Endoscopic thoracic discectomy

J. PATRICK JOHNSON M.D., AARON G. FILLER, M.D., AND DUNCAN Q. MC BRIDE, M.D.

Division of Neurosurgery, School of Medicine, University of California at Los Angeles, California

Object. Thoracoscopic discectomy is a minimally invasive procedure simulating a thoracotomy and is an alternative to the costotransversectomy and transpedicular approaches. In recent studies authors have concluded that thoracoscopic discectomy is the preferred procedure; however, relative historical comparisons were difficult to interpret.

The authors conducted a prospective nonrandomized study in which they compared data on 36 patients undergoing thoracoscopic discectomy with eight patients undergoing thoracotomy between 1995 and 1999.

Methods. Patients affected with one- or two-level lesions underwent a thoracoscopic discectomy, and patients with three-level lesions or more underwent thoracotomy and discectomy. Data were collected on operative time, blood loss, chest tube duration, narcotic agent use, and hospital length of stay (LOS). Longer-term follow-up study of pain-related symptoms and neurological function was conducted.

Patients who underwent thoracoscopic discectomy had shorter operative times, less blood loss, a shorter period of chest tube drainage dependence, less narcotic usage, and a shorter LOS. These findings were statistically significant ($p < 0.05$) for narcotic usage and shorter LOS. Pain related to radiculopathy was improved by means of 75%, and no patients exprienced worsened pain. In patients with myelopathy there was an improvement of two Frankel grades in the thoracoscopic group and one Frankel grade in the thoracotomy discectomy group, but patients in the thoracotomy group were significantly worse preoperatively. One myelopathic patient from each group suffered a worsened outcome postoperatively, although this was not attributed to the method of surgery. The incidence of complications (minor and major) was 31% in the thoracoscopic group and greater than 100% (that is, more than one complication per patient) in the thoracotomy/discectomy group.

Conclusions. One advantage to thoracoscopic discectomy is its reduced incidence of morbidity compared with thoractomy, but its steep learning curve and unfamiliar surgical techniques make this procedure less practical for surgeons not performing it frequently. The more familiar costotransversectomy, transpedicular, and thoracotomy procedures remain viable alternatives for surgeons more experienced in these procedures.

KEY WORDS: • thoracic spine • thoracoscopy • endoscopy • thoracotomy • disc herniation.

The management of thoracic disc disease has evolved over several decades as these ventral lesions have required specialized surgical techniques and are difficult to reach.[1,7–9,13,14,17,20,28,31–33] Thoracotomy has been the accepted standard procedure, providing an optimum ventral exposure.[2,3,5,10,25,26] Alternatively, the costotransversectomy and transpedicular techniques provide a posterolateral exposure by which the surgeon can avoid opening the chest; direct visualization of the ventral spinal cord is not possible.[12,18,19,22,24,34,35] These maximally invasive procedures have provided impetus for the development of minimally invasive thoracoscopic techniques. The literature regarding thoracoscopic disc surgery, however, has not clearly established the procedure's efficacy, indications, or limitations.

Abbreviations used in this paper: LOS = length of hospital stay; MR = magnetic resonance; OPLL = ossification of the posterior longitudinal legament

CLINICAL MATERIAL AND METHODS

The clinical presentation, patient selection process, surgical techniques, outcomes, and complications of patients with symptomatic thoracic disc lesions were reviewed. Patients underwent either a thoracoscopic discectomy or an open thoracotomy and discectomy procedure. The study was conducted in a prospective nonrandomized manner.

Patient Demographics

Patients were treated between 1995 and 1999 for thoracic disc lesions that included soft and calcified disc herniations, OPLL, and discitis. Thirty-six patients underwent thoracoscopic discectomy, and eight patients underwent open thoracotomy and discectomy. The age and sex distribution were similar for both groups (thoracoscopy group: mean age 54.5 years [range 27–77 years], 17 men and 19 women; open thoracotomy group: mean age 50.7 years [range 26–62 years], three men and five women). In

TABLE 1

Number of thoracic levels affected and treated and type of disc lesion in two groups of patients

Characteristic	Thoracoscopic Discectomy	Open Thoracotomy/ Discectomy
level of lesion		
T3–4	0	2
T4–5	0	2
T5–6	9	4
T6–7	15	7
T7–8	2	5
T8–9	6	6
T9–10	6	4
T10–11	0	3
T11–12	6	1
no. of operated levels		
one	30	1
two	6	0
three	0	4
four	0	2
five	0	1
mean	1.2	4.5
type of lesion		
soft disc herniation	18	0
calcified disc herniation (or OPLL)	15	8
discitis	3	0

the 36 thoracoscopy group patients, there were 44 affected vertebral levels, and in the eight thoracotomy group patients, there were 36 affected levels (Table 1). Whereas 17 patients in the thoracoscopy group presented with radicular pain, no patient in the thoracotomy group presented with this symptom. Nineteen patients in the former group presented with myelopathy, and all eight patients in the latter group presented with myelopathy. In the thoracoscopy group the radicular symptoms had persisted for a mean of 12.6 months (range 2–60 months). Myelopathy had persisted for a mean of 8.3 months (range 2–34 months) in the thoracoscopy group and a mean of 14.2 months (range 2–48 months) in the thoracotomy group.

Selection for Thoracoscopic Discectomy or Open Thoracotomy

Patient selection was based on the number of spinal levels involved, the complexity of the lesions, previous transthoracic disc surgery, and the presence of OPLL.

All patients with one- or two-level thoracic disc herniations (33 patients) were treated with a thoracoscopic discectomy. The presenting symptoms or type of lesion (soft or calcified disc lesions) were not factors in the selection. There were three patients in whom a clinical diagnosis of discitis was made who underwent discectomy and in whom a biopsy specimen was obtained to debride the disc space.

Of those selected for thoracotomy, there were three patients with multilevel (three or more levels) thoracic disc herniation, and four patients with multi-segment OPLL. One patient underwent a thoracoscopic discectomy 6 months previously but suffered a recurrent disc herniation requiring surgery. Thoracoscopic reexploration was converted to an open thoracotomy because of dense adhesions

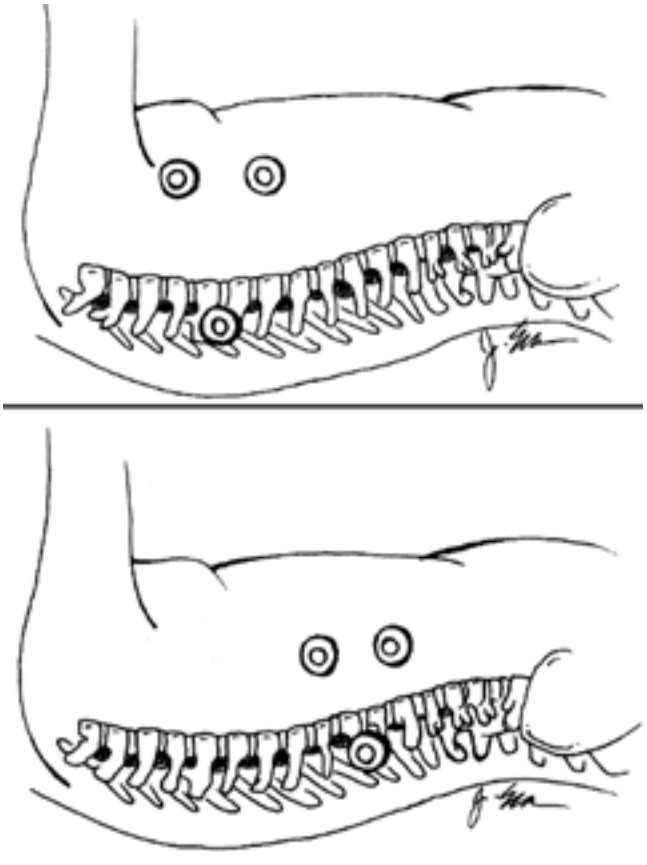

Fig. 1. Illustrations showing the locations of port placement for a T5–6 herniated disc *(upper)* and a T10–11 herniated disc *(lower)*.

at the site of the dura and disc interface that could not be safely dissected.

Thoracoscopic Surgical Techniques

Thoracoscopic procedures are well described in the literature.[7,9,15,21,27,29–32] The procedures require induction of general anesthesia, and the placement of a double-lumen endotracheal tube allows collapse of the ipsilateral lung to perform the procedure within the empty chest cavity while the contralateral lung is ventilated. The patient is placed in a lateral decubitus position so that the ventilated lung hangs down and provides exposure to the ipsilateral thoracic cavity. In our cases standard anesthetic and monitoring techniques for thoracic endoscopic procedures were used. The patient is prepared for a thoracotomy in the event that conversion to this procedure is needed.

A plain anteroposterior radiograph is obtained after a marker is positioned on the chest wall to determine the precise placement level of the endoscopic ports (Fig. 1). Three endoscopic port sites are required: one in the posterior axillary line and two in the anterior axillary line.

Techniques for Thoracic Discectomy. The endoscope is usually inserted into the posterior axillary line portal, and the instruments are placed in the two ports in the anterior axillary line. The lung is retracted and may require coagulation and lysis of any adhesions to the parietal pleura. Additional retraction of the lung can be accomplished

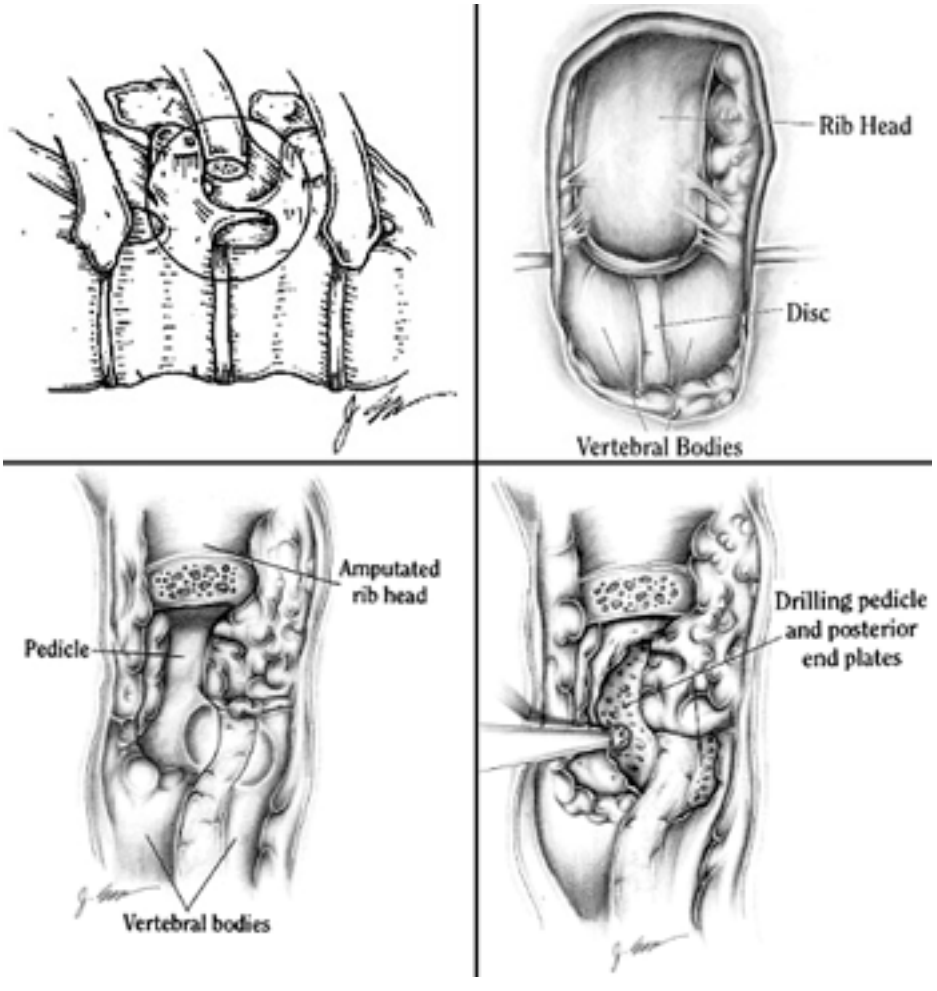

Fig. 2. *Upper Left:* Lateral, right-side view of the thoracic spine. *Circled area* is the region magnified in Fig. 2 *upper right* through Fig. 4 *left*. *Upper Right:* Illustration of a rib head and adjacent disc space with the pleura already opened. *Lower Left:* Illustration of rib head removed showing the underlying pedicle and disc. *Lower Right:* Illustration of pedicle and endplates being drilled beneath spinal canal.

manually by rotation of the operating table to allow the lung to fall forward away from the vertebral column. Localization of the vertebral level is confirmed with an anteroposterior radiograph obtained while a Steinmann pin is inserted into the disc space. The adjacent segmental vessels are usually not divided, as they are located in the mid-portion of the vertebral body. Nevertheless, they can be mobilized and divided if necessary. The parietal pleura is opened widely over the rib head and over the disc space (Fig. 2 *upper left* and *right*). The proximal end of the rib and the disc space are colinear and help to orient the surgeon during the procedure. The proximal 2 cm of the rib is removed using a high-speed drill to expose the lateral surface of the pedicle and neural foramen (Fig 2 *lower left* and *right*). The neural foramen contains epidural fat and is relatively small with the segmental nerve and vessels traversing. The dura matter of the spinal cord is then exposed by removing the pedicle with a high-speed drill which also orients the surgeon during the remainder of the procedure. A round cutting bit (5 mm diameter) is typically used for drilling the bone.

The drilling of the vertebral body is the most critical stage of the procedure: there is the potential for injuring the patient while achieving adequate bone removal to decompress the spinal canal. The decompression requires drilling across the posterior aspect of the disc space and adjacent endplates, which essentially undermines the floor of the spinal canal and creates a tunnel (Fig. 3 *left*). The cortical bone on the ventral aspect of the spinal canal should remain intact until the drilling is completed, as it protects the spinal cord. Bleeding derived from the cancellous bone beneath the endplates can obscure visualization, and hemostasis during every stage of the procedure is essential. Bone wax applied with an endoscopic cotton-tip applicator will effectively control this bleeding. The drilling can be extended to the contralateral pedicle and verified by obtaining an intraoperative radiograph. A disc fragment that has migrated either cephalad or caudally requires additional drilling, which will adequately undermine the spinal canal for complete decompression. Once the drilling is completed, the floor of the spinal canal is then removed using small Kerrison rongeurs or sharp curettage, beginning at the site where the pedicle was initially removed. This often requires pulling soft disc mate-

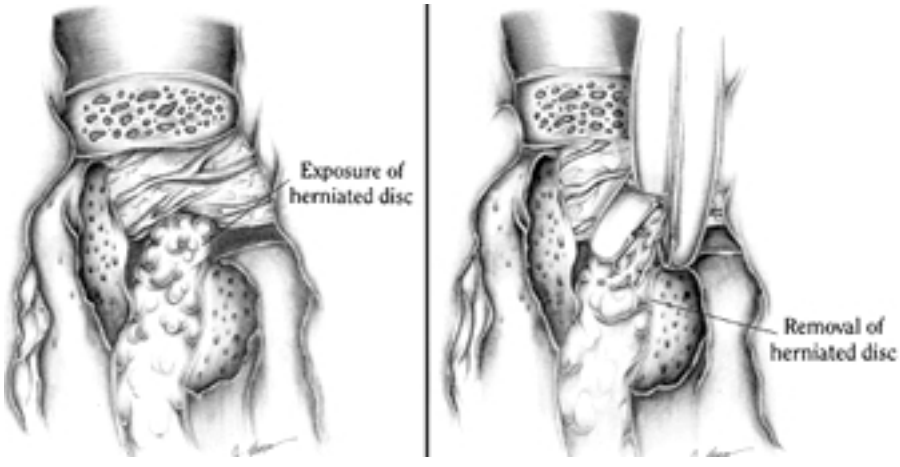

Fig. 3. Illustrations showing site after completion of drilling and exposure of the herniated disc *(left)* and removal of the herniated disc *(right)*.

rial or cracking calcified disc into the defect created by the bone decompression (Fig. 3 *right*). This procedure completely decompresses the ventral aspect of the spinal canal from a ventrolateral endoscopic exposure (Fig. 4).

Wound Closure and Postoperative Management. Using endoscopic guidance, a chest tube is placed through the posterior portal, and 20-cm H_20 suction is applied while the anesthesiologist reinflates the lung. The endoscopic ports are then removed, and the incisions are closed in anatomical layers with absorbable sutures. The patient is extubated at the end of the procedure, and a chest radiograph is obtained in the recovery room to ensure that the lung has been reinflated. Postoperatively, the patients are treated with aggressive pulmonary toilet. The chest tube is removed when drainage diminishes to less than 100 ml per day. Postoperatively oral narcotic agents are provided.

Open Thoracotomy for Thoracic Disc Lesions

In patients undergoing thoracotomy and discectomy a posterior thoracotomy incision of varying size (10–25 cm) is made, depending on the number of vertebral levels to be treated. The discectomy is then performed in essentially the same manner as the thoracoscopic discectomy. Postoperatively, intravenous narcotic therapy is undertaken and then oral narcotic agents are provided.

Clinical Evaluation and Follow-Up Examination

The operative and hospital data for each patient and procedure were evaluated and statistical significance determined using Student's t-test. All patients underwent postoperative MR imaging to ensure that the decompression was successful. Follow-up clinical and neurological evaluations were conducted at 1, 3, 6, and 12 months postoperatively. The Oswestry Pain Scale questionnaire was administered to the patients with radicular pain by a third party interviewer, and a Frankel grade was assigned to patients with myelopathy based on the results of their neurological examination.

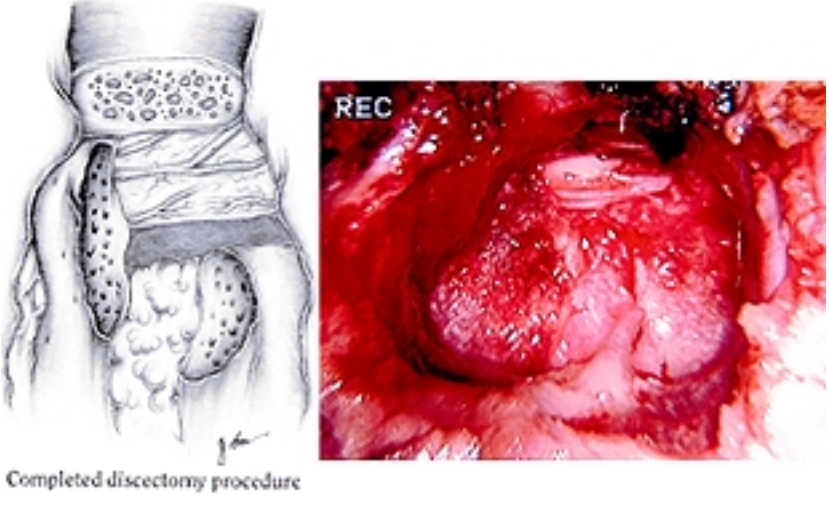

Fig. 4. *Left:* Illustration showing completed discectomy and decompressed spinal dura. *Right:* Intraoperative photograph showing completed discectomy.

Fig. 5. Sagittal neuroimaging studies. *Upper Left:* T_2-weighted MR image revealing a large single-level thoracic disc herniation causing severe myelopathy, which was treated with a thoracoscopic discectomy. *Upper Right:* Postoperative T_1-weighted MR image obtained after thoracoscopic discectomy. *Lower Left:* A computerized tomography reconstruction of multilevel OPLL that caused myelopathy and was treated with open thoracotomy. *Lower Right:* Postoperative T_2-weighted MR image obtained after the open thoracotomy.

RESULTS

All patients in the thoracoscopic discectomy group underwent a one-or two-level procedure (Fig. 5 *upper left* and *right*), and all those in the open thoracotomy/discectomy group underwent multilevel procedures (Fig. 5 *lower left* and *right*) except one patient with a recurrent disc herniation in whom a thoracoscopic reexploration was converted to an open thoracotomy 6 months after the initial process. No fusion procedures were performed in either group.

The operative and hospital data were reviewed and compared for both groups (Table 2). The operative time, blood loss, and duration of chest tube drainage were lower for the patients who underwent thoracoscopy but were not statistically significant. The narcotic usage and hospital LOS were also less for patients in the thoracoscopy group and were statistically different ($p < 0.05$).

Outcomes in Patients With Radiculopathy

Based on comparing pre- and postoperative Oswestry Pain Scale scores patients with radiculopathy improved 75% in terms of pain status (Table 3). All patients experienced some improvement in radiculopathy symptoms, and three patients experienced only limited improvement (> 25%); however, these three patients were satisfied and would undergo the procedure again. No patients experienced worsened status postoperatively.

TABLE 2

Operative and postoperative data

	Thoracoscopic Discectomy	Open Thoracotomy
op time (min)	212 (102–384)	305 (165–442)
blood loss (ml)	225 (100–600)	380 (220–850)
chest tube (days)	1.3* (0–18)	4.1 (2–7)
narcotic usage (mg/day for 3 days†)	6.5* (4–11)	22.6* (10–42)
LOS (days)	3.1‡ (1–21)	5.4‡ (4–12)

* $p < 0.05$, Student's t-test.
† Estimated as milligrams equivalent of morphine sulfate.
‡ $p < 0.05$, Student's t-test; when excluding the patient with chylothorax and 21 day LOS.

Outcomes in Patients With Myelopathy Treated With Thoracoscopic Discectomy

The outcomes for these patients were mostly improved, as reflected by postoperative Frankel grades (Table 4). Myelopathy improved in seven (37%) of 19 patients as indicated by a mean improvement of two Frankel grades. Myelopathy was unchanged in nine patients (47%) including only one patient who remained Frankel Grade C after surgery with a 4-year history of chronic myelopathy. One patient (5%) worsened from a Frankel Grade C to B. This male patient had suffered longstanding paraparesis for 30 years after undergoing a laminectomy for a large calcified thoracic disc herniation; postlaminectomy he was paraplegic for 1 year. He experienced worsening paraparesis and spastic gait and underwent thoracoscopic discectomy that was uncomplicated except for removal of the intradural disc extension, which resulted in a cerebrospinal fluid leak. This was resolved successfully by using a muscle graft, fibrin glue, lumbar subarachnoid drainage, and maintaining the chest tube without suction.

Outcomes in Patients With Myelopathy Treated With Open Thoracotomy/Discectomy

The outcomes in these patients was mostly improved as indicated by improved postoperative Frankel grades (Table 4). Neurologically these patients were generally in worse condition preoperatively than those in the tho-

TABLE 3

Outcome in 17 patients with pain/radiculopathy who underwent thoracoscopic discectomy according to Oswestry Pain Scale score

	Mean Oswestry Pain Scale Score (range)		
Type of Lesion	Preop	Postop	Change
herniated disc	60 (40–80)	14 (0–40)	46
discitis	72 (60–80)	25 (15–40)	48

TABLE 4

Preoperative and postoperative Frankel grades obtained in patients who underwent thoracoscopic discectomy or open thoracotomy/discectomy

	Frankel Grade (postop)				
Frankel Grade (preop)	A	B	C	D	E
thoracoscopy group					
A					
B				2	
C		1*	1	2	3
D				4	2
E					4
thoracotomy group					
A	1†				
B		2	1		
C			1	2	
D					1
E					

* Patient was worsened postoperatively.

† Patient was worsened postoperatively and later died of a pulmonary embolism.

racoscopy group. Myelopathy improved in four patients (50%), as reflected by a mean change of one Frankel grade. Myelopathy was unchanged in three patients (38%) and worse in one patient (13%). This patient was morbidly obese and had a longstanding, progressive myelopathy secondary to a five level OPLL with a preoperative Frankel grade of A. After uneventful thoracotomy and complete decompression, she experienced flaccid paralysis that did not improve. She died of a massive pulmonary embolism 1 week after surgery.

Surgery-Related Complications

Complications occurred in 31% of patients who underwent thoracoscopic discectomy and greater than 100% (that is, more than one complication per patient) of those who underwent open thoracotomy/discectomy (Table 5). Most of these complications were transient and not life threatening. Intercostal neuralgia was the most frequent transient complication, resolving in nearly all thoracoscopy-treated patients by 3 months postsurgery. One patient who continued to experience intercostal neuralgia after 6 months postsurgery, experienced partial improvement after undergoing intercostal nerve blocks and a radiofrequency rhizotomy. This patient was enrolled early in the series and was treated with hard plastic ports; no cases of permanent neuralgia have occurred since we began to use the soft, flexible ports. There was a higher incidence of permanent intercostal symptoms in the thoracotomy-treated group.

All cases of pneumonia resolved after antibiotic therapy and pulmonary toilet. Recurrent disc herniation occurred in an obese, young female patient who underwent thoracoscopic discectomy for primarily chest wall pain and a mild myelopathy. Improvement was demonstrated until, 6 months postoperatively, she experienced recurrent chest wall pain. Computerized tomography myelography revealed a calcified disc fragment that had not been present on her postoperative MR image. Thoracoscopic reexploration was converted to an open thoracotomy procedure, and the disc was removed uneventfully with improvement in her pain symptoms. Chylothorax developed in one patient in the thoracoscopy-treated group; however, no leak had been noted at surgery. There was a persistent high output of whitish fluid (consistent with chyle on laboratory testing) from the chest tube; the patient received no oral feedings and elemental total parenteral nutrition therapy for 2 weeks, which resolved the leak.

TABLE 5

Surgery-related complications

Complication	Thoracoscopic Discectomy (%)	Open Thoracotomy (%)
pneumonia	2 (6)	2 (25)
intercostal neuralgia		
transient (< 3 mos)	5 (14)	6 (75)
permanent (> 3 mos)	1 (3)	2 (25)
recurrent disc herniation	1 (3)	0
chylothorax	1 (3)	0
additional neurological deficit	1 (3)	1 (13)
death	0	1 (13)
total	11 (31)	12 (> 100)*

* More than one complication per patient.

DISCUSSION

Anterior approaches to the thoracic spinal column have become established as the standard for appropriate treatment of vertebral disc lesions primarily anterior to the spinal cord.[4,10,23,25,26,30] With the exception of the lateral extracavitary and transpedicular approaches, in which there is a posterolateral trajectory along the rib or pedicle, respectively, to the disc, the thoracotomy remains the gold standard for midline lesions that compress the spinal cord.[12,18,22,23] Furthermore, the lateral extracavitary and transpedicular approaches do not provide direct visualization of lesions directly ventral to the spinal cord, which cannot always be removed safely without causing possible injury to the spinal cord. This is particularly true with midline calcified disc lesions.

Outcomes of Thoracoscopic Compared With Thoractomy Discectomy

Thoracoscopic interventions for thoracic and pulmonary lesions have been well established as the procedures of choice compared with thoracotomy because of reduced rates of morbidity, LOS, and complications.[11,16,17,30] Similarly in previous reports in which thoracoscopic discectomy was compared with thoracotomy and costotransversectomy, the authors concluded that thoracoscopy has distinct advantages due to the overall lowered morbidity rate.[7,21,23,28,31] The authors compared operative time, blood loss, duration of chest tube drainage, narcotic usage, and LOS with cases in the literature dating back to the previous decade. Although they provided interesting comparisons, their comparisons lack validity because surgical and anesthetic procedures as well as and postoperative management practices were vastly different in the 1980s. For example, in a thoracotomy or costotransversectomy procedure for the treatment of an uncomplicated thoracic le-

sion today the incision would be smaller and the operative time, postoperative pain medications, and LOS would likely be cut by 50%, compared with the same procedure a decade ago. Thoracoscopic discectomy has advantages that are mostly intuitive and obvious, because small incisions precluding rib retraction simply create less acute pain and reduce the risk of long-term postthoracotomy pain syndromes that are difficult to treat.[6,16,17,23,31] It remains unlikely that a true randomized prospective study in which thoracotomy is compared with thoracoscopic discectomy will occur, because patients seeking minimally invasive procedures from surgeons skilled in these techniques would agree to a thoracotomy as a primary procedure. Therefore, we have attempted to draw conclusions from our nonrandomized prospective study that are based on our experiences in developing a thoracoscopy program.[15]

The outcome data in our study indicate that patients who undergo thoracoscopic discectomy have a shorter LOS and require less medication, despite the small number of patients and the nonrandomized selection process. The selection process for thoracoscopic or thoracotomy procedures was based on the complexity of each lesion as well as our perceived ability to treat the lesion effectively and expeditiously with thoracoscopy. We conclude that one- and two-level thoracic lesions are ideally treated using endoscopic techniques, as the minimal incision-related pain and morbidity are markedly different from those associated with a thoractomy. We also believe that a thoractomy may be the best procedure in those patients harboring such complex multilevel thoracic lesions as OPLL in which the operative time and risks may exceed the perceived advantages of an endoscopic procedure. These lesions typically compress a contiguous segment of the spinal cord, rather than having focal herniated disc lesions and would require that several additional ports be placed, thus contributing to a greater operative time than a thoractomy. Although a thoracoscopy for complex multilevel thoracic lesions is indeed feasible, it may not be practical if the procedure requires significantly greater time and potentially greater risk to the patient.

Advantages of Thoracoscopic Discectomy

Thoracoscopic discectomy procedures for thoracic lesions were first reported in the early 1990s.[13,21,28,31] Since then the authors of a limited number of clinical series have reported experiences in thoracoscopic disc surgery; experiences with thoracic vertebral reconstruction procedures have also been reported.[7,8,13,23,27,30,31] These techniques largely simulate an open thoractomy procedure by virtue of the trajectory through the chest cavity and the similar-fashion decompression of the spinal canal. The minimum amount of tissue retraction required in the endoscopic procedure has reduced postoperative pain and the LOS in our patients, and this is supported by the results of the present study in which we compared similar but more complex cases harboring thoracic disc lesions. Although the operative time was not statistically different between the groups, the overall data include patients treated early in our series and the learning curve; operative time is now typically 2 hours for a single-level thoracoscopic discectomy. The similiar improvement is likely for surgery-related blood loss and days of chest tube drainage for the latter patients.

Disadvantages of Thoracoscopic Discectomy

The primary disadvantages of thoracoscopy are related to the way in which the procedure is performed: endoscopic visualization, even with the latest three-dimensional technology, still depends on television projections where depth of field does not compare with direct or microscopic vision; the three-dimensional glasses are sufficiently inconvenient that many surgeons still use two-dimensional endoscopes; cleaning bone dust from the endoscope frequently during the drilling procedure significantly interrupts the flow of the procedure; the ports placed in the chest wall significantly restrict the surgeon's ability to manipulate the instruments, and they act as a fulcrum rather than the usual unlimited degrees of motion allowed within a thoracotomy incision; the instruments are usually longer and more awkward to use; and it is also difficult for the surgeon to use instruments in each hand simultaneously to perform complex tasks, and he or she must often rely on an experienced assistant. Because of these points and the need for acquiring difficult new visual–motor surgical skills, a high level of new skills are required for the surgeon to perform a surgical procedure as complex as a thoracic discectomy.[9,29] These skills are challenging to the surgeon who performs them regularly and may be impractical for the surgeon performing them infrequently. The learning curve is steep, as has been confirmed by surgeons performing them frequently, and formal training is recommended. It also seems appropriate that a sufficient number of cases be performed annually to maintain necessary skills effectively.

CONCLUSIONS

Thoracoscopic discectomy procedures have several distinct advantages over alternative procedures primarily related to reduced surgery-related pain, morbidity, LOS, and complications. The need for adequate training and consistant annual surgical experience to maintain effective skills are necessary for surgeons performing thoracoscopy. The alternative costotransversectomy, transpedicular, and transthoracic procedures clearly remain viable and effective techniques for surgeons experienced in these procedures and have limited experience with thoracoscopic discectomy procedures.

Acknowledgments

The authors wish to thank Josh Emerson for his artistic contributions and Samantha Phu for her assistance in preparing this manuscript.

References

1. Arseni C, Nash F: Thoracic intervertrebral disc protrusion: a clinical study. **J Neurosurg 17:**418–430, 1960
2. Benjamin V: Diagnosis and management of thoracic disc disease. **Clin Neurosurg 30:**577–605, 1983
3. Bohlman HH, Zdeblick TA: Anterior excision of herniated thoracic discs. **J Bone Joint Surg (Am) 70:**1038–1047, 1988
4. Broc GG, Crawford NR, Sonntag VKH, et al: Biomechanical effects of transthoracic microdiscectomy. **Spine 22:**605–612, 1997

5. Chou SN, Seljeskog EL: Alternative surgical approaches to thoracic spine. **Clin Neurosurg 20:**306–321, 1973
6. Dajczman E, Gordon A, Kreisman H, et al: Long-term post-thoracotomy pain. **Chest 99:**270–274, 1991
7. Dickman CA, Karahalios DG: Thoracoscopic spinal surgery. **Clin Neurosurg 43:**392–422, 1996
8. Dickman CA, Mican CA: Multilevel thoracic discectomies and anterior interbody fusion using a microsurgical thoracoscopic approach. Case report. **J Neurosurg 84:**104–109, 1996
9. Dickman CA, Rosenthal DJ, Perin NI (eds): **Thoracoscopic Spine Surgery.** New York: Thieme, 1999
10. Faciszewski T, Winter RB, Lonstein JE, et al: The surgical and medical perioperative complications of anterior spinal fusion surgery in the thoracic and lumbar spine in adults. A review of 1223 procedures. **Spine 20:**1592–1599, 1995
11. Ferson PF, Landreneau RJ, Dowling RD, et al: Comparison of open versus thoracoscopic lung biopsy for diffuse infiltrative pulmonary disease. **J Thorac Cardiovasc Surg 106:**194–199, 1993
12. Fessler RG, Dietze DD Jr, MacMillan M, et al: Lateral parascapular extrapleural approach to the upper thoracic spine. **J Neurosurg 75:**349–355, 1991
13. Horowitz MB, Moossy JJ, Julian T, et al: Thoracoscopic discectomy using video assisted thoracoscopy. **Spine 19:** 1082–1086, 1994
14. Hulme A: The surgical approach to thoracic intervertebral disc protrusions. **J Neurol Neurosurg Psychiatry 23:**133–137, 1960
15. Johnson JP, Obasi C, Hahn MS, et al: Endoscopic thoracic sympathectomy. **J Neurosurg (Spine) 91:**90–97,1999
16. Landreneau RJ, Hazelrigg SR, Mack MJ, et al: Postoperative pain-related morbidity: video-assisted thoracic surgery versus thoracotomy. **Ann Thorac Surg 56:**1285–1289, 1993
17. Landreneau RJ, Mack MJ, Hazelrigg SR, et al: Video-assisted thoracic surgery: basic technical concepts and intercostal approach strategies. **Ann Thorac Surg 54:**800–807, 1992
18. Larson SJ, Holst RA, Hemmy DC, et al: Lateral extracavitary approach to traumatic lesions of the thoracic and lumbar spine. **J Neurosurg 45:**628–637, 1976
19. LeRoux PD, Haglund MM, Harris AB: Thoracic disc disease: experience with the transpedicular approach in twenty consecutive patients. **Neurosurgery 33:**58–66, 1993
20. Love JG, Schorn VG: Thoracic disc protrusions. **JAMA 191:** 627–631, 1965
21. Mack MJ, Regan JJ, Bobechko WP, et al: Application of thoracoscopy for disease of the spine. **Ann Thorac Surg 56:** 736–738, 1993
22. Maiman DJ, Larson SJ, Luck E, et al: Lateral extracavitary approach to the spine for thoracic disc herniation: report of 23 cases. **Neurosurgery 14:**178–182, 1984
23. McAfee PC, Regan JJ, Zdeblick T, et al: The incidence of complications in endoscopic anterior thoracolumbar spinal reconstructive surgery. A prospective multicenter study comprising the first 100 consecutive cases. **Spine 20:**1624–1632, 1995
24. Patterson RH Jr, Arbit E: A surgical approach through the pedicle to protruded thoracic discs. **J Neurosurg 48:**768–772, 1978
25. Perot PL Jr, Munro DD: Transthoracic removal of midline thoracic disc protrusions causing spinal cord decompression. **J Neurosurg 31:**452–458, 1969
26. Ransohoff JR, Spencer F, Siew F, et al: Transthoracic removal of thoracic disc. Report of three cases. **J Neurosurg 31:** 459–461, 1969
27. Regan JJ, Mack MJ, Picetti GD: A technical report on video-assisted thoracoscopy in thoracic spine surgery. **Spine 20:** 831–837, 1995
28. Regan JJ, Mack MJ, Picetti GD III, et al: A comparison of video-assisted thoracoscopic surgery (VATS) with open thoracotomy in thoracic spine surgery. **Todays Ther Trends 2:** 203–218, 1994
29. Regan JJ, McAfee PC, Mack MJ: **Atlas of Endoscopic Spine Surgery.** St Louis: Quality Medical, 1995
30. Rosenthal D, Dickman C, Lorenz R, et al: Thoracic disc herniation: early results after surgical treatment using microsurgical endoscopy. **J Neurosurg 84:**334A, 1996 (Abstract)
31. Rosenthal D, Dickman CA: Thoracoscopic microsurgical excision of herniated thoracic discs. **J Neurosurg 89:**224–235, 1998
32. Rosenthal D, Rosenthal R, de Simone A: Removal of a protruded thoracic disc using microsurgical endoscopy. A new technique. **Spine 19:**1087–1091, 1994
33. Sekhar LN, Jannetta PJ: Thoracic disc herniation: operative approaches and results. **Neurosurgery 12:**303–305, 1983
34. Stillerman CB, Chen TC, Day JD, et al: The transfacet pedicle-sparing approach for thoracic disc removal: cadaveric morphometric analysis and preliminary clinical experience. **J Neurosurg 83:**971–976, 1995
35. Stillerman CB, Weiss MH: Management of thoracic disc disease. **Clin Neurosurg 38:**325–352, 1990

Manuscript received September 6, 2000.
Accepted in final form September 13, 2000.
Address reprint requests to: J. Patrick Johnson M.D., Division of Neurosurgery, UCLA Medical Center, Box 956901, Los Angeles, California 90095–6901. email jpjohnson@mednet.ucla.edu.