased from 12.0° to 21.8°($p = 0.01$). Such observations indicate that ISLD should be considered a phase-related rise in thoracolumbar mechanical mobility, with its maximal manifestation observed during the terminal lumbar phase, whereas static interspinous distance does not make an adequate measure for estimating postoperative mobility.

Keywords: equine spine; computed tomography; interspinous ligament desmotomy; thoracolumbar biomechanics; dorsal spinous processes; kinematic measurement; L1 excursion

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1. Introduction

Pain in the thoracolumbar spine of the horse has been identified for many years as a cause of poor performance, poor willingness to work, behavioral changes under saddle, and palpatory pain. Within the category of bone and soft tissue diseases in this part of the spine, those involving close, impinging or overriding dorsal spinous processes have been studied extensively. They are attractive to researchers since a radiographic lesion may be identified anatomically, but its clinical presentation varies considerably. This connection between anatomical and clinical presentation was first drawn by Jeffcott, studying 443 cases of equine thoracolumbar disease [1]. However, further studies made it clear that an imaging finding may be present without clinical symptoms, while the reverse is also true, and interpretation must take into account imaging results, palpatory examination, analgesia, and functional history [2–4]. It follows that the issue at hand is not merely a radiographic finding of a narrowed interspinous space, but the assessment of how the spine behaves when under certain constraints, when relieved of those constraints, and after surgery to relieve it of them.

The thoracolumbar spine is also a mechanical structure with regional differences in geometry, loads and allowable range of motion. The caudal thoracic and cranial lumbar vertebrae bear loads from the trunk, attach strong epaxial and hypaxial muscles, and transmit the force produced by limbs, rider, saddle and abdominal tension. Townsend et al. classified thoracolumbar motion as consisting of independent but coupled movements of dorsoventral flexion/extension, axial rotation, and lateral bending [5]. More recently, investigations using skin-mounted reflective markers or inertial sensors added to our knowledge by examining the spinal motion in gait, linear motion, circling, and interaction with the rider [6–8]. While these methods are advantageous due to their ability to analyze the motion of a moving animal, they are still subject to soft tissue artefacts, marker displacements, limitations in identifying individual vertebrae, and difficulty isolating a mechanical effect in a study of the whole animal's response. Therefore, an additional method is necessary for answering a localized and purely mechanical question: how much is gained by cutting the interspinous ligament between two dorsal spinous processes?

In addition, an interspinous ligament desmotomy technique was proposed to treat selected cases of dorsal processes impingement and overlapping using a standing approach. It aims to cut the ligament while preserving the supraspinous ligament, avoiding more extensive surgery as dorsal spine osteotomy and subtotal ostectomy [9,10]. Clinical case series show good functional recovery after ISLD; however, there are factors that may affect prognosis, such as diagnostic block, rehabilitative therapy, proper horse selection, and proper post-operative management [11,12]. It is not necessarily purely spatial, in the sense that there are pathological elements in the tissue of the ligament, including disruption of the anatomical integrity of the ligament itself, fibrocartilage metamorphosis, and increase in nerve fibers in the cases where overriding spinous processes have been seen [13]. In this way, the transection of the ligament could decrease the mechanical tension on the structure and its nociception and allow for a more painless rehabilitation and alteration in the physical distance of the processes.

Clinical improvement after ISLD does not per se determine what spatial or kinematic endpoint is going to be chosen as an objective measure for the mechanical change induced by the surgery. While enlargement of the interspinous space has been mentioned in radiography, it cannot be considered as phase-specific 3D movement measurement. Moreover, the resting distance between adjacent spinous processes could be insensitive to the release of the structure, since the mechanical importance happens at the extreme conditions of movement of the segment in both extension and flexion. On the other hand, small changes at multiple interspinous spaces could add up along multiple segments and become more visible at the end of the lumbar vertebral chain. This is the main issue for interpreting the effect of the surgery on T11-L1 motion. A treatment carried out at multiple interspinous levels may be evaluated with different numerical values at each level of adjacent-DSP, segment length, and end of the L1 line. A judgment based only on one of those criteria might result in a wrong interpretation or classification of the treatment outcome.

Both computed tomography (CT) scanning and medical modeling software resolve this issue because they enable segmentation of vertebrae individually, alignment relative to an invariant reference vertebra, and measurement of vertebral motion in various loaded conditions. Biedrzycki and Elane describe a prospective cadaveric CT study in which seven skeletal mature segments of equine thoracolumbar spine between T11 and L1 were subjected to resting, flexion, and extension positions before and after interspinous ligament denervation (ISLD) surgery in eight interspinous spaces [14]. The parameters were defined as interspinous distances, total spinal segment length, and L1 translation/rotation after superimposition of T11. The importance of these parameters comes from the fact that both the same anatomical segments were tested under comparable conditions. In particular, having three conditions of measurement: rest, flexion, and extension, enables mechanical effects to be evaluated as a phase-dependent response.

The core of the research is to establish whether ISLD-induced mobility in the T11-L1 segment of the horse's spine manifests itself either in resting interspinous distance, phase-dependent adjacent interspinous space opening, adjacent interspinous space range of motion, or terminal translation of L1. As we have just seen, these parameters are not interchangeable; their relevance to specific anatomical scales and loading conditions is different. For this reason, numerical results will be considered depending on the condition of the specimen, phase-dependent loading state, spatial levels, and motion direction. The hypothesis is clear: The assessment of ISLD is invalid based on rest radiograph distance if CT measurement reveals that the behavior after surgery is best demonstrated during enforced movement.

2. Materials and Methods

2.1. Study Material and Imaging Conditions

The measurement cohort consisted of seven equine thoracolumbar spinal segments harvested en bloc from T11 to L1. The specimens were taken from skeletally mature horses euthanized for reasons unrelated to lameness and back pain. The body mass of the horses in the cohort ranged between 400 and 550 kg, and all samples were CT-imaged within four hours of euthanasia before the development of rigor mortis. In each sample, the skin, ventral musculature, epaxial musculature, and hypaxial musculature remained, but the ribs were cut off more than eight inches from the vertebral column. Such preparation of the specimens ensured preservation of a significant amount of soft tissues surrounding the vertebral column and a standardized procedure of cadaveric load. However, it did not allow replicating an active muscle tone, pain-induced posture, and adaptive positioning of the spine in the living horse.

The inclusion of such specimen distribution was deliberately kept in place due to the relevance of variation among individual horses in the understanding of thoracolumbar anatomy. Specifically, the cohort consisted of four specimens of Quarter horse, one specimen of Thoroughbred horse, one specimen of Warmblood horse, and one specimen of Spotted Saddle Horse. Four female and three male horses were included in the study. On average, the horses' age was 16.3 ± 3.3 years old, and their body mass was 461 ± 46.6 kg. No sample was excluded due to any abnormality detected during the CT scan. All samples were regarded as normal and used further in this study, which means no spine was overridden, narrowed, and/or excessively radiopaque on the cranial and caudal margin of the dorsal spinous process. This criterion is relevant since in the end, the measurement described here concerns the potential mechanical changes in healthy T11–L1 spinal segments subjected to ISLD, which is different from variations in diseased horses operated. At the same time, this allows ensuring internal reliability of the mechanical measurement and does not enable the generalization of results.

Computation tomography was taken on a 160-slice Toshiba Aquilion CT scanner with helical bone volume acquisition. Imaging slice thickness was 0.5 mm, with an additional slice overlap of 0.3 mm. Three-dimensional reconstruction with a bone reconstruction algorithm allowed measurement. Every specimen was scanned in three different positions both before and after surgery. In the first position called "resting phase," no load was applied. Loading was done using a ratchet loaded from the spinal canal of T11–L1 level through a ratchet device. Ratcheting can be applied through the canal dorsally or ventrally in order to exert compression and flexion/extension forces, respectively. Applied force was fixed to 2000 N and controlled by an inline transducer. Use of a defined force magnitude made comparison of the pre- and post-operative positions possible in this specific mechanical setting [14].

Physical loading protocol is illustrated in Figure 1. It includes mounting of the T11–L1 section, ratchet loading device, inline force control, and corresponding CT image pairings. Measurement scheme allows identification of the main features of experimental setup without consideration of the method purely as radiography. Key feature of methodology is pairing of surgical and loading conditions for the same sample. Main contrast in measurements were achieved not in inter-animal cross-sectional studies but intra-animal phase-matched measurements. The same anatomical segment was studied before and after

ISLD. Therefore, the most crucial comparisons are intra-animal changes, while inter-animal differences increase interpretative noise.

The controlled-loading scheme of Figure 1 further underscores the importance of understanding the postoperative measurements as neither static nor normal X-ray results. Six CT images per spine segment corresponded to three pre-surgery situations and three post-surgery situations. Since surgery occurred midway through two CT series that were identical to each other, the question here concerns the change in the same vertebral segment under the same conditions of loading but after transection of the interspinous ligaments. With such an approach, it becomes possible to separate a slight change in the resting position of the vertebrae from a larger change in forced positions.

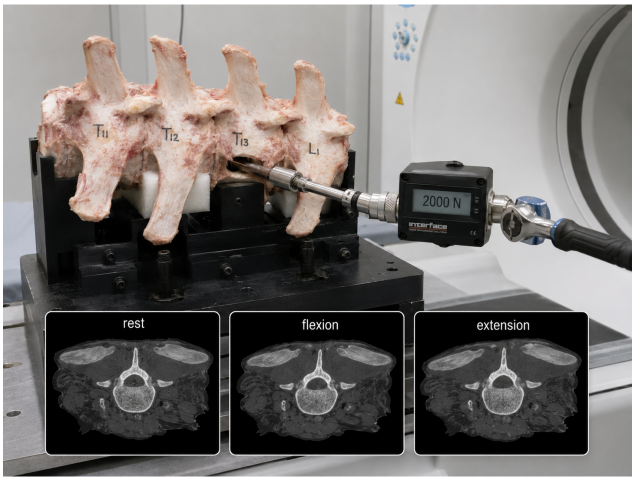

Figure 1. Controlled CT loading.

The specimens are shown in Figure 2. In this figure, the seven prepared specimens from T11-L1 spine segments are placed within the context of CT screening, age, and body mass. It can be seen that the measurements to follow have nothing to do with patients suffering from pain; on the contrary, this study deals with a known population of normal spines subjected to CT screening.

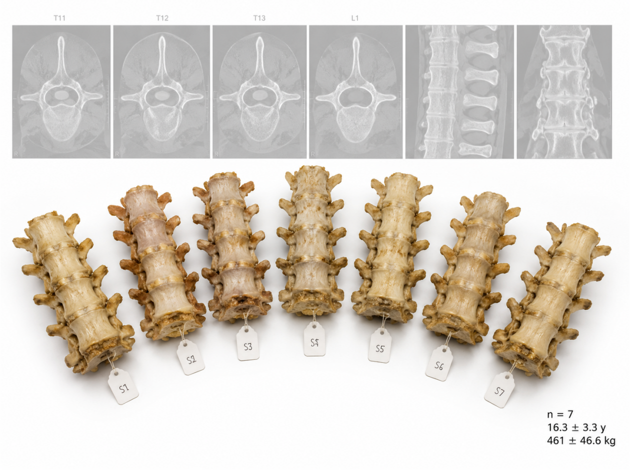

Figure 2. Specimen cohort.

This cohort panel from Figure 2 acts as a reminder of the interpretative limits of this paper. While each section offers a measured anatomical account for investigating the influence of ISLD on imposed motion, the normal screening result precludes the direct application of these values to the predicted postoperative distance of overriding DSSP horses. This issue is especially significant when considering the resting-distance end-point, which involves the use of normal interspinous distance allowing for less room for widening in comparison with a narrowed pathological distance.

The information contained in Table 1 serves as the foundation for analysis by focusing on the actual process of acquiring and preparing the specimen, and not on generalized information relating to kissing spine surgery. The use of the normal cadaver is ideal for studying the effect of ligament section on joint mobility when force is applied in a controlled fashion, although it must not be taken to mean that the results represent clinical outcome data.

Table 1. Specimen and acquisition profile.

Component	Measurement content
Anatomical span Specimens	T11–L1 equine thoracolumbar sections collected en bloc Seven skeletally mature horses
Breed distribution	Four Quarter horses; one Thoroughbred; one Warmblood; one Spotted Saddle Horse
Sex distribution	Four mares and three geldings
Age and body mass	16.3 ± 3.3 years; 461 ± 46.6 kg
Screening status	No specimen showed CT exclusion criteria for ORDSP, inter-DSP narrowing, or marginal radiopacity
CT system and acquisition	160-slice Toshiba Aquilion; helical bone-volume CT; 0.5 mm slices with 0.3 mm overlap
Loading states	Resting, flexion, and extension before and after ISLD
Loading magnitude	2000 N during forced flexion and extension
Surgical exposure	ISLD performed at eight interspinous spaces while preserving the supraspinous ligament
Software pathway	DICOM import into Mimics and 3-Matic, individual vertebral segmentation, T11 superimposition, transformation and distance extraction

2.2. Surgical Procedure and Digital Measurement Procedure

ISLD surgery was performed using a minimally invasive method reported in previous work on sedated, standing horses, but modified based on this cadaveric section. Using spinal needles, each interspinous space was localized, and an approximately 3-cm paramedian incision was created. Then, curved Mayo scissors were placed axially through the interspinous space and used to cut the interspinous ligament without affecting the supraspinous ligament. This procedure was repeated for all eight interspinous spaces within the T11–L1 section [9,14]. Because all spaces were subject to surgery, the experimental conditions allowed for the maximum effect of ligament cutting within the observed chain. Such an operation is not typical of clinical case scenarios because the selection of spaces subject to surgery is made according to imaging findings, palpations, local analgesia, and surgeon judgement.

The anatomical basis of ISLD surgery is represented in Figure 3. In this regard, it is important to emphasize the specific surgical aspect related to the biomechanical consequences of the operation. ISLD entails transection of the interspinous ligament between the adjacent dorsal spinous processes. At the same time, the supraspinous ligament was maintained as one whole as a dorsal restraint. That is why ISLD surgery should not be expected to produce effects similar to those produced by bone resection.

The presence of a preserved supraspinous ligament in Figure 3 makes an essential contribution to the interpretation of the resulting CT-based endpoints. Since there still was a soft tissue structure on the back side of the spine, the spine after ISLD continued to be constrained while the interspinous part of it was weakened. As a result, the surgical intervention caused a selective shift in the balance of resistance forces at the level of the interspinous space, which explains why movement endpoints were more sensitive than the resting adjacent-DSP distance.

DICOM files were imported into Materialise Mimics and 3-Matic software and further analyzed in terms of 3D reconstruction. The vertebrae and corresponding spinous processes were manually segmented separately while ribs were excluded. The 3D mask generation included a Hounsfield unit range of +700 to +3000 for bones, 3D conversion, and wrap and smooth correction when necessary. Once the vertebrae were segmented, the T11 vertebra of all phases was superimposed and set as a cranial reference point. Then, adjacent spinous processes were kept in place relative to the reference point, making it possible to extract the following endpoints: adjacent spinous-process distances, T11–L1 length in the resting phase, L1 translation, and L1 angular rotation.

Figure 3. Ligament release.

The example of registration of the measured points is shown in Figure 4. The following four groups of endpoints were considered. The first endpoint group included the distance from the cranial end of one dorsal spinous process to the cranial end of the other spinous process, representing the interspinous aperture. The second group contained the total distance from the cranial aspect of T11 vertebra to the cranial aspect of L1 vertebra during rest, representing the whole-section length. The third endpoint group consisted of the two components of L1 translation in flexion-extension: dorsoventral and craniocaudal. The last group contained L1 angular rotation, expressed by the median value and range.

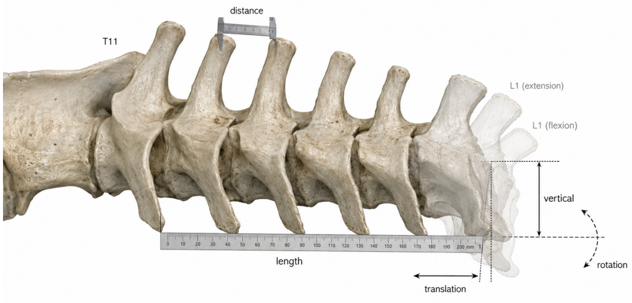

Figure 4. Registered endpoints.

Registered Endpoint Perspective, as shown in Figure 4, brings out the point that there is a disparity between the scales of anatomical levels of measurements. The adjacent DSP distance is a local measurement, total T11–L1 distance a whole-sectional measurement at rest, whereas the L1 displacement is an end path measurement generated after contributions from some interspinous spaces have made up for the terminal end position. The reason for highlighting such a perspective is that a small increment at each individual interspinous space level can be significant when considered from the L1 level while the local resting distance remains constant.

2.3. Endpoint Definitions and Analytical Calculations

Numerical values were organized according to loading condition and anatomical endpoints. Absolute postoperative difference was determined for each mean-based endpoint according to the equation

$$\Delta X = X_{post} - X_{pre}, \tag{1}$$

where X_{pre} and X_{post} corresponded to the pre-ISLD and post-ISLD measures of the same category. Relative change was calculated through the equation

$$RC = \frac{X_{post} - X_{pre}}{X_{pre}} \times 100. \tag{2}$$

Gain values along with their standard deviations were preserved for all endpoints that were specified in that format. For the rest of the mean-based endpoints, relative changes were calculated using preoperative and postoperative means. Angular rotations were considered separately since angular measurements were provided as medians and ranges.

These equations have been included as descriptors of the calculated values rather than an entirely new statistical model. The goal was to facilitate comparison of CT results on measurement scale. Value such as 0.03% of resting adjacent-DSP distance and value like almost 47% of L1 dorsoventral excursion can be obtained from the same equation yet they cannot be compared as is. Thus, calculation acts as a tool to make the value interpretable for the purposes of deciding on the most mechanically meaningful endpoint.

Interpretations were performed according to the used tests for CT values. Paired-samples test was conducted for normally distributed interspinous distances. The effects of vertebral section number and surgical condition were investigated using repeated-measures two-way ANOVA with post hoc Tukey testing when needed. Medians and ranges were used for non-normally distributed data analysis. Statistical significance level was set at $p \leq 0.05$ [14]. There were no new inferential tests applied; thus, the aim was to provide full-fledged endpoint-level analysis of CT values.

3. Results

3.1. Resting Alignment and Specimen-Level Findings

Seven thoracolumbar sections were utilized, all passing CT evaluation. None of these presented evidence of any pre-existing ORDSP, inter-DSP narrowing or radiopaque DSP edges. Importantly, these results ensure that any alteration found in the following measurements does not reflect the pathological condition, but a result of an anatomically normal cadaveric structure modification. This observation is crucial since the postoperative changes described below reflect only the effect of cutting normally functioning interspinous ligaments in cadavers, and therefore cannot represent the effect of ISLD in diseased vertebrae experiencing remodeling, muscle contraction triggered by pain, fibrosis, adaptive posture, etc.

Resting adjacent-DSP distance demonstrated low responsiveness. The mean adjacent-DSP distance before ISLD surgery was equal to 39.89 ± 2.84 mm, and after – 39.90 ± 2.84 mm, p-value of $p = 0.98$ [14]. The difference between means amounted to approximately 0.01 mm, or around 0.03%. In addition, there was insufficient statistical power for such a tiny effect size: only 5%, and 2,013,750 sections were required for achieving 80% power for 20 micrometers of average difference. However, one needs to emphasize that such a result cannot be interpreted as lack of microscopic effects but proves that observed mean difference was negligible and clinically irrelevant at the macroscopic level.

The analysis of whole-section distance proved less equivocal. The mean distance from the cranial surface of the T11 vertebra to the cranial surface of the L1 vertebra grew from

310.0 ± 13.9 mm to 313.9 ± 11.8 mm with $p = 0.03$ [14], or an increase of 3.8 ± 3.1 mm, or 1.2 ± 1.0%. Therefore, there was indeed an extension of the studied section of the spine in its neutral state, but it failed to manifest itself in changing distance between the adjacent DSPs.

The neutral measurement comparison is illustrated in Figure 5. The bilateral images using the caliper demonstrate how identical the distance between the two DSPs is during resting, while the longer image taken from the side clearly demonstrates the small but significant increase in length between T11-L1. This comparison is significant since both measurements were taken under the same resting conditions yet provide different answers.

The neutral-measurement group depicted in Figure 5 ensures that the resting measurement cannot be summarized by a single sentence. The local interspinous distance adjacent-DSP did not substantially increase; however, the accumulated cranial T11 to cranial L1 distance marginally increased. It would thus be misleading to state that the resting measurement remained completely unaffected, and in fact, the resting measurement changed at the whole section level, while the local interspinous distance remained essentially constant.

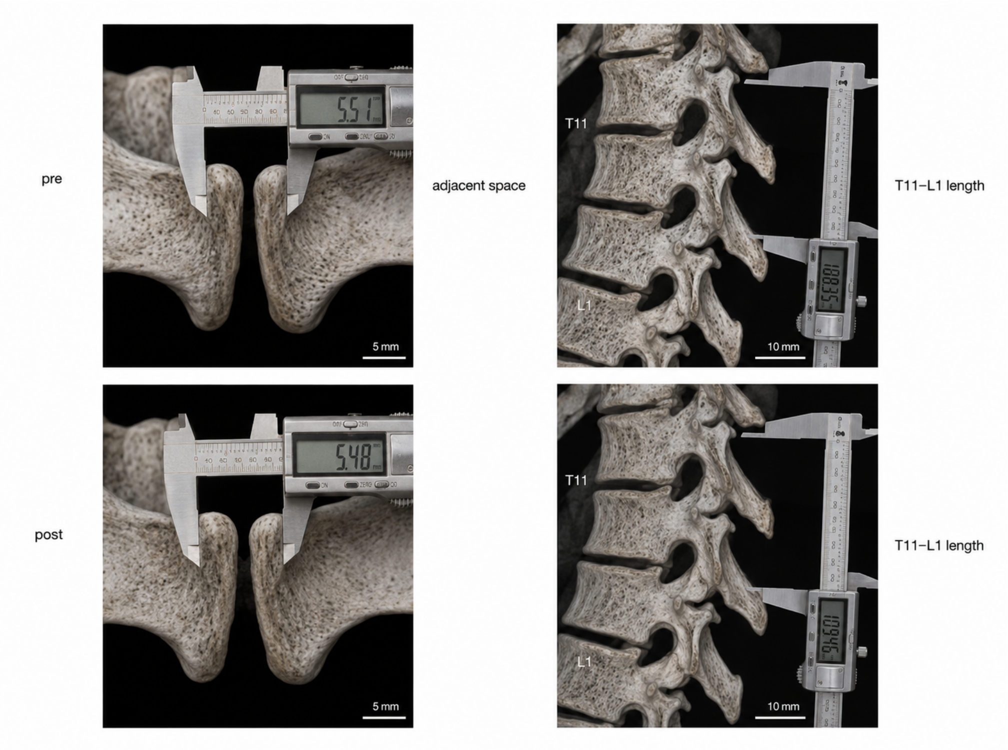

Figure 5. Neutral measurements.

The end point measurements are compiled in Table 2. All the end points mentioned are listed here, with means used for the measurement values and medians used for the angle value. This table also reflects the significance of endpoints without exaggeration.

Table 2. Measured endpoint values.

Endpoint	Pre-ISLD	Post-ISLD	p	Primary reading
Resting adjacent-DSP distance (mm)	39.89 ± 2.84	39.90 ± 2.84	0.98	No meaningful local change at rest
Resting T11–L1 length (mm)	310.0 ± 13.9	313.9 ± 11.8	0.03	Small whole-section lengthening
Extension adjacent-DSP distance (mm)	27.4 ± 19.1	33.9 ± 9.0	0.32	Directional change without statistical support
Flexion adjacent-DSP distance (mm)	34.3 ± 17.4	44.4 ± 10.6	0.046	Significant opening under flexion
Adjacent-space ROM (mm)	17.9 ± 3.0	23.5 ± 4.0	0.02	Increased local movement envelope
L1 dorsoventral excursion (mm)	32.6 ± 10.8	48.0 ± 14.0	0.01	Largest linear endpoint change
L1 craniocaudal translation (mm)	22.9 ± 10.8	29.8 ± 10.9	0.03	Significant terminal translation
L1 mediolateral-axis rotation	12.0° (7.9–35.6)	21.8° (14.7–55.6)	0.01	Significant angular increase

As illustrated by the Endpoint pattern in Table 2, the notion of "resting distances" cannot explain the observed findings. There was no change in adjacent DSP distance during the rest position. On the other hand, there was an observable increase in total length of the segment, flexion space, range of motion, L1 DV movement, L1 CC displacement, and L1 rotation after surgery. It is therefore a pattern whereby specific distances increase depending on the load imposed on them.

3.2. Phase-Dependent Interspinous Aperture

The data from the extension and flexion analyses reveal that the postoperative response of interspinous spacing was dependent on loading phase. While there was no statistical significance for the extension group (where the adjacent-DSP increased from 27.4 ± 19.1 mm to 33.9 ± 9.0 mm, with $p = 0.32$), there was evidence of variability in behavior within the spaces during the loading process (as revealed by the wide standard deviation). By contrast, in the flexion phase, the adjacent-DSP distance was seen to increase from 34.3 ± 17.4 mm to 44.4 ± 10.6 mm, with $p = 0.046$ [14]. The amount of opening measured by flexion was 10.1 mm, representing an approximately 29.45% increase.

A comparative visualization of the resting, extension, and flexion apertures is shown in Figure 6. In these CT-like paired images, the resting and the two load-bearing adjacent-DSPs are depicted anatomically. From this visualization, it is evident that the surgical changes were not observable when considering the resting posture alone.

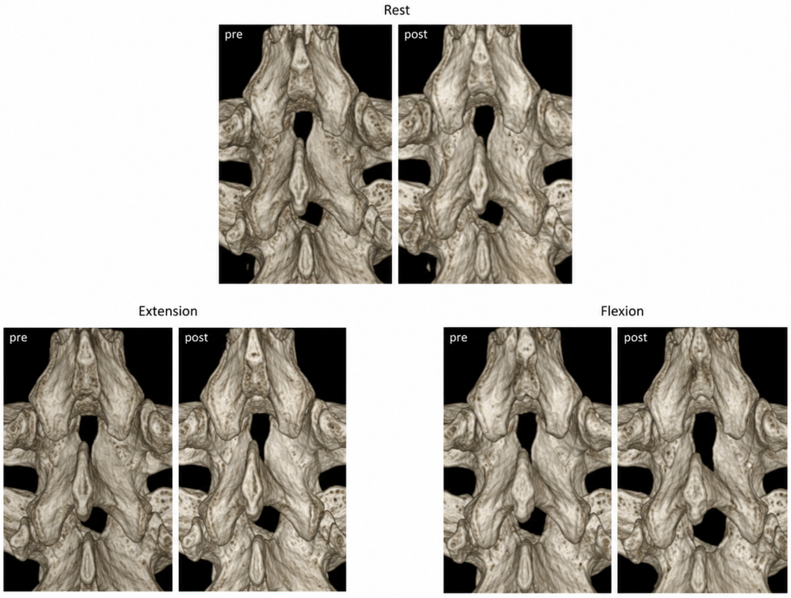

Figure 6. Phase-specific opening.

A cautious reading can be supported by the initial phase panel shown in Figure 6. Postoperatively, there was an apparent increase in extension ROM but it did not pass statistical significance. Flexion ROM, on the other hand, increased significantly but exhibited considerable variability. Notably, the directionality of the flexion result is important since the flexion condition is one in which dorsal spines are subjected to compression relative to each other and where tensions within the interspinous ligaments may affect the movement envelope. Consequently, the result indicates that the effect of cutting through the ligaments is the most apparent when the segment is loaded into a difficult posture.

The endpoint for adjacent space ROM included the results from flexion and extension in order to quantify total local movement range. Adjacent space ROM thus increased from 17.9 ± 3.0 mm prior to ISLD surgery to 23.5 ± 4.0 mm post-ISLD, with a significant difference at $p = 0.02$ [14]. An increase of 5.6 ± 4.9 mm was measured, translating to a 24 ± 21% increase in the maximum ROM of the adjacent segment. In this case, the measurement is more revealing than the phase results alone as it concerns the range of motion available across the complete arc of flexion-extension.

Figure 7 demonstrates the concept of the local movement envelope. It is clear from this figure how adjacent-space ROM differs from an endpoint of either flexion or extension ROM measurement, as the former refers to the full path length covered between these loaded states.

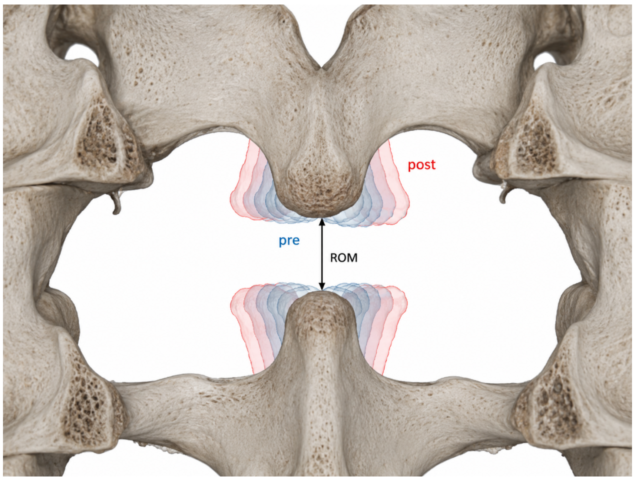

Figure 7. Local motion envelope.

Motion envelope perspective in Figure 7 helps give an anatomical explanation for the 5.6 ± 4.9 mm gain. As can be seen from the illustration, it represents a greater excursion capability between adjacent dorsal spinous processes, not just a single direction motion gain. The point here is that this is the ultimate endpoint which directly corresponds to the ligament transection procedure and its immediate mechanical effect on increased motion capacity.

The ROM finding is also understandable from a surgical perspective. ISLD does not involve the removal of any bone structures nor alter the morphology of the adjacent dorsal spinous processes. Rather, the actual surgical intervention is based on the transection of the ligamentous tissue in the interspinous region. Thus, a larger ROM at the level of the space in question reflects the anticipated mechanical effect of releasing a ligamentous structure responsible for the restriction. However, the amount of the variability, as indicated by the standard deviation, suggests that the effect is not consistent in all specimens and/or spaces. Spatial relations in biology, local ligament stiffness, local anatomy of vertebrae, and remaining soft tissue attachments will certainly play their role in determining how much extra space will be created following a transection.

Such a restriction in time will also help in explaining why sometimes no clear post-surgical alteration is visible on the neutral lateral view but the horse will still demonstrate a functionally different back at work or rehab. Neutral position is a low-stress position. On the other hand, flexion especially when dorsal spines are approximated to each other is a high-stress position for the interspinous tissues. If the effect of surgery shows up only in such a high-stress situation, then there is nothing wrong with it.

3.3. Linear Endpoints at Terminal L1

The most obvious linear movement at the terminal level was L1 dorsoventral displacement. L1 was found to have a highly significant increase in distance moved dorsoventrally when compared after superimposition at T11; L1 movement rose from 32.6 ± 10.8 mm to 48.0 ± 14.0 mm ($p = 0.01$). Gain was calculated at 15.3 ± 11.9 mm, with a relative increase of 47.0 ± 36.5% [14]. When converted into values per individual ISLD, Biedrzycki and

Elane concluded that about 5.9% extra dorsoventral movement was achieved per treated interspinous space – although, again, this is merely a division by eight.

There was also a significant craniocaudal increase in L1 movement. From 22.9 ± 10.8 mm, craniocaudal distance increased to 29.8 ± 10.9 mm ($p = 0.03$). Calculated gain was 6.9 ± 6.5 mm, with a relative increase of 30.1 ± 28.4%. This corresponds to about 3.8% extra craniocaudal translation per ISLD [14]. Importantly, craniocaudal movement demonstrates that surgical manipulation did not limit itself solely to affecting L1's ability to move vertically. Transverse sectioning of the interspinous ligaments caused more complex change in the trajectory of L1 in more than one straight line, in line with the known linkage between flexion-extension, translation, and rotation within the equine thoracolumbar spine [5,6].

A rotational angle became another end point. The median value for L1 rotation about the mediolateral axis rose from 12.0° (with a range of 7.9° to 35.6°) to 21.8° (with a range of 14.7° to 55.6°). Paired-median difference amounted to 6.5° (with a range of 2.1° to 20.8°), and the result was statistically significant ($p = 0.01$) [14]. As the angle was expressed in terms of its median and range values, there is no reason to quantify it together with other millimeter measurements which

L1 terminal trajectory is illustrated in Figure 8. The trajectory obtained from the registered CT-like approach shows the exact same phenomenon depicted in the numeric end points of the movement: L1 traveled a greater distance in the dorsoventral plane, was translated greater distances in the craniocaudal plane, and moved through a larger angle between the flexed and extended position, following ISLD.

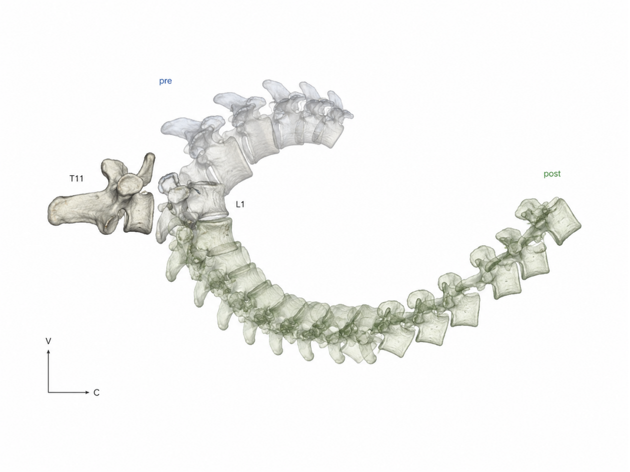

Figure 8. Terminal L1 path.

The terminal-path interpretation of Figure 8 explains why L1 dorsoventral excursion had the greatest linear change compared to the other endpoint measurements. In addition, L1 excursion reflects movement over an entire section of the spine, whereas adjacent-space range of motion indicates movement within a smaller area of the spine. The important point is that the more motion-dependent measurements were those that changed the most.

3.4. Endpoint Contrasts and Relative Change

Calculation of relative changes helps to distinguish between a statistically significant but relatively minor endpoint from a more substantial movement endpoint. An increase in resting T11–L1 length occurred, amounting to roughly 1.2%. The absolute length gain in question was measured at 3.8 ± 3.1 mm and was statistically significant. Nevertheless, it was much less pronounced than both loaded and terminal measurements. The following changes were observed in flexion aperture – 29.45%; adjacent-space range of motion – 24 ± 21%; L1 dorsoventral displacement – 47.0 ± 36.5%; and L1 craniocaudal displacement

– 30.1 ± 28.4%. Resting adjacent DSP distance changed just by 0.03% on average, which can be considered relatively insignificant in comparison to the rest of endpoints.

Table 3 presents calculated endpoint contrasts. As you can see, the same descriptive characteristics apply to all linear endpoints with the angular endpoint being an exception. That said, the table is interpretative in character, given that the point is to assess the location of a signal.

Table 3. Endpoint contrast profile.

Endpoint	Absolute change	Relative change	Evidence	Interpretation
Resting adjacent-DSP distance	0.01 mm	0.03%	$p = 0.98$	Resting local spacing did not express the surgical effect
Resting T11–L1 length	3.8–3.9 mm	1.2%	$p = 0.03$	Whole-section length increased slightly at rest
Extension adjacent-DSP distance	6.5 mm	23.72%	$p = 0.32$	Directional change remained uncertain
Flexion adjacent-DSP distance	10.1 mm	29.45%	$p = 0.046$	Loaded flexion made the local effect visible
Adjacent-space ROM	5.6 mm	24%	$p = 0.02$	The local movement envelope increased
L1 dorsoventral excursion	15.3 mm	47.0%	$p = 0.01$	Terminal vertical travel showed the largest linear gain
L1 craniocaudal translation	6.9 mm	30.1%	$p = 0.03$	Terminal horizontal translation also increased
L1 rotation	6.5°	Not mean-based	$p = 0.01$	Orientation changed significantly

This becomes evident from the contrast profile presented in Table 3. For mobility being described based on resting adjacent-DSP distance, it seems as if there is hardly any influence of the procedure on spatial parameters. However, when mobility is measured based on flexion aperture, adjacent-space ROM, dorsoventral movement of L1, craniocaudal displacement, and angular displacement, then the operation has an unequivocal and statistically significant influence. What can thus be scientifically justified is not the increase of all distances that have been measured, but that the distance measurements, where forceful movement and terminal path have been involved, underwent substantial change due to the ligament transection.

The scale-dependent theory is illustrated through Figure 9. The array displays resting distance between neighboring structures, resting total length of the section, flexion/ROM, and ending distance L1 all as distinct measurements and not as a ranking system. This representation avoids the outcome being reduced to one value and instead indicates which measurements are responding and which are not.

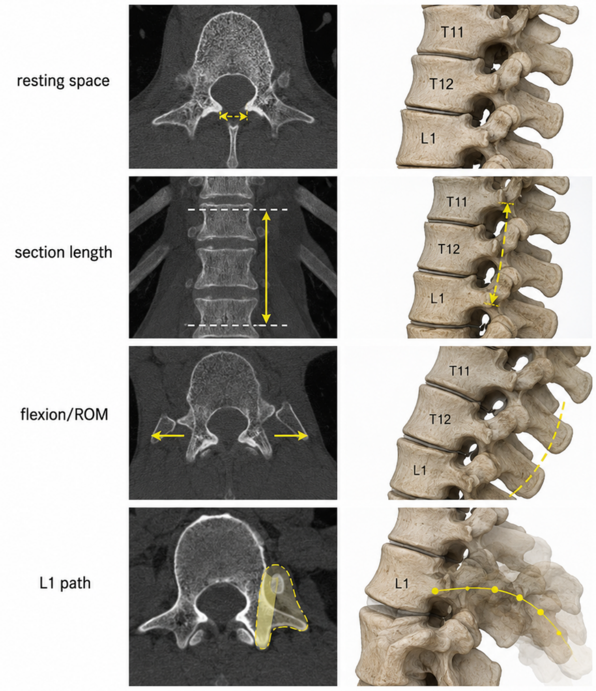

Figure 9. Scale-resolved response.

The scale-resolved composite response shown in Figure 9 clearly shows the distinction between measurements at rest and during loading. While the resting adjacent-DSP response is close to the reference point of zero percent change, flexion aperture, adjacent-space ROM, and terminal L1 endpoints exhibit much larger readings. The implication drawn from this pattern is that neutral posture anatomy cannot be considered sufficient for measuring the mobility produced via ISLD. In addition, scale plays a role, since while terminal L1 displacement is not the same as the individual interspinous space, it is the result of full T11-L1 segment motion.

The endpoint differences reveal that there must be a connection between statistical significance and effect size. The statistical significance of resting T11–L1 length was coupled with small effect size while the relative change for extension aperture was moderate, without being statistically supported. On the other hand, flexion aperture, adjacent space ROM, and terminal L1 ROM were associated with the statistical test and the plausible anatomical mechanism. This is a helpful approach to prevent one-sidedness when interpreting results. For example, an article that highlights only p values will place too much emphasis on small gains in resting length, while one that talks about relative change alone may wrongly interpret the lack of significance in extension.

The same comparison will have implications in terms of designing future protocols of measurement. In cases where time constraints or exposure to radiation may limit the number of states one can capture, the results clearly show that an end point of flexion or movement envelope would be more important than that of adjacent distance neutral endpoint in case of post-operative mobility assessment. Neutral imaging is necessary for diagnosis and surgery planning; however, it cannot be said to be the best way of assessing the mechanical impact of ligament cut. A phase-resolved method does not have to be complicated in order to be instructive; it just needs to maintain the distinction between static alignment and forced movement.

3.5. Integrated Evidence Pattern

Interpretation of the cumulative findings can then be seen as progression towards an increasing requirement for movement in their occurrence. Firstly, no alteration occurred in resting adjacent DSP distance under low movement conditions. Secondly, T11–L1 length showed minimal increase at whole-section resting state. Thirdly, local aperture showed marked increase under forced flexion. Fourthly, when flexion and extension movements were combined to produce adjacent space ROM, the local movement envelope showed marked increase. Lastly, at the TL extremity of the spine, dorsoventral displacement, craniocaudal translation, and mediolateral axis rotation each showed marked increase. The systematic trend conforms to mechanical treatment, with its effects being less pronounced in a neutral position and more evident when the chain is perturbed.

The graphical representation in Figure 9 presents the key finding in an explicit fashion without necessitating any reduction of multiple endpoint values to one value. For the majority of endpoints whose determination relies on motion, percentage change and significance are both large. However, an outlier exists in the form of extension aperture, which although showing substantial calculated percentage change, is unable to demonstrate significance. This is a necessary finding since it avoids overextension of conclusions. ISLD did not generate equal significance for all loaded positions.

What can be deduced from the numbers is that the experiment manipulated the pathway rather than the neutral posture. As the resting adjacent-DSP endpoint was concerned with the distance between the two bones at the absence of any external bending moment, it concluded that there was no significant change. However, the flexion, ROM, and L1 endpoints asked if the prepared chain could move more at the presence of the same force and answered positively. This is a crucial detail for structuring papers since the strongest evidence should not remain hidden beneath the neutral data. Thus, the Results confirm the following hierarchical statement: the neutral adjacent distance remained unchanged, the total length of the section grew slightly, the flexion opening and movement envelope grew considerably, and the most noticeable linear movement was observed in the caudal endpoint of the section.

This model also accounts for the reason why the endpoint of the rotation pattern needs to be considered in conjunction with the millimeter results, without any numeric fusion of the two sets of results. The fact that there was an increase of 6.5 degrees of the angle around the mediolateral axis points towards a new angle of orientation at the end of either the flexion or the extension stage. The increase in angular displacement cannot substitute for 6.5 mm displacement, but rather supports the general idea that the last vertebrae were not just displaced farther away from their normal position but followed a new angular path. For a spinal column segment, a change in angular mobility may affect the distance between dorsal spinous processes, facet load, soft tissue strain, and the position adopted during rehabilitation.

Together, the Results provide for an outcome that is based on specific end points and not just one index. It would be wrong to conclude that ISLD merely opens up the dorsal spinous process, or that it increases movement generally without exception. Instead, it should be noted that ISLD increases the movement range under specific loading, more specifically with regard to flexion and in the final L1 movement, without affecting the resting adjacent-DSP gap. It is vital to mention both the negative resting result and positive movement result in one line.

4. Discussion

4.1. Primary Interpretation of the Results

This investigation provides an answer to a particular mechanical question: Given the transection of the interspinous ligament in the T11-L1 segment of the horse thoracolumbar spine chain, what is the most pronounced CT-based parameter describing the postoperative modification? It is not resting adjacent-DSP displacement. Indeed, the latter parameter experienced only slight modification (0.01 mm) with $p = 0.98$. The most significant results include significant increases in flexion aperture, adjacent-space ROM, L1 dorsoventral displacement, craniocaudal translation, and L1 rotation. Thus, one can conclude that the surgery resulted in a mobility effect that was time-, space- and movement-dependent.

The significance of this finding from a clinical standpoint lies in the potential to make radiographic or CT observations in the rested position default means of evaluating dorsal spinous process pathology. Rested proximity is crucial to diagnosing this condition, particularly if there is proximity, impingement, or remolding involved. However, a therapy specifically aimed at relieving the restriction of a ligamentous structure might influence the opening dynamics of the area without significantly changing its distance in a rested position. The numerical proof provided by the CT report is consistent with this hypothesis, since the rested distance stayed the same, whereas dynamic parameters increased significantly after surgery.

This discovery also bridges the gap between clinical and biomechanical approaches to ISLD. Coomer et al. suggested the surgical intervention that targets cases of kissing spines and postulated that the reduction in ligament strain, along with decreased nociceptive input at the attachment site of the ligaments, provides a mechanism for improvement [9]. Subsequent case series confirmed the recovery of performance in many horses, yet also noted the significance of patient selection and correct interpretation of diagnostics [11,12]. The results from CT cannot provide evidence for pain relief in clinical settings, but the increased mobility demonstrated in this study is indicative of successful treatment in a controlled setting.

4.2. Spatial Anatomy at Rest and the Potential for Underinterpretation

The clear lack of a significant change in adjacent-DSP distance at rest does not undermine ISLD; it sets the limitation on how the outcome can be used. Spatial anatomy at rest depends on vertebral morphology, residual soft-tissue stress, sample preparation, section length, posture, and the lack of forced flexion/extension. Sectioning the ligament removes the restraint but does not cause the adjacent bony markers to separate under these conditions. In other words, the ligament may play its role during range-of-motion tests rather than when the segment remains still.

An increase in total T11–L1 length measured at rest adds an interesting aspect to the analysis of the results. An overall increase in length of 3.8 ± 3.1 mm or 1.2 ± 1.0% of the total length, with an otherwise unchanged mean adjacent-DSP distance, may have resulted from the accumulation of minor variations throughout the section length, temperature and soft-tissue changes during the experiments, or misalignment of segments after cyclic loading. According to Biedrzycki and Elane, this increase in length was minor and potentially related to time-dependent tissue properties since imaging always preceded surgery [14]. Overall, it appears that while this outcome does detect minor changes at rest, it is not the primary endpoint to study mechanics.

It is also consistent with the diagnostic literature more generally. The presence of close or impinged spinous processes on X-ray does not match up perfectly with the clinical findings; in some cases, scintigraphy or radiography will show changes even in the absence of back pain [2–4]. This inconsistency has driven a multimodal approach to diagnosis, where the imaging appearance is assessed alongside clinical evaluation, local anesthetics, and performance testing. Here again, the CT findings lend support to this approach from the surgical and mechanical sides of things. Anatomical imaging is fine for anatomy, but mechanical analysis is needed for function.

4.3. Loaded Flexion as a Sensitive Local State

The loaded state that showed a statistically significant local opening was flexion. This is an important fact in relation to anatomy since it means that flexion brings together the processes of the spine and requires some strain on the interspinous area. As mentioned above, in the CT test, flexion was created using the ratchet mechanism and applying standardized load of 2000 N to cause a flexion-distance increase from 60.9 mm (pre-ISLD) to 71.0 mm (post-ISLD). The change suggests that the interspinous ligament is partially responsible for the limits of the flexion-phase relationship of the adjacent processes. The removal of the structure led to an increase in the gap caused by the same load.

However, extension failed to produce the necessary evidence. Indeed, although the extension endpoint increased in numbers from 27.4 mm to 33.9 mm, there was no statistical significance, since the p value was 0.32, and the pre-surgical variability was quite large. The result cannot be rejected since the direction of the change confirms increased mobility of the joint, but still, this endpoint cannot be used as an argument to prove the hypothesis. The reason is that it is critical to separate the directionality from statistically justified findings. Thus, one needs to compare the flexion, local ROM, and terminal L1 results to the extention endpoint result.

The importance of the local ROM endpoint lies in its ability to integrate both states of motion into a single envelope. It is possible to see that, after the transection, there was a change in the distance between the extreme positions from 17.9 ± 3.0 mm to 23.5 ± 4.0 mm. From the mechanical standpoint, it means that the distance between the phases changed due to the fact that the role of the structure in question was partially performed by other tissues of the joint.

4.3.1. Explanation of Why L1 Excursion Was the Largest Linear Endpoint

A linear increase of 15.3 ± 11.9 mm was seen in the dorsoventral excursion of the L1 vertebra, the largest linear improvement of the whole study. The relatively high magnitude can be explained based on the anatomy of the reconstructed T11-L1 vertebrae. As L1 is the terminal vertebra, motion from all treated interspinous spaces has a cumulative effect on its final position. A small change in distance at any individual interspinous space would not seem like much, but the final position of L1 reflects the total effect of the improvements made through ISLD. It is important to note that not all interspinous spaces had equal effects, nor is it certain which individual space was the most effective. However, terminal path analysis is an accurate measure of chain behavior as a whole.

It should be reasonable to see an average dorsoventral excursion increase of 47.0 ± 36.5% given the knowledge of caudal thoracic and cranial lumbar spinal mobility. According to Townsend et al., caudal thoracic and cranial lumbar spines are less mobile [5]. Given that a certain section starts with lower dorsoventral mobility, releasing a repeated soft tissue restraint could lead to significant improvement in movement percentage-wise, even with moderate increases in interspinous distances. The fact that ISLD was performed at eight interspinous spaces in the cadaveric experiment should be taken into account for future application of this outcome clinically.

Craniocaudal translation and angular rotation add another layer of meaning to the findings. A non-zero value of craniocaudal translation means that the terminal path not only moved further away from the baseline, but also experienced a displacement in the direction of the long axis of the segment. The non-zero value of angular rotation of the terminal vertebra suggests that there was greater angular rotation between phases. Both of these findings coincide with the general idea of the nature of thoracolumbar motion being multiplanar and coupled rather than uniplanar hinges [5,6,8]. Translation and rotation must, therefore, be considered for a complete analysis of ISLD biomechanics, not just interspinous distance.

4.4. Relevance of Results to Previous Surgery Literature

Before 2022, the literature on surgical interventions in horses with dorsal spinous process problems suggested an alternative in ISLD to resection or subtotal ostectomy as a treatment for osseous overriding or impingement [10,15,16]. The former techniques allow the treatment of osseous issues but cause greater trauma, cosmetic changes, and complications after surgery [9]. As compared to them, ISLD is associated with minor invasiveness because it involves cutting a ligament, not removal of much of bone tissue. Many horses showed good results in terms of returning to work or sports after follow-ups. Nonetheless, it is necessary to select cases properly and consider the role of other pain sources in such procedures [11,12]. Although the mechanical results of the procedure confirm its feasibility, the obtained data should not become the main ground for the clinical decision-making.

The histological results are particularly valuable regarding the mechanism involved. According to Ehrle et al., changes were detected in the structure of the interspinous ligaments in horses with overriding spinous processes; there was the disturbance of the anatomical arrangement and fibrocartilaginous metaplasia, increased nerve fibers [13]. Therefore, one can hypothesize that this structure acts as a mechanical barrier as well as the nociceptive structure. Cutting can change the comfort by decreasing the tension of nociceptors during insertion and increasing the mobility. Thus, the endpoint pattern fits the mechanical component of the mechanism better because movement-related parameters changed.

On the other hand, the normal-cadaveric character of the CT analysis warrants careful consideration of possible pathological states. For instance, diseased equine specimens can have reduced interspinous space width, remodeling of osseous tissue, protective muscle splinting, abnormal epaxial musculature, or associated disease of synovial intervertebral joint surfaces and sacroiliac joints. In a case of a horse with chronic back pain, relief may come as the result of direct mechanical change, an analgesic effect, postoperative conditioning, and behavior modification. While the CT analysis examines just one aspect of this multifactorial process, it looks at how movement in the T11–L1 section changes as a result of cutting the same interspinous ligament restraint and applying a repeated external load.

One should also consider the influence of breed, age, and conformation on the results. The sample size was limited, yet the test group comprised four Quarter horses, as well as one animal of each of three other breeds. On average, all animals were older than sixteen years; it might be relevant since both thoracolumbar vertebral and ligament morphologies undergo changes throughout life due to use and cumulative stress. Regional variation in enthesophyte formation and dorsal process overlapping was noted by Clayton and Stubbs, and, thus, pathology may not affect the whole thoracolumbar column [17]. Similarly, Haussler noted in his anatomical study that thoracolumbar morphology varies along the vertebral axis [18]. Thus, future experiments need to focus on both the regional variability of the mechanical impact of ISLD and the specific anatomical structure of the thoracolumbar segment.

In this sense, any clinical recommendations based on the findings of this CT analysis have to be carefully considered. It does prove beyond doubt that multiple desmotomy leads to increased mechanical capacity of the spinal section. However, it still does not address what the optimal number of surgical procedures is, which spinal levels have to be treated, and what degree of subsequent movement is needed. While too limited a range might fail to provide relief by relieving pressure or stretching, excessive uncontrolled mobility might have adverse effects on adjacent structures. Nevertheless, there is no data in this CT record that would confirm the detrimental impact.

4.5. Value of CT-Based Measurement Evaluation

The main strength of the CT image data set is its ability to employ 3D CT segmentation with vertebral registration. Surface marker and inertial analysis techniques have been useful in studying equine back motion during locomotion, but neither technique can segment individual dorsal spinous processes and evaluate their osseous alignment without soft tissue distortion [6–8]. CT reconstruction enabled the utilization of T11 vertebra as a constant reference point after which comparison of successive vertebrae and L1 vertebra position at rest, flexion, and extension was possible. This type of methodological approach fits into the scope of a structural surgical inquiry since it assesses bone-to-bone relationships influenced by ligament release.

A description of terminal L1 displacement using Hausdorff distance and rigid-body registration transforms gives a better computational grounding to the study in contrast to radiographic evaluation. Biedrzycki and his team used Hausdorff distance and computer modeling to compare virtual surgical plan and 3D printing template in orthopedics of horses in one of their earlier works [19]. Similarly, with regard to ISLD CT record, the combination of these two digital principles allowed for objective quantification of maximal L1 displacement after superimposition on T11. Thus, another strength of this methodology lies in providing a quantifiable measure of spinal mobility in a particular direction.

The disadvantage of this methodology does not lie in a lack of precision; on the contrary, it is a lack of life circumstances. It is clear that a spine in a cadaver with attached musculature is not an equine subject experiencing muscular contraction, abdominal pressure, rider's weight, behavior associated with pain response, neuromotor regulation, and compensatory mechanisms. Trager et al highlighted pain assessment and mechanical nociceptive threshold as relevant clinical outcomes in thoracolumbar back pain management in horses [20]. Biedrzycki and Elane's CT protocol did not measure these parameters [14]. It quantified structural mobility subjected to external loads. This was a significant but limited achievement.

4.6. Interpretation of Variability and Statistical Power

The most notable high standard deviations compared to the corresponding mean change scores appeared at extension aperture, L1 dorsoventral excursion, and craniocaudal translation. Variability in such a limited CT record in a single horse sample is expected. Several factors related to vertebral anatomy, regional stiffness, ligament thickness, experimental procedure, and even breed characteristics may have affected the result. With the limited sample, one may expect some degree of lack of precision in results, which Biedrzycki and Elane observed in their power analysis [14]. Thus, a reasonable interpretation strategy should involve the examination of the pattern of supported endpoints rather than overly precise estimates for individual sections.

At 5.9% for dorsoventral excursion and 3.8% for craniocaudal excursion, per-site statistics provide a meaningful approximation of the phenomena under study. Division of the entire effect into eight surgical sites provides a convenient simplification of a situation where spine does not actually consist of eight equally influential mechanical elements. Caudal thoracic and thoracolumbar transition sections demonstrate distinct vertebral morphologies, local stiffness of soft tissues, and potential mobility. Although additional analysis could reveal whether any particular interspinous space is more important to the effect under investigation, the existing data do not allow us to make such conclusions.

Repeated-measures design reduces sample size issues to an extent since each measurement is taken against itself. However, the effect of sequencing cannot be avoided completely. In particular, there were no options for obtaining preoperative measurements other than scanning horses prior to the surgery and no means of avoiding the effect of multiple scans postoperatively. Time-related variability in tissue properties can affect the result, which is a lesser concern regarding larger dynamic outcomes.

4.7. Implications for Future Research and Clinical Translation

Subsequent research might integrate mechanical endpoints derived from CT analysis with clinical data in equine patients receiving ISLD surgery due to naturally occurring disease. This line of investigation would ideally incorporate pre-surgical imaging, diagnostic analgesia, surgical-site selection, rehabilitation protocols, and motion analysis. Such longitudinal evaluation might identify whether increasing forced mobility correlates with recovery, creates adverse events, or depends on disease severity. While the existing literature has demonstrated that some horses recover function after ISLD, better integration of mechanics and patient outcome would strengthen surgical choices [11,12].

Further investigations could supplement the cadaveric CT protocol with dynamic imaging and motion capture systems. The CT technique provides excellent skeletal internal anatomy and phase-specific reconstruction, while inertial or optical tracking systems offer evaluation of living animal movement while riding on circles or straight lines [7,8]. Both techniques should not be seen as competitive. Instead, their combination might consist of high-definition imaging to characterize disease severity and surgical anatomy and then motion analysis to measure actual functional capability following surgical intervention and rehabilitation.

Finally, these results reinforce the need for cautious reporting of mechanical effects on clinical performance in equine back disease cases. A description such as “interspinous space widened” requires information about what phase and measurement was used. For instance, no significant widening of resting adjacent-DSP distance occurred in this cadaveric CT record, yet increased flexion aperture, local ROM, L1 excursion, caudocranial translation, and rotation did take place. Thus, an optimal description of imaging results should distinguish neutral anatomical parameters from functional movement ability and clarify what exact measurement scale was employed — a local interspinous distance, a full section, or a terminal vertebra — because each parameter answers its own question. This approach would avoid unfounded doubt in the absence of changes in resting anatomical imaging and overstatement of postoperative gains in space without measuring functional movement.

This line of discussion also encourages subsequent reports to be equally clear on positive and negative findings. Absence of significant change in the resting adjacent-DSP distance is not a negative result; it might be the most valuable observation due to its definition of what neutral posture imaging is unable to show. Furthermore, the absence of statistically significant effect in extension aperture does not allow making general statements about universal widening of the interspinous space in the load. Therefore, strength of this evidence comes precisely from consistency in supported movement endpoints rather than from uniformity. This practice is especially important considering enthusiasm surrounding clinical procedures in the field where patient expectation can outpace available evidence in small cadaver models.

One final consideration for further research pertains to proper choice of endpoint. Any study should specify what outcome variable it investigates, be it pain relief, athletic performance recovery, local interspinous aperture, vertebral excursions, or coordinated spine motion. These are correlated but not equivalent variables; a clinical trial would probably consider performance as the gold standard, but a scientific experiment should focus on phase-specific and anatomically-specific measurements. The choice of endpoint will make an impact on perception of the magnitude of surgical effect. This lesson can also be applied to other back surgeries in the horse.

5. Conclusion

The CT data from seven normal equine spine sections between T11-L1 show that the clearest mechanical result of ISLD occurs under load and near the distal end of the lumbar chain, not in the resting space distance between adjacent dorsal spinous processes. While mean interspinous distance at rest did not change, resting total length of the spine section showed a slight increase following surgical manipulation. However, flexion-phase interspinous distance, adjacent-space range of motion, L1 dorsoventral movement, L1 craniocaudal translation, and L1 rotation all showed significant increases. To answer the research question posed at the start of the paper, we can conclude that ISLD results in mobility in measurements under load and endpoints rather than rest and spacing measurements. Resting CT imaging still has value for diagnosing proximity of the dorsal spinous processes and bony change, but as a single measurement state, it falls short in measuring the mechanical effect of ligament desmotomy. ISLD mechanics would be fully characterized only by noting the loading conditions, anatomical scale, and endpoints chosen. The ideal endpoint for mechanical diagnosis is not the same as the ideal endpoint for answering the diagnostic question. Diagnosis may begin with imaging showing dorsal spinous process proximity, but a proper mechanical analysis requires measurement in the phase state of load-bearing. With regard to the CT measurements presented here, the distinction means the difference between negligible effect on resting endpoints and considerable increase in loaded endpoints. The final conclusion to be drawn from these data specifically is that ISLD does not reliably widen the interspinous spaces at rest in all cases, but it does increase the motion of the spine chain segment when loaded.

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