Surgical outcomes of posterior thoracic interbody fusion for thoracic disc herniations

Ryoji Yamasaki · Shinya Okuda · Takafumi Maeno · Takamitsu Haku · Motoki Iwasaki · Takenori Oda

Received: 5 November 2012 / Revised: 30 April 2013 / Accepted: 18 June 2013 / Published online: 26 June 2013
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Abstract

Introduction Surgical strategy for thoracic disc herniation (TDH) remains controversial. We have performed posterior thoracic interbody fusion (PTIF) by bilateral total facetectomies with pedicle screw fixation. The objectives of this retrospective study are to demonstrate the surgical outcomes of PTIF for TDH.

Materials and methods We enrolled 11 patients who underwent PTIF for myelopathy due to TDH and were followed for at least 1 year. The mean age at surgery was 55.2 years and the average period of follow-up was 4.3 years. The levels of operation were T10–T11 in three cases, T12–L1 in three, and T2–T3, T3–T4, T9–T10, T11–T12, and T10–T12 in one case, respectively. The pre- and postoperative clinical status was evaluated according to the modified Frankel grade and the Japanese Orthopaedic Association (JOA) score modified for thoracic myelopathy. Additionally, postoperative complications were assessed. Local kyphosis at the operated segment and status of fusion were evaluated using plain radiographs and computed tomography.

Results Improvement of at least one modified Frankel grade was observed in all but one patient. Average pre- and postoperative JOA scores were 4.9 and 8.8 points, respectively. The average recovery rate was 61 %. Bony union was observed in ten cases. One patient's postsurgical outcome resulted in pseudoarthrosis, which required

revision surgery due to kyphosis deterioration. Cerebrospinal fluid leakage was observed in one patient postoperatively with neither neurological deficit nor evidence of infection.

Conclusion PTIF has produced satisfactory outcomes for myelopathy due to TDH. Therefore, PTIF is one of the surgical treatments of choice for patients with TDH causing myelopathy.

Keywords Posterior thoracic interbody fusion (PTIF) · Thoracic disc herniation · Surgical outcomes · Thoracic disc

Introduction

Thoracic disc herniation (TDH) is rare in comparison to cervical or lumbar disc herniation with an occurrence rate of 0.15–4.0 % of all disc herniations [1, 2, 23]. The incidence of TDH has been estimated at approximately one patient per million population [22]. TDH affects men more frequently than women, with a peak age of 40–50 years. Most TDHs are found in the lower thoracic spine with more than 75 % affecting below T8, mainly at T11–T12 [1, 23].

Spontaneous resorption of herniated disc material has been observed in TDH similar to observations in cervical and lumbar disc herniations. Therefore, conservative treatment is primarily selected in patients without myelopathy. However, surgical treatment is necessary when myelopathy is progressive [5, 12, 35].

Conventional decompressive laminectomy for TDH, with or without discectomy, has resulted in a high rate of major morbidity and mortality [1, 18, 19]. As a result, various surgical techniques have been developed, including transthoracic lateral extracavitary, costotransversectomy,

R. Yamasaki (✉) · S. Okuda · T. Maeno · T. Haku · T. Oda
Department of Orthopedic Surgery, Osaka Rosai Hospital,
1179-3 Nagasonecho, Sakai, Osaka 591-8025, Japan
e-mail: yamaryo192@yahoo.co.jp

M. Iwasaki
Department of Orthopedic Surgery, Faculty of Medicine,
Graduate School of Medicine, Osaka University,
2-2 Yamadaoka, Suita, Osaka 565-0871, Japan

transpedicular transversoarthropediclectomy, transfacet pedicle-sparing, microscopic discectomy, and thoracoscopic procedures [7, 8, 15, 17, 28, 30].

Various reports have indicated that anterior surgical approaches provide satisfactory results [11, 22, 24, 26, 27]. Transthoracic approaches have particularly been favored in central, giant and calcified TDH due to their greater safety in achieving ventral spinal cord decompression [14]. However, the anterior transthoracic procedures have a variety of limitations, especially in cases of chest disease and decreased respiratory function [9]. Safe decompression of all involved neural elements and stabilization of the affected segment are essential in treatment of TDH. We applied our technique of posterior lumbar interbody fusion (PLIF) to the thoracic spine to achieve these goals with the posterior approach alone [25]. The objective of this study was to investigate the surgical outcomes of posterior thoracic interbody fusion (PTIF) with bilateral total facetectomies and pedicle screw fixation for myelopathy due to TDH.

Materials and methods

Twelve consecutive patients underwent PTIF for myelopathy due to TDH between 1999 and 2010. This study group consisted of 11 patients (7 men, 4 women) who were followed for at least 1 year. The mean age at surgery was 55.2 years (range 21–81 years) and the average follow-up period was 4.3 years (range 1–11 years).

The levels of PTIF segments were documented at both T10–T11 and T12–L1 in three cases, and one case each at T2–T3, T3–T4, T9–T10, T11–T12, and T10–T12 levels. Ossification of the ligamentum flavum (OLF) occurred at the same segment in which TDH was detected in three patients. In some cases, further additional surgical procedures were required at adjacent levels. This consisted of a laminectomy for OLF in two cases and discectomy for lumbar disc herniation in one case, which were performed simultaneously.

Preoperative magnetic resonance imaging (MRI) and computed tomographic myelography (CTM) were performed in all patients to diagnose and determine the levels which required decompression. In this series, TDH was diagnosed when the herniated disc acting as the main factor compressed the spinal cord regardless of the existence of osteophytes. The localization of herniation was classified as a central type when the bulk of the herniation was located at the middle half of the thoracic canal. It was classified as a lateral type when the bulk of the herniation was located at the lateral side of the middle half of the thoracic canal [4]. The central type of herniation occurred at six levels, and the lateral type was also present at six levels in this study group. The degree of herniation was

characterized as mild, moderate or severe as described previously [9]. Mild herniation consisted of only minimal dural indentation. Moderate herniation created limited cord pressure with no significant deformation. Severe herniation resulted in free fragments or evidence of cord compression manifested by indentation or flattening of the cord. Furthermore, the herniation occupying more than 40 % of the diameter of the spinal canal was defined as giant herniation [14]. All TDHs in this study were categorized as severe and giant herniations (Table 1).

The average period between the onset of initial symptoms and diagnosis was 13 months (range 1–60 months). The initial symptoms were back pain in four cases, lower extremity numbness in three cases, lower extremity pain in two cases, lower extremity weakness in two cases, and intercostal neuralgia in one case. The average period between the onset of gait disturbance and surgical treatment was 1.7 months (range 0.25–7 months).

Clinical outcomes were assessed with several measures to include: operative time, blood loss, pre/postoperative modified Frankel grade (Table 2), pre/postoperative Japanese Orthopaedic Association (JOA) score modified for thoracic myelopathy (Table 3) and intra/postoperative complications [3]. The JOA scoring system for cervical myelopathy quantifies neurologic impairment by evaluating motor function of the upper extremity (4 points), motor function of the lower extremity (4 points), sensory function (6 points), and bladder function (3 points) such that a higher score indicates greater impairment. Therefore, a full JOA score for cervical myelopathy is 17 points. In this study, we used the JOA score modified for thoracic myelopathy (11 points for a full score, Table 3) by excluding motor and sensory functions of the upper extremity from the JOA scoring system for cervical myelopathy [32, 33, 36]. Recovery rate [(postoperative score – preoperative score)/(11 – preoperative score) × 100 %] was evaluated using the formula suggested by Hirabayashi et al. [13]. The recovery rates were classified into five groups: excellent (75–100 %), good (50–74 %), fair (25–49 %), unchanged (0–24 %), and worse (less than 0 %) [24].

The status of fusion and local kyphosis at the operated segment were investigated radiologically as well. Bony union was defined as a condition in which bony continuity between graft bone and vertebra was detected by dynamic radiographs and reconstruction CT, with neither loosening of the pedicle screws nor any motion at the segment. Local kyphotic angle at the operated segment was measured before surgery, immediately after surgery and at the final follow-up by plain neural lateral radiograph except for two cases with upper thoracic fusion (T2–T3, T3–T4) and one case with pseudoarthrosis. The local kyphotic angle was measured as the angle between the upper endplate of the cranial vertebra above the fusion level and the lower

Table 1 Summary of demographic data in 11 patients undergoing PTIF

Case no.	Age (years), sex	Levels of PTIF	FU (years)	Type	Degree	Associated spinal disorders		Frankel		JOA score		Recovery rate (%)	Status of fusion	Complication
						Same level	Other level	Preop	Postop	Preop	Postop			
1	62, M	T10–11, T11–12	11	L, C	S, G			D1	D3	4	10.5	93	Union	
2	32, M	T3–4	10.2	C	S, G	OLF	OLF	D2	D3	5	10.5	92	Union	
3	62, F	T10–11	8.2	L	S, G	OLF	OLF	C	D3	4	8	57	Union	Leakage of CSF
4	60, M	T2–3	6	C	S, G			C	D3	5	7	33	Union	
5	21, M	T11–12	2	C	S, G			B	E	5	10	83	Union	
6	37, M	T12–L1	1	C	S, G		LDH	D1	E	6	10	80	Union	
7	55, F	T10–11	2	L	S, G			D2	D3	7.5	9	43	Union	
8	81, M	T9–10	2	L	S, G			C	D3	1	6	50	Union	
9	71, F	T10–11	2	L	S, G	OLF		D2	D3	5.5	7.5	36	Union	
10	71, M	T12–L1	1.2	L	S, G		DISH	D2	D2	7.5	8	14	Pseudoarthrosis	Local kyphosis
11	54, F	T12–L1	1.7	C	S, G			C	D3	5.5	8	46	Union	

FU follow-up, Frankel the modified Frankel grading system, JOA score the JOA score modified for thoracic myelopathy, C central type, L lateral type, S severe, G giant, OLF ossification of the ligamentum flavum, LDH lumbar disc herniation, DISH diffuse idiopathic skeletal hyperostosis, CSF cerebrospinal fluid

Table 2 The modified Frankel grading system

Grade	Neurological status
A	Complete motor loss and sensory loss
B	Preserved sensation only, voluntary motor function absent
C	Preserved motor less than fair grade (nonfunctional for any useful purpose)
D1	Preserved motor at lowest functional grade (3+/5+) and/or with bowel or bladder paralysis with normal or reduced voluntary motor function
D2	Preserved motor at mid-functional grade (3+ to 4+/5+) and/or with neurogenic bowel or bladder dysfunction
D3	Preserved motor at high-functional grade (4+ to 5+) and normal voluntary bowel or bladder function
E	Complete motor and sensory function normal (may still have abnormal reflexes)

endplate of the caudal vertebra below the fusion level. The correction angle (preoperative kyphotic angle – kyphotic angle immediately after surgery) and correction loss (kyphotic angle at the final follow-up – kyphotic angle immediate after surgery) were calculated [20].

Surgical indication and technique

All patients considered for surgery had myelopathy including gait disturbance, paralysis, or bowel and bladder dysfunction. Back pain alone was not a surgical indication in this series. PTIF procedures were modified from our PLIF technique which has been described elsewhere [25]. Detailed PTIF procedures at each step are shown in Fig. 1.

1. Laminectomy and bilateral total facetectomies were performed with a laminectomy below the pedicle, including the spinous process, bilateral inferior facets of the cranial level, and excision of bilateral superior facets of the caudal level using an air drill.
2. Anterior decompression was completed with a subtotal discectomy consisting of the excision of as much of the annulus and cortical endplate as possible along the lateral border of the endplate bilaterally. This was done to achieve an extensive bone graft area and preserve the bony endplate. Herniotomy was performed by dropping the disc toward the ventral side without the retraction of neural elements. Bilateral total facetectomies provided a wide working space and enabled us to produce a safe decompression and avoid unnecessary retraction of neural elements.
3. The bone graft procedure used autologous bone blocks and chips, which were trimmed from the excised spinous process, lamina, and facets. Posterior iliac crest bone was not harvested.

Table 3 Evaluation system for thoracic myelopathy (the Japanese Orthopaedic Association Score modified for thoracic myelopathy)

Section	Score (points)
Lower extremity motor function	
Unable to stand up and walk by any means	0
Able to stand up, but unable to walk	0.5
Unable to walk without a cane or other support on a level	1
Able to walk without a support, but with a clumsy gait	1.5
Walks independently on a level, but needs support on stairs	2
Walks independently when going upstairs, but needs support when going downstairs	2.5
Capable of fast walking, but clumsily	3
Normal	4
Sensory function of lower extremity	
Complete loss of touch and pain sensation	0
50 % or below of normal sensation and/or severe pain or numbness	0.5
Over 60 % of normal sensation and/or moderate pain or numbness	1
Subjective numbness of a slight degree without any objective sensory deficit	1.5
Normal	2
Sensory function of trunk	
Complete loss of touch and pain sensation	0
50 % or below of normal sensation and/or severe pain or numbness	0.5
Over 60 % of normal sensation and/or moderate pain or numbness	1
Subjective numbness of a slight degree without any objective sensory deficit	1.5
Normal	2
Bladder function	
Urinary retention and/or incontinence	0
Sensory of retention and/or dribbling and/or thin stream and/or incomplete continence	1
Urinary retardation and/or pollakiuria	2
Normal	3
Total score of 11 points	

4. Pedicle screw fixation involved use of the Steffee variable spine plating system (DePuy Spine, Raynham, MA, USA) in the earlier five patients, and the ExpEDIUM Spine system (DePuy Spine, Raynham, MA, USA) in the later six patients (Fig. 2).

Results

The mean operative time was 296 min (range 156–450 min), and the mean blood loss was 399 ml (range

60–1,040 ml). Improvement of at least one modified Frankel grade was observed in all but one patient (Fig. 3). Average pre- and postoperative JOA scores were 4.9 and 8.8 points, respectively. Significant difference was detected between pre- and postoperative JOA scores (paired *t* test, $p < 0.01$). The average recovery rate was 61 % (range 14–93 %). The overall results were excellent in four patients, good in three, fair in three, and unchanged in one, respectively. With regard to complications, neither neurological deficit nor infection was detected. Leakage of the cerebrospinal fluid was observed in one patient, which was resolved with conservative treatment.

The average local kyphotic angle at the operated segment before surgery, immediately after surgery, and at the final follow-up was 9.5°, 6.5°, and 8.1°, respectively. The average correction angle and correction loss were 3.0° and 1.6°, respectively. No statistical difference was detected in the change of local kyphotic angle. Bony union was observed in ten patients (Table 1). One patient had resulting pseudoarthrosis, which required revision surgery due to kyphosis deterioration (Fig. 4). The fusion rate was 91 %.

Representative case

The patient was a 21-year-old man who suffered from TDH myelopathy at T11–T12. He was very obese, with his body height/weight being 170 cm/150 kg. He could not stand unassisted before surgery. PTIF was performed and his lower extremity muscle strength improved gradually after surgery. He could ambulate using a walker 3 months after surgery. At the final follow-up, he could run unassisted. Pre- and postoperative modified Frankel grades were B and E, respectively. Pre- and postoperative JOA scores were 3 and 10 points, respectively. His recovery rate was 87.5 % and bony union was confirmed at 5 months after surgery (Fig. 5). The local kyphotic angle at the operated segment before surgery, immediately after surgery, and at the final follow-up was 11°, 9°, and 10°, respectively.

Discussion

Treatment of TDH remains controversial due to its lower incidence than herniations in the cervical or lumbar spine. Anterior approaches have been favored due to their ability to safely achieve ventral spinal cord decompression. The anterior approach technique for TDH was first described by Crafoord et al. [8]. Subsequently, many reports of anterior approach procedures for the treatment of TDH have been reported [11, 24, 26, 27]. The anterior surgical approach is effective in decompressing the central and calcified TDH

Fig. 1 Schematics showing procedures for PTIF. **a–c** Laminectomy and bilateral total facetectomies as seen by the anteroposterior view. Laminectomy below the pedicle, including the spinous process, and bilateral inferior facets of the cranial level (**b**), and excision of bilateral superior facets of the caudal level (**c**). **d–f** Anterior decompression seen by axial view. Herniotomy is performed by dropping the disc toward the ventral side without neural element retraction

Fig. 2 Postoperative lateral radiographic (*left*) and CT (*right*)

with the presence of osteophytes. However, anterior approaches have been found to be difficult in cases of chest disease, decreased respiratory function, and extreme obesity [9, 22]. In patients with TDH involving the upper thoracic spine, anterior approaches have required special modifications [10]. Additionally, postoperative pneumonia and intercostal neuralgia have been serious sequelae [22]. The anterior approach also could not deal with the pathogenesis of posterior compressive factors such as OLF associated with anterior disc herniation. Although various posterior approaches have been developed, it has been difficult to decompress the central and calcified herniation, with or without osteophytes [29, 31]. Previous reports had

described that conventional decompressive laminectomy for TDH resulted in a high rate of major morbidity and mortality [1, 18, 19]. Management for TDH at the upper thoracic level has also been difficult in both anterior and conventional posterior approaches.

A modified transfacet pedicle-sparing decompression and fusion for TDHs was reported by Bransford et al. [4]. This procedure is similar to our PTIF. Bilateral total facetectomies were used at the upper thoracic lesions. However, Bradford's report also included cases with unilateral facetectomy and he utilized interbody augmentation. Therefore, their procedure was not always the same as our PTIF. Machino et al. [20] reported transforaminal thoracic

interbody fusion (TTIF) including three patients with TDH. TTIF is a useful method for patients with a lateral type of disc herniation. However, application of TTIF for patients with the central type of disc herniation is limited. In addition, the upper thoracic level was at T7–9 in the case reports of those successfully treated with TTIF. The distance between the bilateral pedicles is narrower especially at the upper thoracic spine levels. Therefore, it is more difficult to achieve safe decompression at the upper thoracic spine with TTIF.

In the present study, PTIF for myelopathy due to TDH provided satisfactory clinical outcomes. Bilateral total

facetectomies could provide an adequate and wide working space and avoid excessive retraction of the neural elements. As a result, PTIF enabled safe decompression, even if the lesion was either central with calcification or at the upper thoracic level. Postoperative neurological deficits were not evident in the present series.

Local kyphosis was corrected slightly in the present study. In the PTIF procedure, subtotal discectomy and bone graft enabled spontaneous kyphosis correction, and the alignment at the operated segment became less kyphotic as a result without forcible correction by instrumentation. Stabilization with dekyphosis enabled us to not only maintain spinal stability, but also reduce the ventral compressive pressure on the spinal cord. Furthermore, the improved or lessened kyphosis impacted a change of the spinal cord alignment and slackened the tension of the spinal cord [16, 36]. This appeared to produce a positive influence on the clinical outcomes for the PTIF procedure.

Interestingly, five patients (45 %) had other pathogenesis combined with TDH in the present series. OLF was observed at the same level as TDH in three patients and at the adjoining level in two patients. Lumbar disc herniation was observed in one patient. This distribution suggested that TDH tended to combine with other spinal disorders at the same or adjoining level. Previous reports recommended that additional laminectomy should be performed if OLF occurred in combination with TDH at the same level [27]. PTIF enabled us to easily perform the additional posterior procedures at the same or adjoining level.

		Postoperative Neurological Status						
Preoperative Neurological Status		A	B	C	D1	D2	D3	E
	A							
	B							1
	C					1	3	
	D1						1	1
	D2					1	3	
	D3							
	E							

Fig. 3 Preoperative and postoperative neurological status using the modified Frankel grading system. The *numbers* indicate the number of patients. Improvement of at least one modified Frankel grade was observed in the *gray zone*

Fig. 4 Case 10. The coronal CT reconstruction image (*left*), and the midsagittal CT reconstruction image (*right*) at postoperative 3 months. Loosening of the pedicle screws in the caudal vertebra

and vacuum around the graft were detected. The findings of diffuse idiopathic skeletal hyperostosis (DISH) were observed at the cranial levels of the PTIF

Fig. 5 Case 5. **a**, **b** Preoperative T2-weighted MRI in the midsagittal plane (**a**), and the axial plane (**b**). TDH was confirmed at T11–12. The spinal cord was flattened by a severe central type of TDH. **c**, **d** Postoperative T2-weighted MRI at the midsagittal plane (**c**), and the axial plane (**d**). TDH was removed completely. The spinal cord was decompressed. Intramedullary high signal intensity was confirmed

Pseudoarthrosis was observed in one patient, who required additional surgery due to deterioration of the local kyphosis. In this patient, diffuse idiopathic skeletal hyperostosis (DISH) was associated and TDH existed at the caudal level of the ankylosed spinal segment [34]. Loosening of the pedicle screw was detected 3 months after surgery. Thereafter, kyphosis progressed gradually. We speculate that the reason for pedicle screw loosening and kyphosis deterioration in this patient may be related to mechanical stress of the long lever arm of the ankylosed spinal segments concentrated at the PTIF level and short segment fixation could not maintain the stability [6, 21]. Therefore, if DISH is recognized in patients with TDH, a wider area of instrumentation including ankylosed spinal segments should be recommended in association with PTIF.

In conclusion, the advantages of PTIF include safe decompression of the spinal cord regardless of axial or sagittal TDH localization, dekyphosis, and the ability to manage other pathogenesis combined with TDH.

Disadvantages associated with PTIF include the inevitability of the rigid instrumentation to reconstruct the stability of the spinal column and to obtain fusion due to bilateral total facetectomies. In the present study, PTIF produced satisfactory clinical outcomes for myelopathy due to TDH. Therefore, PTIF is one of the surgical treatments of choice for patients with myelopathy due to TDH.

Conclusion

This study demonstrated that the various types and levels of TDH were treated and sufficient stability of the spine was obtained with PTIF. Bilateral total facetectomies enabled us to provide safe decompression and sound interbody bone grafting. Consequently, bony union was achieved without neurological complication. In addition, posterior decompressive procedures for other spinal disorders were easily performed at the same time.

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

References

- Arce CA, Dohrmann GJ (1985) Herniated thoracic disks. *Neurol Clin* 3:383–392
- Boriani S, Biagini R, De Lure F, Rocella P, Veronesi V, Dal-buono S et al (1994) Two-level thoracic disc herniation. *Spine* 19:2461–2466
- Bradford DS, McBride GG (1987) Surgical management of thoracolumbar spine fractures with incomplete neurologic deficits. *Clin Orthop Relat Res* 218:201–216
- Bransford R, Zhang F, Bellabarba C, Konodi M, Chapman JR (2010) Early experience treating thoracic disc herniations using a modified transfacet pedicle-sparing decompression and fusion. *J Neurosurg Spine* 12:221–231
- Brown CW, Deffer PA Jr, Akmakjian J, Donaldson DH, Brugman JL (1992) The natural history of thoracic disc herniation. *Spine* 17:S97–S102
- Burkus JK, Denis F (1994) Hyperextension injuries of the thoracic spine in diffuse idiopathic skeletal hyperostosis. *J Bone Jt Surg Am* 76:237–243
- Carson J, Gumpert J, Jefferson A (1971) Diagnosis and treatment of thoracic intervertebral disc protrusions. *J Neurol Neurosurg Psychiatry* 34:68–77
- Crafoord C, Hierton T, Lindblom K, Olsson SE (1958) Spinal cord compression caused by a protruded thoracic disc: report of a case treated with antero-lateral fenestration of the disc. *Acta Orthop Scand* 28:103–107
- Fessler RG, Sturgill M (1998) Review: complications of surgery for thoracic disc disease. *Surg Neurol* 49:609–618
- Fujimura Y, Nishii Y, Nakamura M, Toyama Y, Suzuki N (1996) Anterior decompression and fusion for ossification of the posterior longitudinal ligament of the upper thoracic spine causing myelopathy: using the manubrium splitting approach. *Spinal Cord* 34:387–393
- Fujimura Y, Nakamura M, Matsumoto M (1997) Anterior decompression and fusion via the extrapleural approach for thoracic disc herniation causing myelopathy. *Keio J Med* 46:173–176
- Haro H, Domoto T, Maekawa S, Horiuchi T, Komori H, Hamada Y (2008) Resorption of thoracic disc herniation. Report of 2 cases. *J Neurosurg Spine* 8:300–304
- Hirabayashi K, Miyakawa J, Satomi K, Maruyama T, Wakano K (1981) Operative results and postoperative progression of ossification among patients with ossification of cervical posterior longitudinal ligament. *Spine* 6:354–364
- Hott JS, Feiz-Erfan I, Kenny K, Dickman CA (2005) Surgical management of giant herniated thoracic discs: analysis of 20 cases. *J Neurosurg Spine* 3:191–197
- Hulme A (1960) The surgical approach to thoracic intervertebral disc protrusions. *J Neurol Neurosurg Psychiatry* 23:133–137
- Kawahara N, Tomita K, Murakami H, Hato T, Demura S, Sekino Y et al (2008) Circumspinal decompression with dekyphosis stabilization for thoracic myelopathy due to ossification of the posterior longitudinal ligament. *Spine* 33:39–46
- Lesoin F, Rousseaux M, Autricque A, Reesaul Y, Villette L, Clarisse J et al (1986) Thoracic disc herniations: evolution in the approach and indications. *Acta Neurochir (Wien)* 80:30–34
- Logue V (1952) Thoracic intervertebral disc prolapse with spinal cord decompression. *J Neurol Neurosurg Psychiatry* 15:227–241
- Love JG, Schorn VG (1965) Thoracic-disc protrusions. *JAMA* 191:627–631
- Machino M, Yukawa Y, Ito K, Nakashima H, Kato F (2010) A new thoracic reconstruction technique “transforaminal thoracic interbody fusion”: a preliminary report of clinical outcomes. *Spine* 35:E1000–E1005
- Miyamoto K, Shimizu K, Arimoto R, Sakaguchi Y, Nishimoto H, Kodama H et al (2003) Spontaneous symptomatic pseudoarthrosis at the T11–T12 intervertebral space with diffuse idiopathic skeletal hyperostosis: a case report. *Spine* 28:E320–E322
- Mulier S, Debois V (1998) Thoracic disc herniations: transthoracic, lateral, or posterolateral approach? A review. *Surg Neurol* 49:599–606
- Okada Y, Shimizu K, Ido K, Kotani S (1997) Multiple thoracic disc herniations: case report and review of the literature. *Spinal Cord* 35:183–186
- Ohnishi K, Miyamoto K, Kanamori K, Kodama H, Hosoe H, Shimizu K (2005) Anterior decompression and fusion for multiple thoracic disc herniation. *J Bone Jt Surg Br* 87:356–360
- Okuda S, Oda T, Miyauchi A, Haku T, Yamamoto T, Iwasaki M et al (2007) Surgical outcomes of posterior lumbar interbody fusion in elderly patients. Surgical technique. *J Bone Jt Surg Am* 89:310–320
- Otani K, Nakai S, Fujimura Y, Manzoku S, Shibasaki K (1982) Surgical treatment of thoracic disc herniation using the anterior approach. *J Bone Jt Surg Br* 64:340–343
- Otani K, Yoshida M, Fujii E, Nakai S, Shibasaki K (1988) Thoracic disc herniation. Surgical treatment in 23 patients. *Spine* 13:1262–1267
- Pterson RH Jr, Arbit E (1978) A surgical approach through the pedicle to protruded thoracic discs. *J Neurosurg* 48:768–772
- Stillerman CB, Weiss MH (1992) Management of thoracic disc disease. *Clin Neurosurg* 38:325–352
- Stillerman CB, Chen TC, Day JD, Couldwell WT, Weiss MH (1995) The transfacet pedicle-sparing approach for thoracic disc removal: cadaveric morphometric analysis and preliminary clinical experience. *J Neurosurg* 83:971–976
- Stillerman CB, Chen TC, Couldwell WT, Zhang W, Weiss MH (1998) Experience in the surgical management of 82 symptomatic herniated thoracic discs and review of the literature. *J Neurosurg* 88:623–633
- Tomita K, Kawahara N, Baba H, Kikuchi Y, Nishimura H (1990) Circumspinal decompression for thoracic myelopathy due to combined ossification of the posterior longitudinal ligament and ligamentum flavum. *Spine* 15:1114–1120
- Tuzuki N, Hirabayashi S, Abe R, Saiki K (2001) Staged spine cord decompression through posterior approach for thoracic myelopathy caused by ossification of posterior longitudinal ligament. *Spine* 26:1623–1630
- Resnick D, Niwayama G (1976) Radiographic and pathologic features of spine involvement in diffuse idiopathic skeletal hyperostosis. *Radiology* 119:559–568
- Wood KB, Blair JM, Aepple DM, Schendel MJ, Garvey TA, Gundry CR et al (1997) The natural history of asymptomatic thoracic disc herniations. *Spine* 22:529–530
- Yamazaki M, Mochizuki M, Ikeda Y, Sodeyama T, Okawa A, Koda M et al (2006) Clinical results of surgery for thoracic myelopathy caused by ossification of the posterior longitudinal ligament: operative indication of posterior decompression with instrumented fusion. *Spine* 31:1452–1460