



# Clinical outcomes of symptomatic thoracic disk herniations treated surgically through minimally invasive lateral transthoracic approach

Ismail Oltulu<sup>1</sup> · Hemra Cil<sup>1</sup> · Mustafa Onur Ulu<sup>2</sup> · Vedat Deviren<sup>1</sup>

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## Abstract

Although symptomatic thoracic disk herniation (TDH) is relatively rare, its treatment is quite difficult. Our aim is to present the outcomes and complications in patients with thoracic disk herniation treated with minimally invasive lateral transthoracic approach (LTTA). Fifty-nine consecutive patients with 69 symptomatic disk herniations that underwent minimally invasive LTTA to treat TDH between 2007 and 2016 were enrolled. Medical records were reviewed retrospectively. The numbers of TDH were as follows: 41 central, 10 paracentral, and 18 both central and paracentral. The number of calcified disk herniations was found to be 32. No patient developed neurological deficit. Postoperative neurological improvement occurred in 39 (90.7%) of 43 patients with myelopathy. Preoperative VAS scores, ODI scores, and SF-36 scores improved at the follow-up, respectively. Mean blood loss, hospitalization period, and follow-up period were found to be 391.2 mL, 4.7 days, and 60 months; respectively. The following complications were observed: dural tear (five patients), intercostal neuralgia (three patients), rib fracture (one patient), pleural effusion requiring chest tube (two patients), hydropneumothorax requiring chest tube (one patient), small pneumothorax (one patient), atelectasis (one patient), pulmonary embolism (one patient), and pneumonia (one patient). Minimally invasive LTTA not only minimizes the manipulation of the thecal sac decreasing the risk for neurological injury compared to traditional posterior methods but also significantly decreases the pulmonary complications associated with traditional open procedures. Based on the authors' experience, anterior approach should be preferred especially in calcified central disk herniations regardless of surgeon's experience.

**Keywords** Thoracic disk herniation · Minimally invasive approach · Extreme lateral interbody fusion · Surgery · Thoracic · Calcification

## Introduction

Thoracic disk herniations (TDH) are rarely symptomatic and generally incidentally diagnosed with MRI [1]. They rarely necessitate surgery when compared to cervical and lumbar disk herniations [2–4]. Recent studies using magnetic resonance imaging (MRI) and postmyelographic computed tomography (CT) scanning found the prevalence of TDH to be 11.1% to 14.5 [1, 5]. Diagnosis is frequently delayed until the onset of the myelopathy symptoms [6].

Surgical treatment is necessary for the patients with radiculopathy or myelopathy symptoms not responding to conservative treatment [7–9]. The ideal approach should allow safe and adequate decompression of the neural structures with the least possible morbidity. While posterior interlaminar or translaminar approaches are the standards for lumbar disk herniations, they are associated with significant morbidity and mortality in TDHs [10, 11]. This is secondary to the need to mobilize the dural sac in order to visualize and remove the disk herniation. Therefore, alternative approaches were described such as transthoracic (transternal) [12], transpleural [13], and retropleural [14] approaches; costotransversectomy [11]; lateral extracavitary [15] approaches; transpedicular [16] or transfacet pedicle-sparing [17] approaches; and thoracoscopic [18] approaches. Each approach has its unique advantages and complication profile [17, 19–21]. The authors adopted and gained experience with minimal invasive lateral transthoracic approach (LTTA) to treat TDH over the past 10 years. In the

✉ Vedat Deviren  
devirenv@orthosurg.ucsf.edu

<sup>1</sup> Department of Orthopaedic Surgery, University of California, 500 Parnassus Avenue, MU 320W, San Francisco, CA 94143-0728, USA

<sup>2</sup> Department of Neurosurgery, Cerrahpasa Medical Faculty, Istanbul University-Cerrahpasa, Istanbul, Turkey

current study, the authors report the clinical outcomes and perioperative complication profile of minimally invasive LTTA in a consecutive series of patients with TDH treated in a single institution by a single surgeon.

## Materials and methods

### Patient population and surgical indication

Following institutional ethical review board approval (IRB#16–20,405), a prospectively maintained database was reviewed to identify patients who had minimally invasive LTTA to treat TDH by the senior author between 2007 and 2016. Medical records were reviewed to collect demographic information, radiographic data, involved level, clinical presentation, estimated blood loss (EBL), operation time (OT), length of stay (LOS), perioperative and postoperative complications, and neurological and clinical course.

Indications for surgery were myelopathy/radiculopathy and/or persistent/chronic axial pain that failed to respond to the conservative treatment. Surgical contraindications were pulmonary disease and morbid obesity. Previous thoracotomy and TDH at T4 and upper levels were considered as relative contraindications.

### Perioperative imaging

All patients were evaluated preoperatively with MRI to assess cord and nerve root compression, X-ray to assess overall alignment, and presence of associated deformity and fine-cut CT to assess disk calcification. The level of TDH was preoperatively marked with a fiducial screw under CT guidance in all patients [22]. Postoperative imaging was performed only for the patients with persistent symptoms.

### Outcome analysis

All patients were evaluated at 1, 3, 6 months, 1 year, and annually thereafter. The functional outcomes were disability and pain based on the Oswestry Disability Index (ODI) [23] and visual analog scale (VAS). Clinical outcomes are measured preoperatively, immediate postoperative, and postoperatively in the follow-up visits with physical component summary (PCS) and the mental component summary (MCS) scores of the Short Form Health survey (SF-36) in all patients.

### Statistical analysis

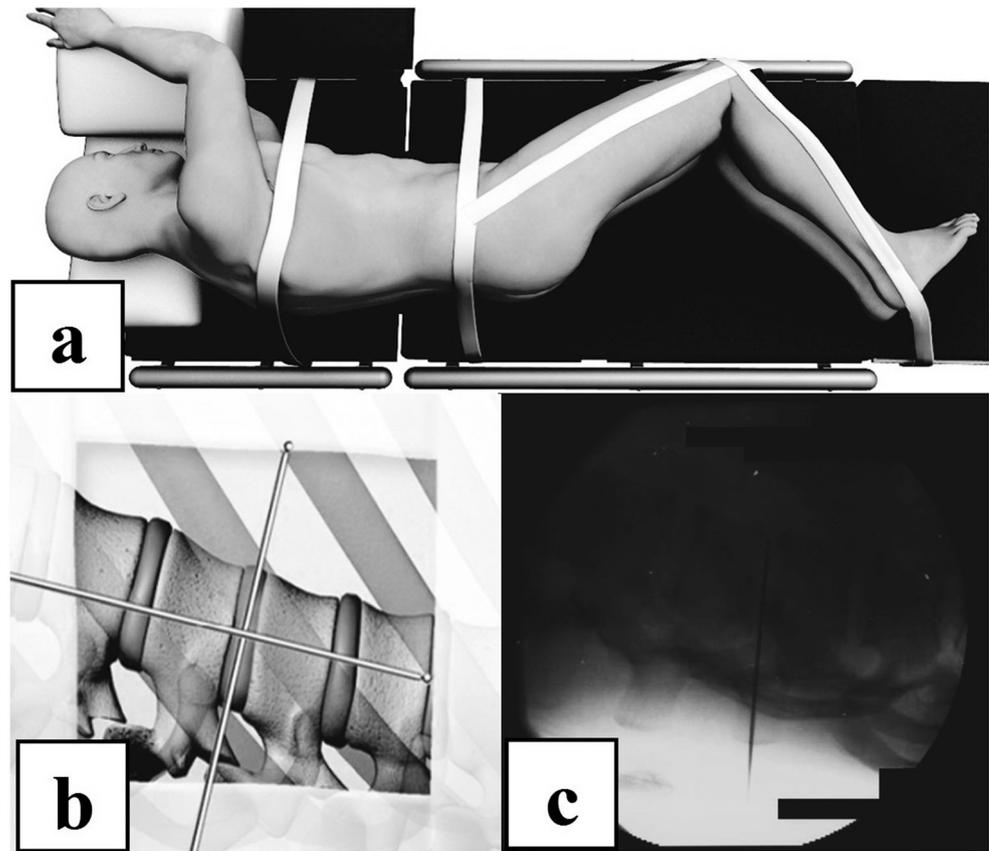
Number Cruncher Statistical System (NCSS) 2007 (Kaysville, UT, USA) program was used for the statistical analysis. Student's *t* test was used for the intergroup

comparisons of quantitative data with normal distribution, and Mann-Whitney *U* test was used for the intergroup comparisons of variables without normal distribution. Fisher-Freeman-Halton test, Fisher's exact test, and Yates-corrected chi-squared test were used for comparison of qualitative data. Significance was evaluated at the levels of  $p < 0.01$  and  $p < 0.05$ .

### Surgical technique

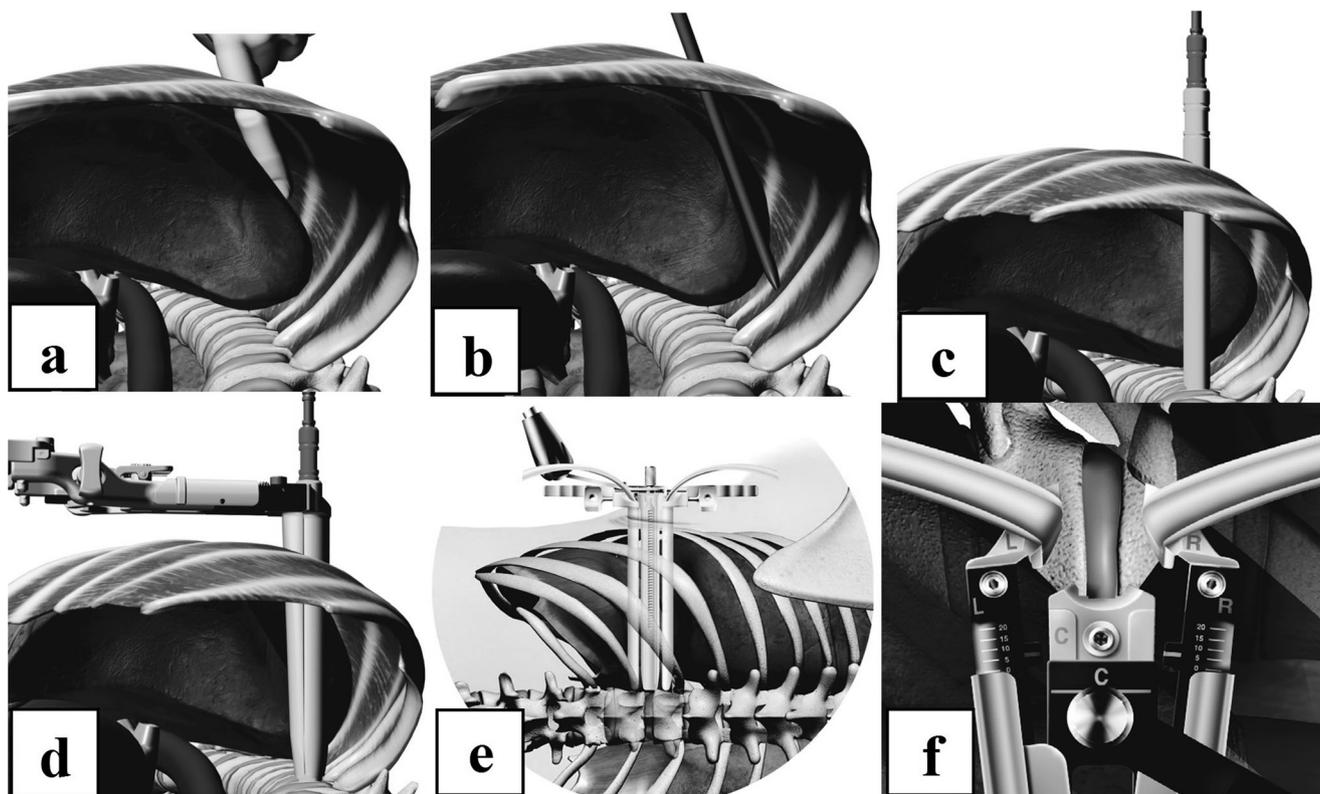
Minimally invasive LTTA has been described by Deviren et al. in 2011 [24]. Briefly, under general endotracheal anesthesia and neuromonitoring including the somatosensory and motor-evoked potentials, the patient is placed in a true 90° lateral decubitus position so that the affected level lies exactly at the break of the table (Fig. 1a). The herniations were approached from the side of the herniation. Left-sided approach was preferred by the senior author for central disks for minimizing the risk of thoracic duct injury and because the liver has an obscuring effect on right-sided approaches. Once the patient is secured with tape, the table is adjusted so that true anteroposterior images are obtained when the C-arm is horizontal and true lateral images are obtained when the C-arm is vertical. These real-time films should provide a three-dimensional picture, allowing the pedicles, endplates, and vertebral bodies to be aligned perfectly with the true orthogonal images. The table should be adjusted when accessing each level to maintain this relationship. It may be necessary to count vertebral levels multiple times from above and below the surgical level to ensure that the correct level is targeted, to confirm accuracy of the fiducial screw placement. When the correct level is aligned and identified, the junction between the posterior and middle thirds of the disk space is marked on the skin using C-arm fluoroscopy (Fig. 1b, c). Then, a lateral 3- to 5-cm oblique incision is centered over the mark which is perpendicular to a direct posterior approach. The subcutaneous tissue and the intercostal muscles are divided with electrocautery, and the thoracic cavity is entered through the superior edge of the rib that is overlying the disk space to avoid the neurovascular bundle that runs at the inferior edge of the rib above (Fig. 2a). For a single-level discectomy below T10, the rib-spreading technique is most commonly used. The standard technique involves dissection between the ribs, through the intercostal muscles, and down to the pleura. Pleural access is achieved by blunt hemostat dissection. In multilevel discectomies and/or in patients with herniations particularly above T10, a small portion of the rib (approximately 2 to 3 cm) can easily be resected at the beginning of the procedure for preventing rib fractures and for getting better exposure. The resected rib is saved for bone graft material. In a subset of patients, retropleural

**Fig. 1** **a** The patient is placed in a true 90° lateral decubitus position so that the affected level lies exactly at the break of the table. **b**, **c** When the correct level is aligned and identified, the junction between the posterior and middle thirds of the disk space is marked on the skin using C-arm fluoroscopy



approach was used where the parietal pleura was carefully deflected from the inner thoracic wall. During retropleural approach, parietal pleura keep the lung away from the surgical area and patients less likely require the chest tube. Once the dissection reaches to the level of the lateral aspect of the vertebral column, access is established by inserting an initial dilator directed posteriorly along the interior chest wall and docking it, stopping at the junction of the rib head and vertebral body of the affected level (Fig. 2b, c). A cross-table antero-posterior image should confirm that the dilator is positioned on, and in the plane of, the disk space of the affected level. Depth markings on the dilator indicate the size of the appropriate length of the blades to be attached to the retractor (MaXcess©, NuVasive, Inc., San Diego, CA, USA). Then the retractor is introduced into the thoracic cavity and opened so the surgeon can visualize the pertinent anatomy (Fig. 2d–f). In case of transpleural approach, the parietal pleura is incised longitudinally and dissected. The rib head overlying the posterolateral corner of the disk is identified and osteotomized (Fig. 3a), which helps identify the posterolateral corner of the disk and the vertebral body (Fig. 3b). Care should be taken not to damage the structures deep to the contralateral annulus, as indicated on the preoperative MRIs. Pituitaries, curettes, disk

cutters, endplate scrapers, and other disk preparation instruments can be used to thoroughly evacuate the disk and prepare the endplates for fusion. The anterior and posterior annuli are left intact. Then, the posteroinferior corner of the vertebra above and the posterosuperior corner of the vertebra below are excised in a wedge-shaped cut with a straight osteotome to facilitate decompression (Fig. 3c, d). This was carried out in a piecemeal manner with small cuts until the posterior longitudinal ligament (PLL) was fully exposed. The osteotome is used for wedge cut to preserve the local bone to be used as a bone graft during the anterior fusion. A high-speed burr can also be used to facilitate bone resection. Following the discectomy, the posterior border of the posterior annulus and PLL are dissected off the dura using a Penfield dissector and the decompression is extended to the level of the contralateral pedicle. In all of the patients in this series, we performed interbody fusion using polyetheretherketone cages (CoRoent©, NuVasive, Inc., San Diego, CA, USA) with supplemental internal fixation using either a screw-rod construct or a plate (Fig. 3e, f). A pigtail drain was routinely placed when the pleural cavity was entered and removed on postoperative day 1 or 2, depending on the output. No drains were placed in a subset of patients treated with a retropleural approach. All patients are



**Fig. 2** **a** The subcutaneous tissue and the intercostal muscles are divided with electrocautery, and the thoracic cavity is entered through the superior edge of the rib that is overlying the disk space to avoid the neurovascular bundle that runs at the inferior edge of the rib above. **b, c** Once the dissection reaches to the level of the lateral aspect of the vertebral column, access is established by inserting an initial dilator and the disk

level is again confirmed by fluoroscopy. **d–f** Then, the retractor (MaXcess©, NuVasive, Inc., San Diego, CA, USA) is introduced into the thoracic cavity and opened so the surgeon can visualize the pertinent anatomy depth markings on the dilator indicate the size of the appropriate length of the blades to be attached to the retractor

braced with a thoracolumbosacral orthosis for 6 weeks before they are allowed to move as tolerated. A demonstrative case of T9–10 XLIF is shown in Fig. 4.

## Results

Fifty-nine patients with 69 thoracic disk herniation were operated at tertiary, academic spine center between February 2007 and 2016 by using minimally invasive LTTA by senior author.

### Demographic and perioperative data

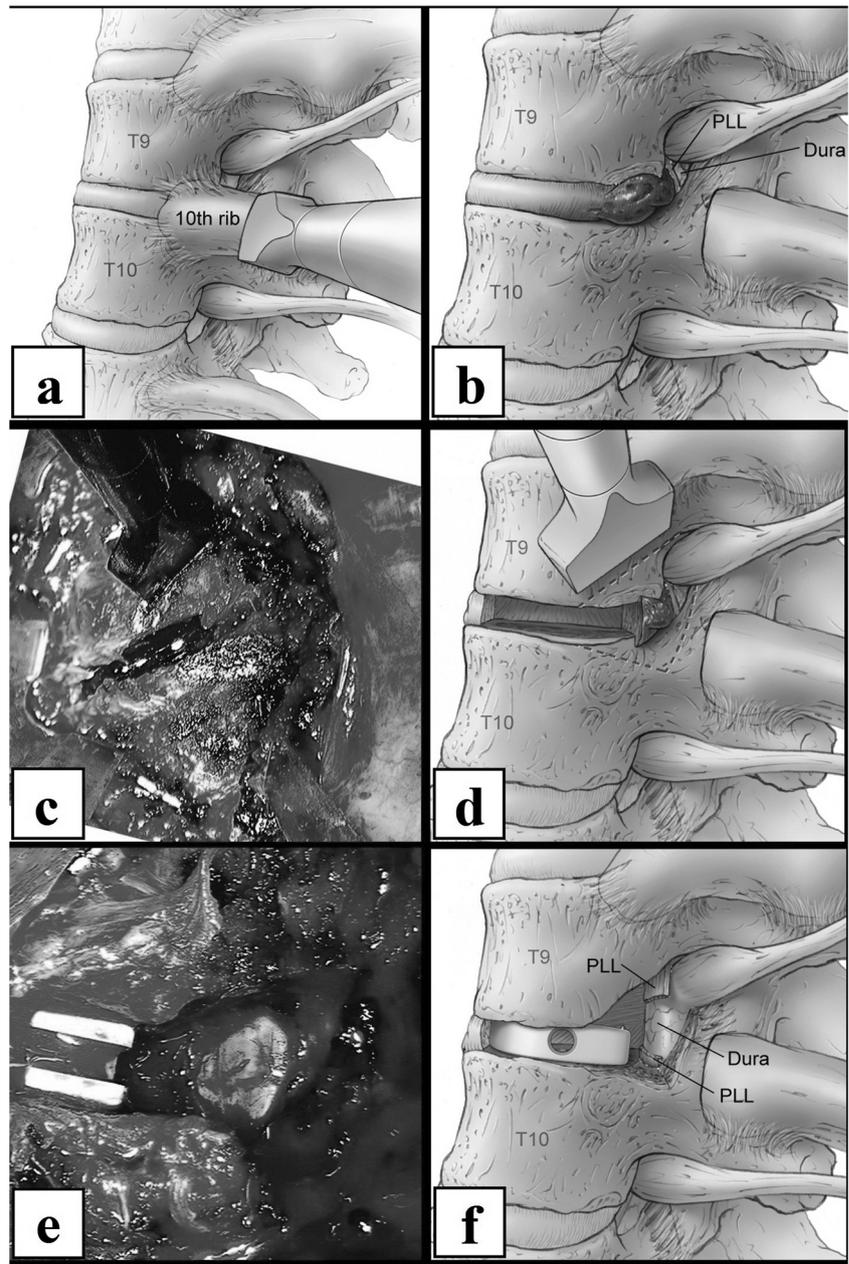
The demographic and perioperative data are summarized in Tables 1 and 2. The most common presentation was axial back pain (54 patients [91.5%]), followed by radiculopathy (48 patients [81.4%]), myelopathy (43 patients [72.9%]), and 21 (35.6%) patients had bladder and/or bowel dysfunction. Sixty-nine disk levels were treated. There were 51 single-level cases, six two-level cases, and two three-level cases. Calcification was present in 32 (46.4%) of disks. The average OT was

168 min (range 71–298 min), and the average EBL was 391 mL (range 50–2,000 mL). The mean LOS was 4.7 days (range 1–14 days). The average follow-up was 60.08 months (range 6–119). An illustrative case was presented in Fig. 1.

### Clinical outcomes

Among 43 (72.9%) patients who had myelopathy findings, 39 (90.7%) had improved postoperatively. The mean preoperative VAS of 7.7 (range 3–10) improved to 4.3 (range 0–10) at final follow-up ( $p < 0.05$ ). The mean preoperative ODI score of 51.1 (range 18–88) improved to 39.3 (range 0–84) at final follow-up ( $p < 0.05$ ). The mean preoperative SF-36 PCS scores improved from 29.4 (range 14.6–41.4) to 41.1 (range 16.4–52.4) at final follow-up, and the mean preoperative SF-36 MCS scores improved from 40.8 (range 12.4–71.8) to 53.7 (range 36.7–68.6) at final follow-up ( $p < 0.05$ ). When compared to the SF-36 PCS and SF-36 MCS values of (age and sex matched) normal healthy US population [25], the MCS values did not differ significantly ( $p > 0.05$ ); however, PCS measurements were found to be lower than normal population ( $p < 0.05$ ).

**Fig. 3** T9–10 XLIF procedure. **a** The rib head overlying the posterolateral corner of the disk is identified and osteotomized, **b** which helps identify the posterolateral corner of the disk and the vertebral body. **c, d** Then, the discectomy is performed using pituitaries, curettes, disk cutters, endplate scrapers, and other disk preparation instruments. The posteroinferior corner of the vertebra above and the posterosuperior corner of the vertebra below are excised in a wedge-shaped cut with a straight osteotome to facilitate decompression. **e, f** Then, a polyetheretherketone XLIF cage (CoRoent©, NuVasive, Inc., San Diego, CA, USA) is inserted for achieving interbody fusion. PLL posterior longitudinal ligament



## Complications

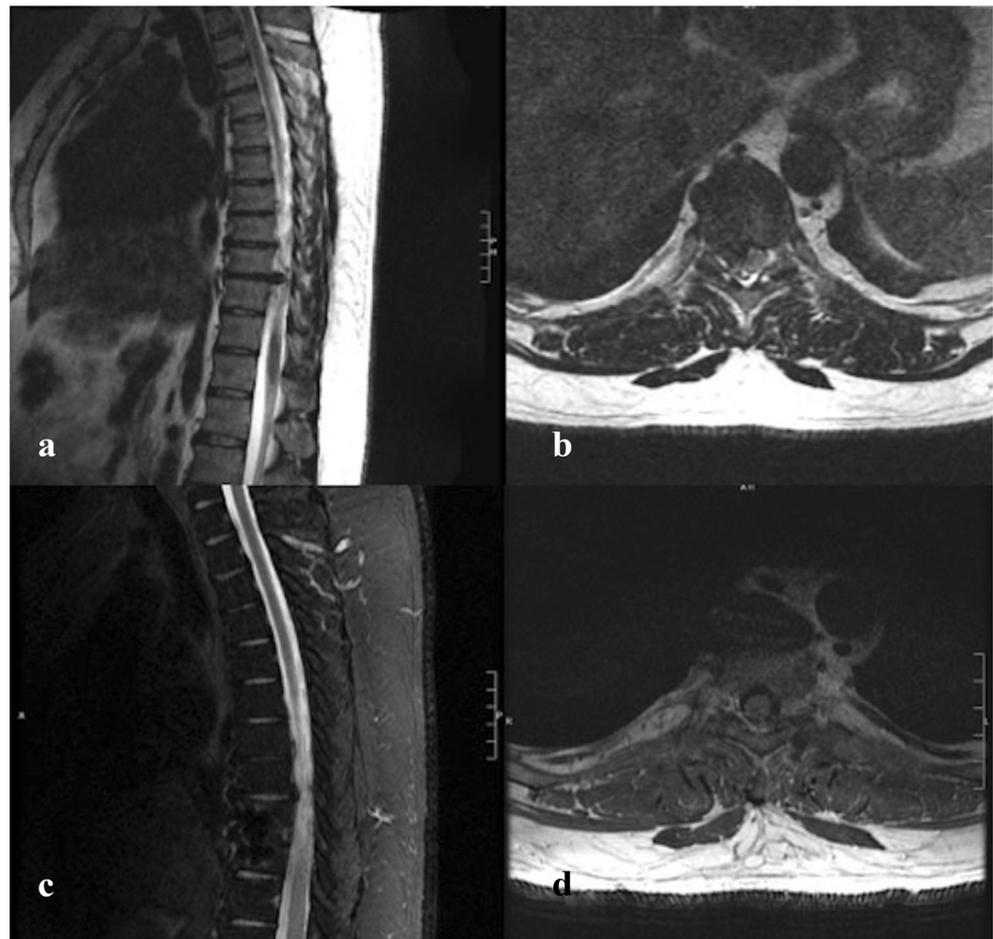
The complications are shown in Table 3. The authors defined a major complication as any conditions necessitating reoperation or which might cause significant morbidity and mortality in the patients. None of the patients developed neurological complication. Major complication was observed in three patients. All patients with major complications healed uneventfully. One patient was diagnosed with pseudoarthrosis at 37 months follow-up and underwent posterior fusion. Seventeen minor complications were observed. All patients with major complications healed uneventfully. Dural tear was

the most minor complication and were repaired successfully with primary suture and sealed with myofascial autograft.

## Discussion

The debate on the ideal approach to treat TDH is ongoing. Posterior approaches require significant manipulation of the thecal sac and the spinal cord to reach central disk herniation resulting in high complication rates. On the other hand, anterior approaches have the direct line of sight of the pathology and allow removal of the disk material with minimal

**Fig. 4** A 39-year-old male with back pain and progressive lower extremity weakness (right > left) **a** Preoperative sagittal MR images show large disk herniation at T9/10 with displacement of the spinal cord. **b** Preoperative axial MR images show large right-sided disk herniation at T9/10 with displacement of the spinal cord. **c** Postoperative sagittal MR images after right T9–10 XLIF. **d** Postoperative axial MR images. Estimated blood loss was 250 mL, operation time was 173 min, and LOS was 3 days



**Table 1** Demographic data of the patients who had mini lateral transthoracic approach (LTTA) ( $n = 59$ )

	Number of patients (percentages)
Mean age in years (range)	55.9 (range 23–84)
Male gender	35 (59.3%)
Body mass index (range)	30.8 (range 18.3–42.5)
Comorbidities	
Hypertension	22 (37.3%)
Diabetes mellitus	10 (16.9%)
Obesity	31 (52.5%)
Cardiac disease	11 (18.6%)
Level of herniated disk	
T5–6	2 (2.9%)
T6–7	7 (10.1%)
T7–8	14 (20.3%)
T8–9	7 (10.1%)
T9–10	8 (11.6%)
T10–11	11 (15.9%)
T11–12	13 (18.8%)
T12–L1	7 (10.1%)

manipulation of the thecal sac. An important limitation of the anterior approaches, however, is the unfamiliar territory for the surgeons to operate in the thoracic cavity as well as associated pulmonary complications. Newer, minimally invasive LTTA have a faster learning curve and decrease the pulmonary complications. In 2013, Nacar et al. reported that minimally invasive LTTA is a safe and efficacious technique for achieving adequate decompression in TDH in a less invasive manner than conventional approaches [26]. Current study reports the experience of a single surgeon with minimally invasive anterior thoracic discectomy over a 10-year period, and shows that

**Table 2** Perioperative data

	Number of patients (percentage)
Location of disk herniation	
Central disk	41 (59.4%)*
Paracentral	10 (14.5%)**
Central and paracentral	18 (26.1%)†
Disk calcification	32 (46.4%)

\*16 disk calcification, \*\*6 disk calcification, †10 disk calcification

**Table 3** Postoperative complications after mini lateral transthoracic approach (LTTA) ( $n = 69$ )

	Number of patients (percentage)
<b>Major complications</b>	
Neurological deterioration	0
Pulmonary embolism	1 (1.7%)
Pseudoarthrosis	1 (1.7%)
Pneumonia	1 (1.7%)
<b>Minor complications</b>	
Dural tear	5 (8.5%)
Pleural effusion	2 (3.4%)
Pneumothorax	1 (1.7%)
Atelectasis	1 (1.7%)
Ileus	2 (3.4%)
Urinary retention	1 (1.7%)
Intercostal neuralgia	3 (5.1%)
Rip fracture	1 (1.7%)

it is associated with very few pulmonary complications and no neurologic complications.

Conservative treatment is the rule for the majority of TDH, and surgical treatment is considered when there are radiculopathy and/or myelopathy symptoms not responding to conservative treatment [19, 27–29]. In this study, axial back pain was seen in 54 patients (91.5%), radiculopathy symptoms in 48 patients (81.4%), and myelopathy symptoms in 43 patients (72.9%). When a patient is considered for surgical intervention to treat TDH, they always have neurologic symptoms (myelopathy and/or radiculopathy); hence, decompression of the neural elements is the main goal. Therefore, the most important point that should be considered while selecting surgical approach is to select the approach that enables a successful decompression with minimum manipulation of the spinal cord. Unlike the cervical and lumbar spine, thoracic spine is naturally kyphotic, which is a disadvantage for the indirect decompression efforts via laminectomy when the pathology is anterior. Due to this natural alignment, the cord will not translate away from the pathology with a posterior approach; therefore, adequate decompression of the neural elements requires removal of the anterior compressive pathology. Unfortunately, the spinal cord is fixed in position with the dentate ligaments in the thoracic spine. Besides, it is draped over the anterior compressive pathology leaving almost no room to access the pathology through a posterior approach. Approaches as costotransversectomy and lateral extracavitary were developed to overcome these disadvantages and provide better anterolateral exposure; but they are still unable to visualize especially contralateral region and ventral thecal sac optimally [11, 15, 30]. Therefore, posterolateral approaches have risk for neurological injury or dural tear due to manipulation of the thecal sac [31, 32] This is

especially important in the setting of a calcified central TDH, where the disk is frequently adhered to the dura, and inadvertent dural tears may happen, which would be even more challenging to address from the back. On the other hand, anterior approach provides the best visualization of the lesion and it not only allows efficient decompression, and should be used as it is in cervical disk herniations, but also provides an easier intervention in the case of complications such as dural tear and hemorrhage which may occur [13, 33–36]. However, anterior approaches necessitate entry into of the thoracic cavity which is an unfamiliar territory for the spine surgeons, and there are complications directly associated with the intervention such as intercostal neuralgia and pulmonary complications. There are several variations of this approach. Open thoracotomy may necessitate a thoracic surgeon's assistance for the exposure as well as a bigger incision and associated morbidity. The ipsilateral lung is frequently deflated during the procedure, which could be a contributing factor to atelectasis. Thoracoscopic approaches provided similar results to the open procedures, with less bleeding, less morbidity associated with the approach and rapid recovery. Thoracoscopy also has some disadvantages including long learning curve, occasional need for conversion to the open procedures, visualization difficulties (2D vs 3D), instrumentation mobility limitations, and single-lung intubation [37–39]. The minimally invasive LTTA technique has been described by Deviren et al. in 2011 in a series of 12 patients harboring single-level TDHs [24]. This is a technique between classical open thoracotomy and thoracoscopic intervention combining advantages of both techniques. It does not require single-lung intubation in addition to providing sufficient working space and direct visualization of the surgical field [24], hence limiting the pulmonary complications without compromising visualization of the pathology. Short learning curve is another advantage of the approach compared to mini LTTA thoracoscopic methods. Difficulty in performing procedure above the T4 level is its disadvantage. Due to scapula and the muscles attaching to the surface of the scapula, it is quite difficult to perform approach at these levels. While thoracic disk herniation is rarely seen at these levels, the authors recommend the use of the other approaches.

Current study reported improvement of myelopathy symptoms in 91% of the patients that compares favorably with the thoracoscopy. Elhadi et al. performed a systematic review compiling data from 12 studies including 545 patients undergoing thoracic discectomy using minimal invasive methods, and reported symptom improvement in 79.5% of the patients, no change in 9.5% of them, and worsening in 11% of them [40]. Current study also reported significant improvement in the ODI and SF-36 scores with the minimal invasive lateral approach. The literature reviews of invasive and open approaches for the surgical management of TDH are summarized in Table 4.

**Table 4** Literature review of minimal invasive and open approaches for the surgical management of thoracic disk herniation

Authors and year	Type of approach	Number of patients	Follow-up (months)	ORT in minutes (range)	EBL in mL (range)	LOS in days (range)	Percent of total complications
Johnson et al. (2000)	Endoscopic thoracoscopy	36	–	212 (102–384)	225 (100–600)	3.1 (1–21)	31.0
Bartels & Peul (2007)	Endoscopic thoracoscopy	7	13.2	315	365	13 ± 13	57.1
Anand et al. (2002)	VATS	100	48	172 (80–300)	261 (50–2500)	4 (1–11)	21
Oskuian & Johnson (2005)	VATS	46	12	216 (102–384)	227 (100–600)	3.1 (1–21)	43.5
Quint et al. (2012)	Thoracoscopic discectomy	167	24	–	–	–	15.6
Wait et al. (2012)	Thoracoscopic discectomy	121	29	–	310 (50–2300)	4.8 (1–22)	–
Rosenthal & Dickman (1999)	Open TT	18	–	268 (210–690)	683 (250–1200)	16.2 (5–34)	111.0
Machino et al. (2010)	Open TT	8	–	184	539	–	13.0
Ayhan et al. (2010)	Open TT	27	12	–	605 (50–1500)	7 (3–15)	40.7
Khoo et al. (2011)	Open TT	11	12	175	295	5.3	182
Bartels & Peul (2007)	Mini TTA	21	–	222	732	6	9.5
Moran et al. (2012)	Mini TTA	17	–	–	–	5.5	–
Arts et al. (2014)	Mini TTA	56	49 ± 25	229 (90–510)	1157 (100–12,000)	10.1 (3–70)	38
Current study	Mini LTTA	59	60.08 (6–119)	168 (71–298)	391 (50–2000)	4.7 (1–14)	34

ORT operation room time, EBL estimated blood loss, LOS length of stay, VATS video-assisted thoracoscopic surgery, TT transthoracic, LTTA lateral transthoracic approach

Pulmonary complications are other complications reported in anterior and lateral approaches. Pulmonary complication was observed in six (10.2%) of our patients. While our pulmonary complication rates were very low compared to open thoracotomies, they were found to be consistent with previous reports of minimal invasive thoracotomies [14, 27, 28, 35, 37, 41–44]. Current results also compared favorably with thoracoscopy where the rate of atelectasis and pleural effusion was 2.8% and 2.6%, respectively. The authors attributed low rates of pulmonary complications in this series to the avoidance of single lung intubation by the approach. The patients following the first 25 cases were treated by using retropleural approach. However, pleura could still be damaged during the procedure when small-bore “pigtail” catheters were used instead of large-bore chest tubes as it was in conventional thoracotomies. The authors observed only one small pneumothorax with this approach. Moran et al. reported pleural tears in 5 of 17 patients treated by using mini-open retropleural transthoracic approach and only one of them required the placement of a chest tube. They also implemented early mobilization in patients who did not need chest tube which decreased the LOS in hospital [45].

Intercostal neuralgia was seen in three patients (5.1%) in the current study, which is similar to other minimal invasive thoracic discectomy approaches, where it is reported as the most common complication (6%). Quint et al. also confirmed intercostal neuralgia as the most common complication in 167 patients treated using thoracoscopic technique. Quint attributed the lower rate of intercostal neuralgia to the use of the soft trocar and immediate postoperative administration of cortisone and local anesthetic into the wound [46]. Intercostal neuralgia was shown to be significantly higher in patients undergoing thoracic discectomy using open surgery with a rate ranging from 4.3 to 50% [30, 47, 48]. In general, incisional

pain complications in the current study were found to be at the same rates with previously reported minimal invasive approaches; however, intercostal neuralgia remains among disadvantages of this intervention.

Dural tear was observed as the most common complication in five patients (8.5%) in the current study. Strom reported dural tear in seven (11%) patients [49]. Arts reported that cerebrospinal fluid leakage developed in 10 (18%) of 56 patients treated with mini transthoracic approach but this complication was not observed in patients treated with transpedicular approach. This difference was attributed to the large number and volume of calcified disks of the patients treated in mini transthoracic group and less number and small volume of calcified disks of the patients in posterolateral group [29]. In the authors’ opinion, dural tear occurs with a higher rate in association with posterior approaches during removal of these calcified disks impinging on the anterior aspect of the thecal sac, in which case, not only the repair of tear on the ventral aspect will be impossible but also the risk for neurological deterioration will increase. Central calcified disk was also more commonly observed in patients (four out of five) who had dural tears in the current study. All dural tears healed uneventfully after primary repair, and neurological deterioration did not develop in any of the patients in the current series, which is in line with very low rates of neurological deterioration in the patients operated by using mini transthoracic approach in the literature [28, 45, 50, 51].

Fusion is another controversial subject in the treatment of symptomatic TDH. Fusion was performed in all patients in the current series. The authors do not perform routine imaging method to assess the fusion in the postoperative period, as it is quite difficult to assess the fusion on X-ray and CT is associated with higher levels of radiation exposure. In addition, since the success of decompression can be evaluated very

clearly during the surgery, the authors do not perform routine imaging to assess whether there is residual disk material or not. While some authors reported using routine imaging methods during postoperative period [19, 52], in author's own practice the use of imaging methods was reserved only in symptomatic patients. Pseudoarthrosis was determined in one patient and it was treated successfully with posterior fusion.

The limitations of the current study are its retrospective design and absence of control group. However, currently, there is no randomized prospective study comparing different approaches. The authors think that such a study cannot be performed due to limited number of patients requiring surgery, variability of the surgical method depending on the surgeon's experience, and preference of especially anterior surgical approaches in central calcified disks.

## Conclusion

This study reports a consecutive series of patients with thoracic disc herniation who were treated with minimally invasive LTTA in a single institution by a single surgeon. This technique not only minimizes the manipulation of the thecal sac and decreases the risk for neurological injury greatly compared to the posterior methods but also significantly decreased the pulmonary complications associated with traditional open procedures. Based on the authors' experience, anterior approach should be preferred especially in calcified central TDH regardless of surgeon's experience.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** UCSF Institutional ethical review board approval (IRB#16–20,405) was received before the study. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Consent** For this type of study, formal consent is not required.

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