Full-endoscopic uniportal decompression in disc herniations and stenosis of the thoracic spine using the interlaminar, extraforaminal, or transthoracic retropleural approach

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OBJECTIVE Surgery for thoracic disc herniation and spinal canal stenosis is comparatively rare and often challenging. Individual planning and various surgical techniques and approaches are required. The key factors for selecting the technique and approach are anatomical location, consistency of the pathology, general condition of the patient, and the surgeon's experience. The objective of the study was to evaluate the technical implementation and outcomes of a full-endoscopic uniportal technique via the interlaminar, extraforaminal, or transthoracic retropleural approach in patients with symptomatic disc herniation and stenosis of the thoracic spine, taking specific advantages and disadvantages and literature into consideration.

METHODS Between 2009 and 2015, decompression was performed in 55 patients with thoracic disc herniation or stenosis using a full-endoscopic uniportal technique via an interlaminar, extraforaminal, or transthoracic retropleural approach. Imaging and clinical data were collected during follow-up examinations for 18 months.

RESULTS Sufficient decompression was achieved in the full-endoscopic uniportal technique. One patient required revision due to secondary bleeding, and another exhibited persistent deterioration on myelopathy. No other serious complications were observed. All but one patient experienced regression or improvement of their symptoms.

CONCLUSIONS The full-endoscopic uniportal technique with an interlaminar, extraforaminal, or transthoracic retropleural approach was found to be a sufficient and minimally invasive method. To cover the entire range of thoracic disc herniations and stenosis within the criteria named, all full-endoscopic approaches are required.

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KEYWORDS transthoracic retropleural approach; interlaminar approach; extraforaminal approach; thoracic disc herniation; thoracic spinal stenosis; full endoscopic

THORACIC disc herniations are rare and constitute only 0.15% to 4% of all nucleotomies of the spine. They may be soft or calcified;^{39,54,61} a special form, termed giant disc herniation, has been described¹⁸ that displaces more than 40% of the spinal canal.^{11,28,39} In Europe and the US, thoracic spinal stenosis is usually due to spondylosis;

in Asia, ossification of the ligamentum flavum (OFL) often occurs. Congenital narrowing of the spinal canal is often found in combination with these conditions.^{22,34}

Depending on the location, from intraforaminal to intraspinal, radicular and/or central neurological (myelopathic) symptoms may occur.^{36,37,39} Atypical symptoms

ABBREVIATIONS mJOA = modified Japanese Orthopaedic Association; NASS = North American Spine Society; OFL = ossification of the ligamentum flavum; VAS = visual analog scale.

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(e.g., gastrointestinal, cardiopulmonary, abdominal) have also been reported.^{40,52} Intolerable and/or persistent pain or acute, progressive radicular, or central neurological deficits are criteria for the indication for surgery, which can also be considered for atypical symptoms.^{3,34,37}

In decompression, surgical manipulation of the thoracic spinal cord must be avoided. Therefore, depending on the location and consistency of the pathology, various anterior approaches and nonanterior approaches are used to cover the entire area around the spinal cord.^{2,4,7,10,27,30,51,55,62} Non-anterior approaches may involve difficult or inadequate visualization or handling of the area anterior to the spinal cord and approach-related destabilization of the posterior structures.^{5,6} Anterior approaches allow sufficient and direct access to the anterior spinal canal but may lead to problems due to opening the thoracic and pleural cavities^{15,39,63} and have a higher rate of complications.^{15,63} Overall, there are no clear standards. Additional stabilization is discussed but is usually recommended only if there is damage to anterior structures or if more than half of the vertebral body has been resected.^{12,32,33} In general, an attempt is made to achieve adequate results and reduce the known problems with minimally invasive modifications.^{21,30,41,53,59}

Good outcomes and advantages of full-endoscopic uniportal operations under continuous irrigation have been described for surgery of herniated discs and stenoses in the lumbar and cervical spine.^{23,44–46,48} In this study, we evaluated the technical implementation and outcomes of a full-endoscopic uniportal technique via the interlaminar, extraforaminal, or transthoracic retropleural approach in patients with symptomatic disc herniation and stenosis of the thoracic spine, taking specific advantages and disadvantages and literature into consideration.

Methods

Patient Characteristics

The routinely collected prospective data of all opera-

tions of the thoracic spine (T1–12) for treatment of disc herniation or spinal canal stenosis were evaluated retrospectively. The research protocol for this study was reviewed and approved by our hospital's institutional review board. Specific patient consent was not required according to the federal data privacy act because this retrospective study was based on intradepartmental medical records. A total of 55 consecutive patients who underwent decompression with a full-endoscopic uniportal technique via an interlaminar, extraforaminal, or transthoracic retropleural approach between 2009 and 2015 were included. The patient characteristics are summarized in Table 1.

Inclusion Criteria and Selection of Approach

The criteria for a full-endoscopic technique were as follows: monosegmental disc herniation and/or spinal stenosis, persistent or progressive radicular and/or central neurological symptoms (pain, neurological deficit at T-1 or T-12, myelopathy), axial pain not pronounced, and no high-grade deformity/instability or prior surgery in the target segment.

Selection of the surgical technique is similar to that for conventional surgery. The pathology and thus the target area were determined and assessed (e.g., intraspinal, extra-spinal, extent, consistency). Depending on the assessment results, the approach in which technical implementation allowed the target region to be reached and decompressed while avoiding manipulation of the thoracic spinal cord was selected. If the extraforaminal and the transthoracic retropleural approaches were considered equally suitable, the extraforaminal approach was preferred. The larger, more medial, or more calcified the disc herniation was, the more likely a transthoracic approach would be selected. Taking the individual situation into consideration, the approaches used for the following pathologies were as follows: 1) interlaminar for posterior pathologies, such as spinal canal stenosis, OFL, or intraspinal extradural cyst;

TABLE 1. Patient characteristics

Surgical Technique	No. of Pts	F/M	Mean Age in Yrs (range)	Location (no. of pts)	Pathology (no. of pts)	Leading Sx (no. of pts)	Additional Sx (no. of pts)	Mean Duration of Sx in Wks (range)
Interlaminar	20	12/8	53 (23–71)	T1–2 (6), T4–5 (1), T7–8 (2), T9–10 (4), T10–11 (5), T11–12 (2)	Soft DH (12; 6 at T1–2), posterior stenosis (3), OFL (4), facet cyst (1)	Radiculopathy (8), myelopathy (12)	Axial pain (7)	Radiculopathy: 5 (<1–23); myelopathy: 7 (<1–48)
Extraforaminal	26	16/10	58 (41–82)	T6–7 (1), T7–8 (1), T8–9 (3), T9–10 (5), T10–11 (11), T11–12 (5)	Intraforaminal DH (4), soft DH (5), calcified DH (15), giant DH (2)	Radiculopathy (7), myelopathy (19)	Atypical (4), axial pain (15)	Radiculopathy: 11 (3–34); myelopathy: 9 (<1–61)
Transthoracic retropleural	9	4/5	56 (39–68)	T7–8 (1), T8–9 (2), T9–10 (4), T10–11 (2)	Calcified DH (4), giant DH (5)	Myelopathy (9)	Axial pain (3)	Myelopathy: 4 (2–56)
Overall	55	32/23	56 (23–82)	T1–2 (6), T4–5 (1), T6–7 (1), T7–8 (4), T8–9 (5), T9–10 (13), T10–11 (18), T11–12 (7)	Intraforaminal DH (4), soft DH (17), calcified DH (19), giant DH (7), posterior stenosis (3), OFL (4), facet cyst (1)	Radiculopathy (15), myelopathy (40)	Atypical (4), axial pain (25)	Radiculopathy: 8 (<1–34); myelopathy: 7 (<1–61)

DH = disc herniation; Pts = patients; Sx = symptoms.

posterior sequestered intraspinal disc herniation; or intraspinal craniocaudal sequestered disc herniation lateral to the spinal cord; 2) extraforaminal for intra-/extraforaminal disc herniation, mediolateral to medial intraspinal disc herniation, or possibly giant disc herniation; and 3) transthoracic retropleural for medial disc herniation or giant disc herniation. The transthoracic approach can be used only up to about T-5 in the cranial direction due to anatomical conditions. More cranial pathologies that cannot be decompressed using the extraforaminal approach must be surgically treated using conventional methods.

Full-Endoscopic Instruments

The endoscope used has an oval shaft cross-section measuring 6.9×5.9 mm and a working length of 165 mm and is introduced through a working sheath. The view angle is 25° . For the uniportal technique, an intraendoscopic, eccentric working channel with a diameter of 4.1 mm, light guide, inflow for continuous irrigation, and the rod lens system are needed. For coagulation and tissue ablation, a bipolar articulating probe that applies the radiofrequency current of 4 MHz, which reduces the transmission of heat to adjacent tissue structures, is used.¹⁷ The endoscopic system is used as an open system,^{23,45,46,48} so that for the length of the working sheath, a maximum pressure of the irrigation fluid of 14.3 mm Hg is reached even in a closed working channel. On average, the CSF pressure in the high cervical region is 15.5 mm Hg,¹⁹ thus minimizing the risk of compression or leakage of the irrigation fluid into the CSF system. All surgical and optical instruments are products of RIWOspine (RIWOspine GmbH; Fig. 1).

Interlaminar Surgical Technique

The interlaminar technique is the same as that already described for the lumbar and cervical spine.^{23,24,45,46,48,49} After skin incision, the dilator, operating sheath, and endoscope are introduced bluntly. The further procedure is full endoscopic and uniportal, i.e., all surgical instruments are introduced under continuous visual control and irrigation through the intraendoscopic working channel. The laminae, the vertebral joint, and the ligamentum flavum are dissected. The cutter is used to start bone resection at

the medial edge of the descending facet and at the bottom of the spinous process. Resection can be continued in a cranial direction until a hemilaminectomy is performed or beyond. The ligamentum flavum remains closed as long as possible. Resection is carried out at the caudal lamina and ascending facet. The precise extent of bone decompression depends on the respective situation. The ipsilateral ligamentum flavum is incised or resected and the dura exposed, and the pathology or additional stenotic segments are resected. The spinal cord is decompressed up to the contralateral side in an “over-the-top” technique for posterior spinal canal stenosis or OFL. Free-floating dura mater in the irrigation fluid is a sign of sufficient decompression (Fig. 2).

Extraforaminal Surgical Technique

The extraforaminal technique is the same as that already described for the lumbar spine.^{42,46,47,49} The approach angle is measured preoperatively, and the dilator, the operating sheath, and the endoscope are then inserted bluntly into the extraforaminal area. The further procedure is full endoscopic and uniportal, i.e., all surgical instruments are introduced under continuous visual control and irrigation through the intraendoscopic working channel. The foramen is dissected and widened by resecting bone with a cutter and punches, and the spinal canal is entered. The precise extent of bone decompression depends on the respective situation; sequestered disc tissue can possibly be resected. If there is intraspinal or medial calcification, paradiscal bone segments must be resected from the posterior edge of the vertebral body (box-shaped resection). This allows indirect and direct anterior decompression from the ipsilateral to contralateral side without manipulation of the spinal cord. Free-floating dura mater in the irrigation fluid is a sign of sufficient decompression (Fig. 3).

Transthoracic Retropleural Surgical Technique

The transthoracic retropleural technique has not been described previously. Preparation and setup correspond to the usual standards for transthoracic and endoscopic operations. The irrigation fluid is warmed to body temperature. Depending on the pathology and anatomy, the

FIG. 1. Left: Endoscope with a 25° view angle and intraendoscopic working channel. Right: Full-endoscopic uniportal interlaminar operation. Left: Copyright Sebastian Ruetten. Published with permission. Figure is available in color online only.

FIG. 2. A: Interlaminar approach. **B:** Posterior to contralateral decompression can be achieved in the over-the-top technique. **C:** Intraoperative view of the posterior spinal cord (stars) after over-the-top decompression of an OFL. The long arrow indicates the cranial lamina, and the short arrows indicate the decompressed recesses. **D:** Intraoperative C-arm image using the drill. A and B: Copyright Sebastian Ruetten. Published with permission. Figure is available in color online only.

procedure is performed in a right or left lateral position with the operator standing at the anterior side. For the skin incision, the posterior edge of the vertebral body and target level are marked on the skin laterally using the C-arm. To determine the correct level, the vertebrae are counted from caudal or cranial using inserted cannulas under C-arm control. One lung may be deflated during the approach. A skin incision is made, and the upper edge of the rib is located. The operating sheath and the endoscope are inserted. The further procedure is full endoscopic and uniportal, i.e., all surgical instruments are introduced under continuous visual control and irrigation through the intraendoscopic working channel. The intercostal muscles are separated from the upper edge of the rib until the retropleural space can be reached. It may be helpful to widen it with a finger, which requires that the skin incision be enlarged. Blunt retropleural dissection is carried out until the head of the rib in the target segment is reached. The head of the rib is resected with the cutter, and the pedicle is exposed. The pedicle is resected using the cutter and punch, and the epidural space is resected. The posterior disc is

opened and removed. If there is intraspinal or medial calcification, the paradiscal bone segments must be resected from the posterior edge of the vertebral body (box-shaped resection). This allows indirect and direct anterior decompression from the ipsilateral to contralateral side without manipulation of the spinal cord. Free-floating dura mater in the irrigation fluid is a sign of sufficient decompression. The endoscope and operating sheath are withdrawn, and the integrity of the pleura is checked. If the pleura is injured, a thorax drain can be placed via the operating sheath (Fig. 4).

Follow-Up and Statistical Analysis

The data were routinely recorded pre- and postoperatively and after 6 weeks, 6 months, and 18 months. The patients were assessed during follow-up in person. In addition to clinical and radiological parameters, the visual analog scale (VAS) for thoracic back pain and arm pain, the classification according to Nurick and the Japanese Orthopaedic Association (JOA) adapted to the evaluation of

FIG. 3. **A:** Extraforaminal approach. **B:** The anterior spinal cord can be reached by resecting bone at the posterior vertebral bodies. **C:** Intraoperative view of the decompressed lateral and anterior spinal cord (stars), disc space (long arrow), and resected bone (short arrow) from the posterior vertebral body. **D:** Intraoperative C-arm image showing the use of a rongeur. A and B: Copyright Sebastian Ruetten. Published with permission. Figure is available in color online only.

thoracic pathologies (modified JOA [mJOA]) for patients with myelopathy,^{30,39} and the German version of the North American Spine Society (NASS) instrument with the subscales pain and neurology for patients with radicular pain were used. Preoperatively, postoperatively, and during follow-up, radiographs and MRI or CT scans were obtained depending on the finding. Of the 55 patients, 51 (92.7%) underwent follow-up in the designated period. The Wilcoxon test and the Mann-Whitney U-test were applied for comparison of pre- and postoperative global results and for the comparison of outcomes in the groups at different times. McNemar's test was used to compare characteristics. Depending on the group characteristics, descriptive assessments and analytical statistics were performed with IBM SPSS software (version 20, IBM Corp.). A positive significance level was assumed at $p < 0.05$.

Results

Surgical Technique and Intraoperative Findings

Based on the intraoperative findings (free-floating dura), the full-endoscopic technique allowed sufficient decompression. This was also confirmed by the clinical results, but not always by imaging, as not all patients underwent routine CT. For the different pathologies, the individual selection of the respective approach made it possible to reach the target area without manipulating

the spinal cord. The combination of an angled field of view and the range of movement of the endoscope using a joystick technique allowed a sufficient working area in all directions that exceeded the requirements. All nonsequestered disc herniations that showed no calcification on preoperative imaging (2 interlaminar, 9 transforaminal) were found to have at least a partial hard consistency intraoperatively, which made resection more difficult. Of the 47 disc herniations, 30 (63.8%) were calcified or hardened, and all sequestered herniations (10 interlaminar) were soft. Adhesions between the dura and the pathology were found 4 times with posterior stenosis and 3 times with calcified disc herniations.

The interlaminar approach also allowed contralateral decompression in cases of bilateral posterior stenosis in the over-the-top technique. In the extraforaminal technique, the rib and pleura restricted movement in a lateral direction, which prevented a flat angle during access. It was therefore necessary to resect bone at the facets to allow entry into the spinal canal or the foramen. The angle of the endoscope could be flattened later in the procedure. The region anterior to the spinal cord was easily reached due to the 25° view angle and articulating instruments. The extraforaminal approach had the broadest indication for anterior pathologies and was used most frequently (Fig. 5). There were no technical difficulties using the transthoracic retropleural approach. No pleural tears were

FIG. 4. **A:** Transthoracic retropleural approach. **B:** Box-shaped bone resection for decompression of the anterior spinal cord in calcified pathologies. **C:** Intraoperative view of decompressed spinal cord (stars) and anterior epidural space (arrows). **D:** Intraoperative C-arm image. A and B: Copyright Sebastian Ruetten. Published with permission. Figure is available in color online only.

found. In the transthoracic and extraforaminal approaches, performing indirect box-shaped decompression before direct decompression prevented spinal cord manipulation in cases with medial calcified pathology. Particular care had to be taken to continue the resection over to the contralateral side in these cases, as the 25° field of view allowed a good view below the anterior spinal cord and there was a tendency to carry out less contralateral decompression. In all techniques, free-floating dura mater in the irrigation fluid was evidence of sufficient decompression. Overall, working with a 25° view angle and continuous irrigation resulted in good visibility with the corresponding field of view and working area. No specific problems of the full-endoscopic uniportal technique were found. In no case was the degree of anticipated destabilization due to the resection of the relevant structures so pronounced that a decision was made for additional stabilization.

Intra- and Perioperative Data and Complications

The intra- and perioperative parameters are presented

in Table 2. The intraoperative blood loss was so low that it could not be measured due to continuous irrigation. Three patients remained in the ICU overnight; all others were immediately mobilized depending on the effect of anesthesia. No surgery-related pain medication was required. There were 2 cases of a postoperative epidural hematoma with radicular pain. In 1 case, a revision was carried out at T1–2 with removal of the hematoma and subsequent freedom from pain. Two anterior dural leaks occurred during the resection of calcified disc herniations with adhesions. They could not be sutured and were therefore covered with dura substitute and a fat flap as is done in other procedures and required no further treatment. There were 2 cases of postoperative clinical deterioration involving myelopathy symptoms in giant disc herniations, which were persistent in 1 case. No other serious problems requiring treatment, such as post-thoracotomy pain syndrome, pleural effusion, impaired wound healing, infections, and thrombosis, occurred. No other complications were observed during follow-up examinations, and no patient died. No recurrence was found during the follow-up period.

FIG. 5. **A and B:** Preoperative sagittal and axial MR images of a disc herniation (*short arrow*) with myelomalacia (*long arrow*). **C and D:** Axial MR image and CT scan obtained immediately postoperatively, showing bone resection of the facet joint and the posterior vertebral body (*stars*) and still irrigation fluid in the decompressed area (*arrows*) after decompression with the extraforaminal approach.

Clinical and Radiological Outcome

The clinical scores are presented in Table 3. The Nurick and mJOA scales were applied only for the patients with myelopathy, the NASS scale for patients with a T-1 radiculopathy, the VAS for radicular pain for all patients with radiculopathy, and the VAS for thoracic pain for all patients. All patients with radiculopathy showed symptom regression. In 2 patients with preoperative T-1 motor deficits (2 with 4/5 intrinsic hand muscle strength) and 3 with T-12 deficits (2 with 4/5 and 1 with 3/5 abdominal wall muscle

strength), no muscle weakness was found later. Among the patients with myelopathy, 1 patient showed deterioration (a decrease in the mJOA score by 2 points and an increase in Nurick grade by 1 point). Otherwise, all patients presented here showed regression or termination of their symptoms. No significant differences were found between spinal canal stenosis and disc herniations regarding the outcomes. The patients with a shorter duration of myelopathy had less pronounced symptoms and achieved better outcomes, but the differences were not statistically significant. The

TABLE 2. Intraoperative and perioperative data and complications

Surgical Technique (no. of followed pts)	Blood Loss	Mean Op Time in Mins*	ICU (no. of pts)	Mean Hospital Stay in Days*	Complications
Interlaminar (18 [90%])	Not measurable	95 (35–135)	None	3 (2–5)	1 epidural hematoma (revision), 1 transient arm dysesthesia (4 days)
Extraforaminal (25 [96%])	Not measurable	90 (40–155)	None	3 (2–6)	1 dural tear, 1 epidural hematoma (conservative), 2 transient intercostal neuralgias (2 & 7 days), 1 deterioration of myelopathy
Transthoracic retropleural (8 [89%])	Not measurable	125 (85–225)	12 hrs (3)	4 (2–8)	1 dural tear, 1 transient leg dysesthesia (14 days), 1 transient deterioration of myelopathy (5 wks)
Overall (51 [92.7%])		97.5 (35–225)		3.6 (2–8)	10 (19%), moderate & severe 6 (11%), severe 3 (5.8%)

* Ranges are given in parentheses.

TABLE 3. Clinical outcome

	Surgical Technique			Overall (n = 51 [92.7%])
	Interlaminar (n = 18 [90%])	Extraforaminal (n = 25 [96%])	Transthoracic Retropleural (n = 8 [89%])	
Nurick				
No. of pts	11	18	8	37
Preop grade	3.3	3.4	3.2	3.33
18-mo grade	2.3	2.3	2.5	2.34
p value	<0.05	<0.05		<0.05
mJOA				
No. of pts	11	18	8	37
Preop score	9.8	9.7	9.6	9.71
18-mo score	12.2	12.3	12.3	12.27
p value	<0.05	<0.05		<0.05
NASS pain (T1–2)				
No. of pts	6	0	0	6
Preop score	3.32			3.32
18-mo score	1.29			1.29
p value	<0.05			<0.05
NASS neurology (T1–2)				
No. of pts	6	0	0	6
Preop score	3.2			3.2
18-mo score	1.33			1.33
p value	<0.05			<0.05
VAS radicular pain				
No. of pts	7	7	0	14
Preop score	82.9	77.9		80.4
18-mo score	5	2.1		3.6
p value	<0.05	<0.05		<0.05
VAS thoracic pain				
No. of pts	18	25	8	51
Preop score	12.2	18	12.5	15.1
18-mo score	10.6	15.6	7.5	12.6
p value				

outcomes achieved remained stable during the entire follow-up period. No surgery- or approach-related increase in thoracic spine pain was reported. Overall, preoperative thoracic spine pain was reduced, but not significantly. Follow-up images showed sufficient decompression of bone and soft tissue in all cases. No evidence of increasing instability was found during the entire follow-up period.

Discussion

In addition to other diseases (e.g., infection, tumor, trauma), disc herniation and degenerative spinal canal stenosis in particular can lead to compression syndromes in the thoracic spine.^{29,60} Thoracic disc herniations are rare (incidence 1/1,000,000) and constitute only 0.15% to 4% of all nucleotomies of the spine. They can be soft or calcified, frequently occur at lower levels, and usually lead to anterior compression of spinal nerves or the spinal cord.^{39,54,61} In our study, 79% of the nonsequestered disc herniations were calcified or hard. A particular form termed giant disc

herniation has been described¹⁸ that displaces more than 40% of the spinal canal, is often calcified, erodes the dura mater, and causes a myelopathy. The pathophysiology of its development is unclear.^{11,28,39} Thoracic stenosis is usually due to spondylosis in Europe and the US; in Asia, ossification of the ligamentum flavum (OFL) or the posterior longitudinal ligament often occurs. In addition, congenital narrowing of the spinal canal is often found in combination with these conditions.^{22,34} OFL is a posterior pathology with varying degrees and forms that leads to posterior compression of the spinal cord, frequently with adhesions to the dura.^{16,25,26,64} In spondylosis, the spinal cord can be compressed from any direction depending on the accompanying degenerative changes.²²

The thoracic spinal cord is especially vulnerable to anterior compression because of thoracic kyphosis, limited mobility of the spinal cord due to the dentate ligaments, and limited blood supply in the terminal arterial territory.^{14,20} Depending on the location from intraforaminal to intraspinal, radicular and/or central neurological (my-

elopathic) symptoms may occur.^{36,37,39} Radiculopathies are usually caused by disc herniation and can cause intercostal pain. T-1 compression, which occurred 6 times in our patient group, can also cause pain in the arm and weakness of the intrinsic hand muscles (especially the abductor pollicis brevis muscle);³⁸ T-12 compression (subcostal nerve), which affected 4 patients in our study, can cause weakness of the muscles of the abdominal wall.^{36,37} Myelopathies are caused primarily by compression of the anterolateral funiculus and can show signs of central neurological deficits (e.g., hyperreflexia, gait disorders, paresis, bladder disorders, paraplegia).^{37,39} Atypical symptoms (e.g., gastrointestinal, cardiopulmonary, abdominal) have also been reported.^{40,52}

In decompression, surgical manipulation of the thoracic spinal cord must be avoided. Therefore, depending on the location and consistency of the pathology, various anterior approaches and nonanterior approaches are used, which cover the entire area around the spinal cord.^{2,4,7,10,27,30,51,55,62} The nonanterior approaches may involve difficult or inadequate visualization or handling of the area anterior to the spinal cord, with an increased risk of injury and approach-related destabilization of the posterior structures.^{5,6} Anterior approaches allow sufficient and direct access to the anterior spinal canal but may lead to problems due to opening the thoracic and pleural cavities^{15,39,63} and may be more difficult due to anatomical or pathological conditions.^{15,39,63} In comparison with nonanterior approaches, anterior approaches also have negative aspects and likely are approach related (e.g., higher overall complication rates in the hospital, a higher mortality rate, longer hospital stays, and higher hospital costs).^{15,63} However, the complication rates for anterior approaches (11% to 26.8%) and nonanterior approaches (9.6% to 15%) have been assessed using different methods and uniform definitions are not used.^{1,15,37,63}

The rate of all complications in our study was 19%, that of serious complications was 5.8% (1 epidural hematoma with revision, 1 temporary deterioration of myelopathy for 5 weeks, and 1 persistent deterioration of myelopathy) and is thus as low as or lower than the rate reported in the literature.^{13,37,39,50,64} Due to the known risk of surgery-induced deterioration of a myelopathy, as was also the case in our patient collective, the most direct access route to the anterior epidural space may be required.^{37,39,64} The larger, more medial, or more calcified a disc herniation, the more likely it is that a lateral (transthoracic) approach should be considered. In this case, the use of neuromonitoring is also limited, as it has no advantages for decompression if there are already existing central neurological symptoms.⁵⁶ We therefore do not use neuromonitoring routinely for the pathologies described, even with conventional techniques. No other complications or problems requiring treatment associated in particular with a transthoracic technique that required treatment occurred. Overall, a low rate of complications or problems can be achieved with the full-endoscopic techniques; however, the validity is reduced by the cumulative numbers of cases and length of the operator's experience with the full-endoscopic technique for thoracic pathologies such as these.

In general, an attempt is made to achieve adequate results and reduce problems with minimally invasive modifi-

cations.^{21,30,41,53,59} Based on the clinical results and intraoperative findings, the full-endoscopic uniportal techniques achieve technically sufficient compression, and the results correspond with the clinical and radiological outcomes in published studies.^{37,39,50,64} These results are consistent with those of others' experiences with full-endoscopic operations of disc herniations and spinal canal stenosis in the cervical and lumbar spine.^{24,45} The combination of an angled field of view and freedom of movement of the endoscope using a joystick technique results in an adequate working area with all approaches. The duration of surgery is shorter than that of the methods described in the literature.^{13,39,50} The intraoperative blood loss is so low that it cannot be measured due to continuous irrigation, but it is also not considered to be problematic in other techniques.^{13,50} No surgery-related thoracic spine pain was observed immediately postoperatively or in the follow-up period. The hospital stay is comparatively short.⁵⁰ No recurrences were observed and are also not reported to be a frequent problem in the literature;^{37,50} however, this could be due to the fact that generally only medium-term follow-up periods have been reported. One specific intraoperative problem can be the adhesion of the pathology to the dura, which can involve the risk of injury to the dura.^{11,16,18,64} In 2 patients, an anterior dural leak was detected intraoperatively. These adhesions cannot always be removed endoscopically, so the described box-shaped resection at the posterior edge of the vertebral bodies as indirect decompression may sometimes be the only solution to prevent greater injuries to the dura. Such injuries cannot be sutured and, as in other full-endoscopic or conventional spine operations, can be covered (e.g., with a synthetic dural substitute and a fat flap).^{23,46,48} Lateral or posterior injuries of the dura can also be additionally sutured in a full-endoscopic technique.

The individual selection of the respective full-endoscopic approach enables different working areas to be used and makes it possible to reach the target area without manipulating the spinal cord. The interlaminar approach can be used for posterior pathologies or soft disc herniations that have posterior sequestration. Bilateral posterior decompression with an ipsilateral approach is possible in the over-the-top technique, which is also performed in the lumbar spine.²³ The extraforaminal approach is used for intra-/extraforaminal disc herniations and intraspinal mediolateral or medial disc herniations. Therefore, when the criteria are met, giant disc herniations can also be treated via an extraforaminal approach, as is also described in literature with other posterolateral approaches.^{5,7,35} The extraforaminal technique has the broadest range of indications for anterior pathologies and is also the method that we most often use. The transthoracic retropleural approach is used for anterior medial pathologies that cannot be treated using an extraforaminal approach. For anatomical reasons, the approach described here is possible only up to approximately T-5 in the cranial direction. In general, the comparatively high rate of problems associated with anterior approaches is reduced by a mini-thoracotomy or thoracoscope-assisted techniques.^{41,59} In addition, a retropleural approach can avoid the need for opening the pleural cavity and the problems associated with this. Because the pleura is preserved, the irrigation fluid remains

FIG. 6. Different approaches are necessary to be able to reach every area of the spinal canal without manipulating the spinal cord. Copyright Sebastian Ruetten. Published with permission. Figure is available in color online only.

in the operation field and ensures the advantages of the endoscopic technique under water. Retropleural dissection should thus be continued even if there is an approach-related tear of the pleura. Because it cannot be ruled out that irrigation fluid may leak into the pleural cavity if there is an unnoticed pleural injury, we think that it is useful to warm the irrigation fluid to body temperature because of the proximity to the central cardiovascular system. The lungs should therefore be ventilated after the approach has been made. If the pleura remains intact until the end of the operation, no pleural drainage is required.³⁰ Despite retropleural dissection, the indication should be established strictly if there have been previous thorax operations. If the transthoracic and extraforaminal approaches are considered equally suitable, we prefer the extraforaminal technique, as the setup and operation are simpler.

Overall, there are no clear standards in the literature with respect to the surgical technique. To minimize the risk of surgery-induced damage to the spinal cord, the approach must be individually adapted to the pathology.⁶ The same applies to the full-endoscopic techniques investigated here. While previous publications have included the surgical treatment of soft herniated discs with a transforaminal approach, usually in the form of case reports,^{8,9,31,58} the entire range of thoracic disc herniations and spinal canal stenoses can be covered within the criteria mentioned only using all full-endoscopic approaches from posterior to lateral (Fig. 6). The inclusion criteria described have proven to be a good guideline for selecting the approach; nevertheless, the surgical technique must be determined for every pathology on a case-by-case basis. If the inclusion criteria for a full-endoscopic technique are not met, decompression must always be performed using a conventional method. This applies especially in cases of

multisegmental pathologies, deformities, and instabilities or previous operations in the target segment. Conventional techniques can offer a more versatile working area and better-adapted work steps. Ultimately, the selection of the operative approach, whether conventional or full endoscopic, is a decision in which subjective parameters and experience also factor in.

The full-endoscopic uniportal technique under continuous irrigation has the proven technical advantages known from arthroscopies or other endoscopic spine operations, such as an enlarged visual field due to the 25° view angle, excellent illumination and visualization, reduced bleeding due to continuous irrigation, and low complication rates.^{23,43,44,46,48} For the operator, the uniportal technique with an angled field of view can be unfamiliar at first. The same applies to the 2D work at the monitor. One general disadvantage for endoscopic procedures is the steep learning curve,⁵⁷ which, however, can be overcome with new or modified techniques. It appears to be useful to initially learn full-endoscopic techniques in the lumbar spine. No other technical disadvantages were noted in the pathologies treated in this study.

The methodology limitations of the study involve the heterogeneity of the pathologies and symptoms treated and the different surgical approaches. After grouping the patients based on these parameters, the case numbers are small and thus also limit the interpretation of the results.

Additional stabilization is discussed but is usually recommended only if there is pronounced surgery-induced damage to posterior structures or resection of more than half of the vertebral body.^{12,32,33} We are not aware of relevant biomechanical data or results in the literature for the thoracic spine. Based on our results and the minimal trauma and destabilization using the full-endoscopic technique, we will also attempt in the future to perform decompression without primary additional stabilization.

Conclusions

Surgery for thoracic disc herniation and spinal canal stenosis is comparatively rare and often challenging. The goal is to achieve sufficient decompression without manipulating the spinal cord. Individual planning and various surgical techniques and approaches are required. The key factors for selecting the technique and approach are anatomical location, consistency of the pathology, general condition of the patient, and the surgeon's experience. The full-endoscopic uniportal technique with an interlaminar, extraforaminal, or transthoracic retropleural approach presented here is an alternative or complementary method that allows sufficient decompression, can minimize trauma, and has technical advantages and low complication rates. To cover the entire range of thoracic disc herniations and spinal canal stenosis within the criteria named, all full-endoscopic approaches are required. If the inclusion criteria are not met, decompression must be performed using a conventional method. Overall, there is only limited clinical and technical experience in literature due to the low incidence of the pathologies named and in addition because the inhomogeneous patient collective makes it difficult to form control groups.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Ruetten, Godolias, Komp. Acquisition of data: Oezdemir. Analysis and interpretation of data: Ruetten, Baraliakos, Merk. Drafting the article: Ruetten, Hahn, Baraliakos. Critically revising the article: Oezdemir, Komp. Reviewed submitted version of manuscript: Hahn, Merk, Komp. Approved the final version of the manuscript on behalf of all authors: Ruetten. Administrative/technical/material support: Hahn, Godolias. Study supervision: Ruetten, Oezdemir, Baraliakos, Komp.

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