



# Anatomy of the diaphragmatic crura and other paraspinal structures relevant to en-bloc spondylectomy for lumbar spine tumours

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## Abstract

**Introduction** En-bloc spondylectomy in the lumbar spine is a challenging procedure mainly due to a complex prevertebral anatomy. The aim of our study is to describe the anatomy of the diaphragmatic crura and surrounding vascular and neural structures which may be iatrogenically injured during the surgical resection.

**Materials and methods** Ten embalmed specimens were meticulously dissected. Widths of the diaphragmatic crura, abdominal aorta, cisterna chyli, thoracic duct, sympathetic trunks, and inferior vena cava as well as their distances from the midline were measured at nine levels (L1 to L4 vertebra and adjacent intervertebral discs).

**Results** The right crus was attached to the L2–L4 vertebral bodies and L2/3 intervertebral disc, while the left crus inserted onto L1–L3 vertebrae. The thoracic duct arose commonly at the level of L2 vertebra and overlaid the right crus at the L3 vertebra and L2/3-disc levels. The cisterna chyli was present in 70% of specimens and overlapped with the left crus at the same levels. Both sympathetic trunks emerged underneath the crura at the L1/2 discs or L1 vertebra level. The aorta overlapped with the crura at all levels.

**Conclusion** The L3 level appears to be the riskiest for spondylectomy due to the overlap of both diaphragmatic crura with the thoracic duct and cisterna chyli, respectively. Spondylectomy at the L2 level also brings the risk of lymphatic structures injury while injury to the left sympathetic trunk may be the main issue at the L1 level.

**Keywords** Abdominal aorta · Cisterna chyli · Diaphragmatic crura · Sympathetic trunk · Thoracic duct · Total en bloc spondylectomy

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## Introduction

The complete removal of a spinal tumour based on the oncological principles is performed by its en-bloc resection with a continuous layer of healthy tissue (wide resection) or with a margin along the pseudocapsule of the tumour (marginal resection), without entering the tumour [1]. In some cases, a total en-bloc spondylectomy (TES) meaning a complete removal of the vertebral body and posterior elements in two pieces is necessary [2]. TES may be performed from a combined anterior/posterior or single posterior approach [3]. The posterior approach is demanding due to limited visualisation of the structures located anterior to the vertebral column [4, 5]. Moreover, in the lumbar segment of the vertebral column (lumbar spine), the procedure is complicated by the presence of the diaphragmatic crura inserting onto the anterolateral aspect of the lumbar vertebral bodies and put the nearby coursing structures (cisterna chyli, thoracic duct, sympathetic trunks, and thoracic splanchnic nerves) at risk of iatrogenic injury during detachment of the crura from the vertebrae [6–10]. The function of the crura is to fixate the central diaphragm, acting as an antireflux barrier by compressing the esophagus [11]. The anatomy of the vascular structures in regard to TES was described by Kawahara et al. (1996). Specifically for the diaphragmatic crura transection, great care must be taken to avoid injury to the second segmental artery, which runs dorsally to the crura [12]. However, the relationships of the thoracic duct (which drains lymph from the majority of the body) [13], sympathetic trunks and thoracic splanchnic nerves (which

contribute to the autonomic supply of the abdomen, pelvis, and lower limbs) [14] to the diaphragmatic crura still seek for detailed topographical assessment.

Therefore, the aim of our study is to describe the topography of the structures ventrally surrounding the lumbar spine, in particular the diaphragmatic crura, and to predict the topography of the anatomical structures that are prone to iatrogenic injury during the crura resection during TES.

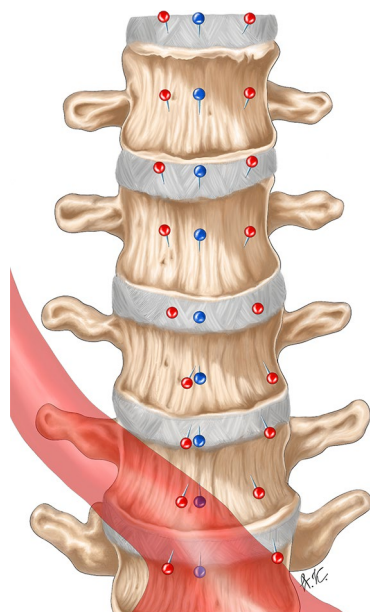
## Materials and methods

Ten embalmed specimens (5 female and 5 male) of Central European origin (mean age 73.8; range 68.2–79.6 years) without any external evidence of spine injury or significant deformity were dissected to study the diaphragmatic crura and other structures surrounding the anterior lumbar spine. All dissections were performed by the same researcher. Abdominal wall was opened through a middle laparotomy, intestines were removed, and the duodenum and the pancreas were detached from the retroperitoneum and reflected cranially. The margins of the abdominal aorta projecting onto the lumbar spine were marked with office pins (Fig. 1). Subsequently, the aorta was transected at the level of the aortic hiatus, detached from the lumbar spine and reflected caudally. Renal arteries and veins were transected while manoeuvring with the aorta. Thoracic duct, cisterna chyli, sympathetic trunks and inferior vena cava were identified and meticulously dissected in relationship to the diaphragmatic crura. Then, widths of the lumbar vertebrae (L1 to L4) and intervertebral discs (T12/L1 to L4/5), and distances between the centres (midline) of the vertebrae and adjacent discs, marked with office pins, to the structures of interest, were measured with digital Vernier calliper (Anyi Instrument Co. Guilin, China) with an accuracy of  $\pm 0.02$  mm. Consequently, widths of the diaphragmatic crura, abdominal aorta (in relationship to the pins representing the margins of the aorta), cisterna chyli, thoracic duct, sympathetic trunks and inferior vena cava were measured, as well as their distance to the midline at nine levels: vertebra L1 to L4 and T12/L1 to L4/5 discs. The levels, where the greater, lesser and least thoracic splanchnic nerves pierced the diaphragmatic crura, were also noted.

All data supporting the findings of this study are available within the paper and its Supplementary Information.

## Statistical analysis

GraphPad Prism v. 9.5.1 (GraphPad Software, USA) was used for statistical analysis and data presentation. All morphometric values were averaged and are reported with standard deviation. Box and Whisker plots with 5–95 percentile



**Fig. 1** Figure illustrating the measuring technique. The midline is marked with blue office pins. After marking the margins of the abdominal aorta with red pins, the aorta was transected and reflected caudally

were used to demonstrate the distances from midline to the margins of the particular anatomical structures at different levels of the vertebral column.

### Results

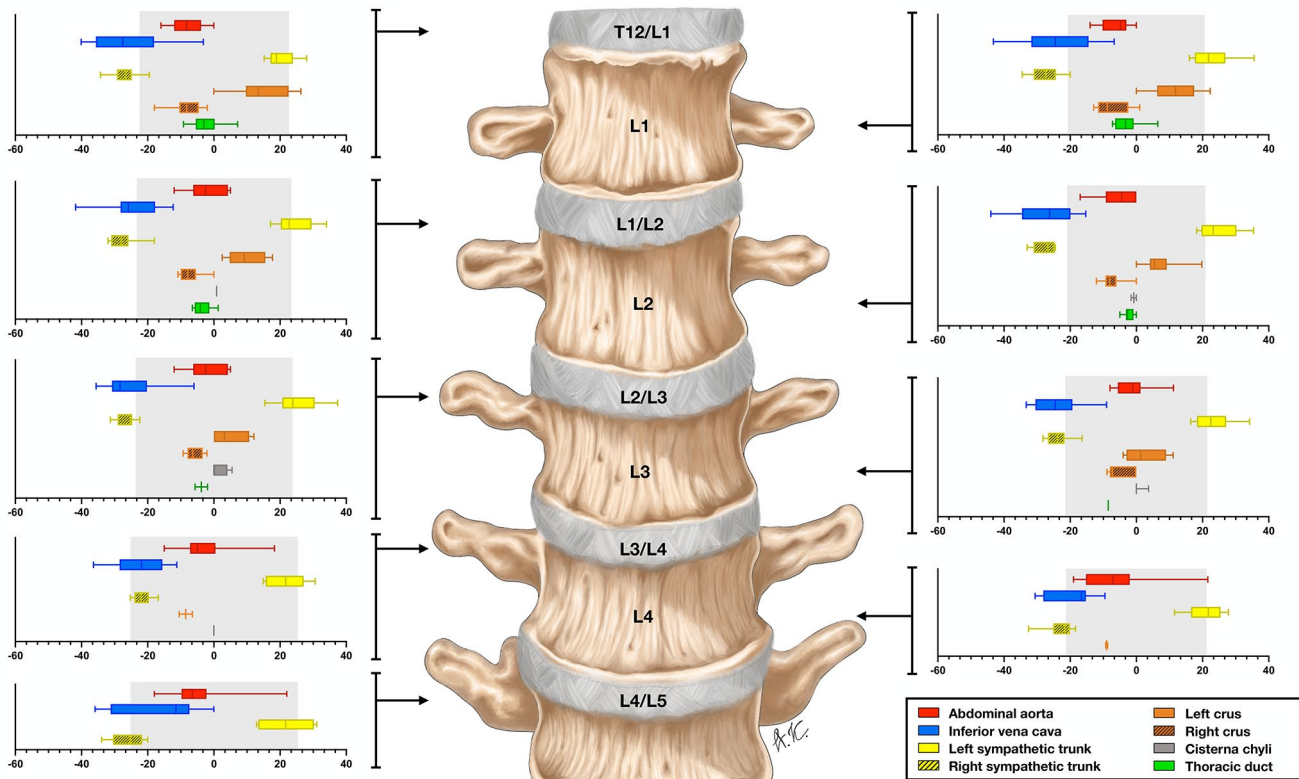
The widths of the vertebral bodies and intervertebral discs are summarised in Table 1. The distances of the structures to the midline are presented in Table 2. Based on these measurements, Fig. 2 outlines the relationship of the structures to the midline of the vertebral bodies and intervertebral discs and their mutual relationship. The widths of the structures

**Table 1** Widths (in millimetres) of the intervertebral discs and vertebral bodies measured at nine levels (vertebrae L1 to L4 and discs T12/L1 to L4/5)

Intervertebral disc	
T12/L1	45.0±1.1
L1/2	51.4±2.0
L2/3	55.3±6.6
L3/4	60.0±5.3
L4/5	60.1±2.7
Vertebra	
L1	43.6±2.6
L2	45.8±4.5
L3	51.1±5.4
L4	50.2±1.4

**Table 2** Distances (in millimetres) from the medial margin of the structure to the midline measured at nine levels (vertebrae L1 to L4 and discs Th12-L1 to L4-5). NA=not applicable

Level	Thoracic duct	Cisterna chyli	Right crus	Left crus	Right sympathetic trunk	Left sympathetic trunk	Inferior vena cava
T12/L1	2.3±5.2	NA	8.4±4.9	14.1±8.5	26.7±4.3	20.3±4.2	25.5±12.0
L1	2.7±4.6	NA	7.6±5.1	11.3±7.3	27.7±4.7	22.6±6.2	23.9±11.5
L1/2	4.0±2.7	-0.8	7.3±3.3	9.7±5.5	27.5±4.1	24.6±5.8	24.7±8.6
L2	2.4±1.0	0.8±1.1	7.4±3.4	7.0±5.6	27.6±3.2	25.0±5.9	27.1±9.0
L2/3	3.8±2.7	-1.8±2.8	5.9±2.5	4.6±5.8	26.3±2.8	25.5±7.0	25.2±8.6
L3	8.5	-1.2±2.1	4.9±4.1	2.4±6.4	23.8±3.6	23.3±5.5	24.4±7.4
L3/4	NA	0	8.5±2.8	NA	21.6±2.7	21.8±5.7	22.5±7.9
L4	NA	NA	9.0±0.4	NA	23.0±4.7	21.1±5.4	19.7±7.2
L4/5	NA	NA	NA	NA	26.0±4.7	21.9±7.3	16.4±12.9

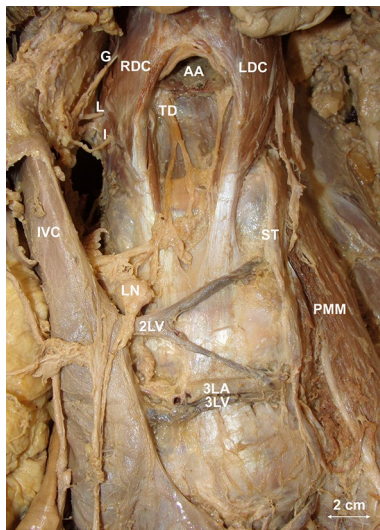


**Fig. 2** Graphical presentation of the data. The plots show the medial margins of the right-sided structures (inferior vena cava, right sympathetic trunk, right diaphragmatic crus, thoracic duct) and the medial margins of the left-sided structures (abdominal aorta, left sympathetic

trunk, left diaphragmatic crus, cisterna chyli) at the different vertebral column levels. Grey area represents the average diameter of the corresponding vertebra/intervertebral disc. Distances are in millimetres

**Table 3** Widths (in millimetres) of the structures on the anterolateral surface of the lumbar spine measured at nine levels (vertebrae L1 to L4 and discs Th12-L1 to L4-5). NA=not applicable

Level	Thoracic duct	Cisterna chyli	Right crus	Left crus	Right sympathetic trunk	Left sympathetic trunk	Inferior vena cava	Abdominal aorta
T12/L1	3.2±1.0	NA	34.9±1.3	21.6±6.7	3.0±1.0	3.4±1.1	25.8±5.8	23.5±2.2
L1	3.4±1.2	NA	32.3±8.8	16.7±8.5	3.1±1.1	3.4±1.0	27.1±5.3	24.0±2.1
L1/2	3.4±1.0	9.1	26.6±14.3	12.2±5.7	3.1±0.7	4.0±1.4	25.4±4.6	21.9±3.6
L2	3.4±1.3	11.1±2.5	13.6±6.2	8.8±3.3	3.4±1.4	3.1±0.9	24.7±4.0	22.0±4.0
L2/3	2.7±0.4	8.5±2.3	11.4±5.2	9.1±3.9	3.7±1.2	3.7±1.2	22.9±6.4	21.7±3.4
L3	3.1	8.0±3.8	9.4±5.0	7.7±1.7	2.8±1.3	3.5±1.5	20.7±3.4	22.1±4.0
L3/4	NA	6.7	14.6±15.3	NA	4.4±1.4	4.2±1.7	22.8±5.6	21.5±4.0
L4	NA	NA	7.2±4.3	NA	3.1±1.4	3.2±1.4	24.1±5.1	21.8±4.1
L4/5	NA	NA	NA	NA	3.8±1.4	3.1±1.1	24.7±5.2	21.5±4.8

**Fig. 3** Photograph of a male cadaveric specimen showing the relationship of structures on the anterolateral surface of the first three lumbar vertebrae (L1–L3) and interposed intervertebral discs. The abdominal aorta was transected at the aortic hiatus of the diaphragm and lumbar arteries were detached. **Legend:** AA – transected abdominal aorta; G – greater thoracic splanchnic nerve; IVC – inferior vena cava; I – least thoracic splanchnic nerve; L – lesser thoracic splanchnic nerve; LDC – left diaphragmatic crus; LN – lymph node (retrocaval); PMM – psoas major muscle; RDC – right diaphragmatic crus; ST – right sympathetic trunk; TD – thoracic duct; 2LV – second lumbar vein; 3LA – transected third lumbar artery; 3LV – third lumbar vein

surrounding the anterolateral surface of the lumbar spine are described in Table 3.

### Diaphragmatic crura

The right diaphragmatic crus was most commonly attached to the L3 vertebra (60%) while the attachment onto the L2 (20%) and L4 vertebral body (10%) or the L2/3 intervertebral disc (10%) was seen less frequently. The left diaphragmatic crus attachment was observed more cranially at the L3 (40%), L2 (50%) or L1 (10%) vertebral body. The left crus lateralised in cranial direction. However, the right crus approached the midline at the level of the L2/3 intervertebral

disc and lateralised both cranially and caudally (Table 2). The dimensions of both crura are attached in Tables 2 and 3.

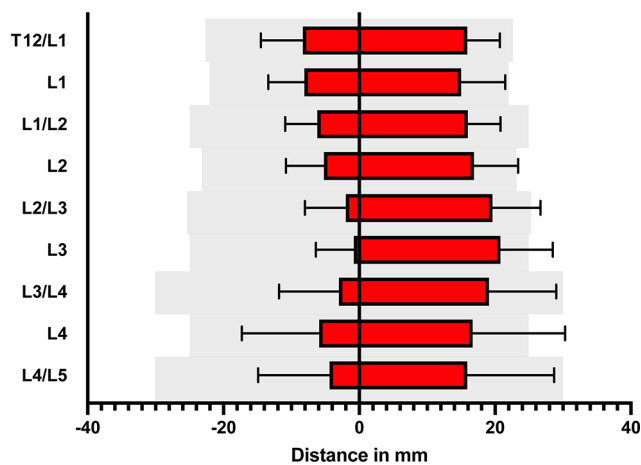
### Thoracic duct and cisterna chyli

The thoracic duct was observed arising from the cisterna chyli in 70% or directly from the confluence of lumbar and intestinal lymphatic trunks in 30% of cases, specifically at level of the L3 (10%), L2/3 disc (10%), L2 (60%), L1/2 disc (10%) or L1 vertebra (10%). Our observations showed that the thoracic duct was especially coursing right of the midline with a tendency to lateralise in cranial direction, while the cisterna chyli appeared more so on the left side or overlaid the midline (Fig. 2). The cisterna chyli was present as plexiform (30%) or fusiform (40%) structure at the level of the L1/2 to the L3/4 intervertebral discs. In all bodies, in addition to the thoracic duct, there was also noticed an accessory left-sided lymphatic trunk which had rich communications with the thoracic duct (Fig. 3).

The thoracic duct frequently overlaid the right crus at the L3 vertebra and L2/3-disc levels (Fig. 2). In more cranial levels this close relationship remained within a 5 mm distance (Table 2; Fig. 2). The cisterna chyli, due to its left position, overlapped with the left crus, especially at the L3 vertebra level and L2/3-disc level. At the more cranial levels (L2 vertebra and L1/2 disc) the cisterna chyli was present over the midline but did not overlap with the right crus due to the cranial lateralisation of the crus.

### Sympathetic trunks

The sympathetic trunks were present bilaterally at all levels. The right sympathetic trunk emerged from underneath the right diaphragmatic crus at the L1/2-disc level while the left sympathetic trunk was already underneath the left diaphragmatic crus at the L1 level (Fig. 3). Our data showed that the right sympathetic trunk tended to be more lateral in relation to the corresponding vertebra compared to the left one (Fig. 2; Table 2).



**Fig. 4** Graphical presentation containing both the right and left margins of the abdominal aorta by the average diameter of the corresponding vertebra/intervertebral disc (grey area)

### Thoracic splanchnic nerves

The greater, lesser and least thoracic splanchnic nerves entered the retroperitoneum by piercing the diaphragmatic crura in all specimens (Fig. 3). The piercing points for the greater thoracic splanchnic nerves were located predominantly at the L1 level (60% right, 80% left) or L1/2-disc level (40% right, 20% left) bilaterally. The lesser thoracic splanchnic nerve left the crura at the L1/2 level more often on the right side (80%), while emergence at the L1 level was more common on the left side (60%). The least thoracic splanchnic nerves emerged at the L2 (40%), L1/2 disc (40%) or L1 levels (20%) bilaterally.

### Great vessels

The abdominal aorta overlapped with the midline in all our cases (Fig. 2). Furthermore, it was always present within the width of the corresponding vertebra or intervertebral disc (Fig. 4).

The inferior vena cava was always found right to the midline with no overlap over the centre of the corresponding vertebra or intervertebral disc (Fig. 2; Table 2).

### Discussion

The current cadaveric study presents valuable data on the relationship of the neurovascular structures with respect to the diaphragmatic crura obtained through meticulous dissection of cadaveric specimens. This knowledge is crucial in preventing their damage and consequent redundant morbidity and postoperative complications after the TES of the

lumbar vertebrae (L1–L4), where the diaphragmatic crura are transected during this procedure.

En-bloc spinal tumour resection which may include one- or multilevel TES is a technically high-demanding procedure with complication rate of almost 60%. The most frequent complications are neurological damage, hardware failure, dural tear and cerebrospinal fluid leakage, wound-related complications and vascular injury and bleeding [15]. A big challenge in the lumbar spine poses the diaphragmatic crura inserting onto the anterolateral surface of the lumbar vertebrae. Their transection is a crucial and unavoidable part of the TES in this location [6–10]. Depending upon the approach, the crura are detached from the spine by blunt dissection and then transected through anterior [7–10] or posterior approach [6]. Special attention should be given to avoid iatrogenic injury to the thoracic duct, cisterna chyli, sympathetic trunks and great vessels at this stage. High blood loss due to tearing off the lumbar arteries or injury to the great vessels could be a potentially fatal complication [15, 16]. Even though injuries to the other structures surrounding the crura may be considered as a minor complication [15], they can also significantly influence the quality of life and, in particular situations, require surgical revision [17].

The right diaphragmatic crus is usually longer (up to 20 cm) and broader since it is attached to the L2–L4 vertebrae, while the left crus inserts onto L1–L3 vertebra [11, 12, 14]. The crura consist of muscular and tendinous portions with a transformation zone at a mean of 27% of their length [11]. The tendinous part inserts onto the vertebral bodies and merges with the anterior longitudinal ligament [11, 14]. Our findings regarding the attachment levels of the crura are consistent with the above-mentioned literature.

The thoracic duct arises from the cisterna chyli or directly from the confluence of lumbar and intestinal lymphatic trunks, usually at the L2 level and extends up to the neck [13]. The cisterna chyli is a dilated portion of the lumbar segment of the thoracic duct, present in about 50% of cases (being probably a developmental remnant) and is mostly located at the L1–L2 vertebra level [13, 14, 18]. The thoracic duct can be up to 5 mm large in its abdominal segment and can be found underneath the medial margin of the right diaphragmatic crus [13, 14]. Davis [18] found that doubled abdominal segment of the thoracic duct, as a result of persistence of the right and left trunks, is the most frequent variation. According to his thorough study the second trunk is always present, although it is tiny and communicates with the proper thoracic duct through numerous anastomoses. This finding was consistent with observations in our study (Fig. 3). The thoracic duct and cisterna chyli were found in a close

proximity to the attachment level of the diaphragmatic crura.

In the thoracic spine the iatrogenic injury of the thoracic duct is hardly avoidable [19], and subsequent iatrogenic postoperative chylothorax often requires a revision [17]. According to our data the thoracic duct in the lumbar spine showed consistent anatomy, and, thus, it could be reliably expected in the stated position during the surgery. However, the overlap between the thoracic duct and left diaphragmatic crus, and between the cisterna chyli and right crus at the L3 vertebra and the L2/3-disc levels puts the lymphatic structures at risk of injury during the crura resection. In more cranial levels the structures are localised between the crura. From our observations, the L3 level is a common attachment site for the right (60%) and left (40%) diaphragmatic crus. Therefore, a resection of the L3 vertebra may potentially violate the lymphatic structures. As a consequence, chylous ascites and chyloretroperitoneum are troublesome complications that may not be recognised intraoperatively due to preoperative fasting reducing lymphatic flow [20]. These complications are either treated with revision or more commonly by a low-fat diet. A long-term diet may bring a risk of wound infections, poor wound healing, malnutrition, dehydration, hypoalbuminemia and leukopenia [21].

Sympathetic trunks usually enter the abdomen just dorsal to the crura with a close relationship to the left margin of the inferior vena cava on the right side, and the left margin of the abdominal aorta on the left side [22]. Our data show that the right sympathetic trunk crosses the right crus at the level of the L1/2 disc, while the crossing point on the left side is localised more cranially at the level of L1 vertebra. These points may be considered as a danger zone for their injury. Another pitfall of the complex topography is that the sympathetic trunk may be confused with the tendinous part of the diaphragmatic crura leading to an unwanted sympathectomy [22]. Intraoperative sympathectomy commonly results in increased limb temperature due to a loss of vasoconstriction [23]. It can also cause dysesthetic pain [23], postoperative hypotension [24] and even complex regional pain syndrome [23]. The neurological damage occurring after TES was reported in 12.7% of patients (in 57.1% of them unspecified) according to Li et al. [15]. Considering other neural structures surrounding the lumbar spine, the thoracic splanchnic nerves and lumbar spinal nerves should also be taken into account when performing the TES. Moreover, the spinal nerves are attached to the surroundings of the intervertebral foramen by extraforaminal ligamentous attachments [25, 26], which should be carefully detached from the nerves if their preservation is attempted during the TES.

To avoid lymphatic injury, Varga [6] recommended to cut the crura 10 mm from the vertebral bodies when performing the posterior approach. The presented data allow

us to predict at which levels the anatomical structures can be expected, and, thus, help to reduce their potential injury during the crura resection. At the L4 vertebra level there is much lower risk of iatrogenic injury to lymphatic or neural structures due to the fact that the thoracic duct is not yet present at this level and the lumbar trunks are much thinner, and sympathetic trunk is situated more laterally than the right crus attachments. The L3 vertebral level is the most problematic due to the attachment of the crura and intimate relationship of the thoracic duct with the right crus and cisterna chyli with the left crus. One should be aware that these structures still overlap with the crura at the level of the L2/3 disc, and the proposed 10 mm reference for cutting the crura due to rich lymphatic chain [6] might not assure safety in performing total TES of the L3 level. At the L2 level caution must be taken in order not to violate the lymphatic structures that are localised between the crura. The level of the L1 vertebra contains the left crus attachment only sporadically (10%) which brings a danger of the left sympathetic trunk injury due to its emergence underneath the left diaphragmatic crus. Resection of the crura at all levels is always dangerous for the abdominal aorta. The inferior vena cava can overlay the right diaphragmatic crus at the most cranial levels (L2 and L1 vertebra). The thoracic splanchnic nerves emerge through the muscular portion of the crura, and that is why they can be violated only in case of intentionally more distant resection from the vertebral body.

Imaging findings of the thoracic duct are limited due to its size. However, was reported that the thoracic duct can be imaged on CT and MRI (both contrast-enhanced and non-contrast) in relation to the vertebral bodies [27]. The main pitfall is its position in relation to the diaphragmatic crura, whose attachments are difficult to differentiate from the anterior longitudinal ligament. This highlights the importance of cadaveric studies, which provide critical anatomical insights for medical understanding and procedures such as TES.

## Limitations

The usage of preserved cadaveric specimens may lead to slight differences in measuring since the fixation process causes a shrinkage of soft tissues and dissection-related shifts in structures. Furthermore, collapsed inferior vena cava in a specimen poses a limitation due to its possible displacement. While translating our results into clinical practice, it must be noted that the natural anatomy is usually altered secondary to tumour growth, degenerative processes or ventral intervertebral disc herniation.

## Conclusion

Although several vascular and neural structures may be potentially injured during the TES in the lumbar spine, especially the lymphatic structures are at risk when performing removal of the L2 or L3 vertebra.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s00586-025-08716-0>.

**Author contributions** Anhelina Khadanovich: Methodology, Investigation, Data Curation, Visualization, Writing – Original Draft. Michal Benes: Formal Analysis, Visualization, Writing – Review & Editing. Radek Kaiser: Validation, Writing – Review & Editing. Jeremy Reynolds: Methodology, Writing – Review & Editing. Gerard Mawhinney: Methodology, Writing – Review & Editing. Jan Stulik: Methodology, Writing – Review & Editing. David Kachlik: Supervision, Validation, Resources, Visualization, Writing – Review & Editing.

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**Data availability** All data supporting the findings of this study are available within the paper and its Supplementary Information.

## Declarations

**Competing interests** The authors declare no competing interests.

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