

One-stage posterior debridement and fusion combined with irrigation and drainage for the treatment of postoperative lumbar spondylodiscitis

Tao Zhang^{a, b}, Jianzhong Hu^{a, b}, Jianhuang Wu^a, Jinyang Liu^a, Shuangfei Ni^{a, b}, Chunyue Duan^{a, b, *}

^a Department of Spine Surgery, Xiangya Hospital, Central South University, Changsha, Hunan, PR China

^b Research Center of Sports Medicine, Xiangya Hospital, Central South University, Changsha, Hunan, PR China

ARTICLE INFO

Article history:

Received 8 May 2017

Received in revised form

7 January 2018

Accepted 11 April 2018

Available online 18 May 2018

Keywords:

Postoperative lumbar spondylodiscitis

Posterior surgery

Interbody fusion

Instrumentation

Closed irrigation and drainage

ABSTRACT

Objective: The aim of this study was to evaluate the clinical outcomes of one-stage posterior debridement, interbody fusion, and instrumentation, combined with irrigation and drainage, for treating lumbar spondylodiscitis.

Methods: The study included 23 patients (13 male and 10 female, mean age: 45 years) who had posterior debridement, interbody fusion, and instrumentation, followed by continuous closed irrigation and drainage for lumbar postoperative spondylodiscitis. The visual analog scale, Oswestry disability index, and lumbar lordosis angle were assessed before and after surgery to evaluate the clinical outcome.

Results: The mean follow-up time was 27 (24–36) months. All patients tolerated the procedure well, and there were no instances of spondylodiscitis recurrence, though a dorsal dermal sinus developed in one patient after surgery. Infection was eliminated, as evidenced by the normalization of the erythrocyte sedimentation rates and C-reactive protein levels. The mean visual analog scale scores were significantly decreased after the operation. The mean lumbar lordosis angle before surgery was $21.61 \pm 6.88^\circ$ and the angle at the final follow-up was $31.61 \pm 4.24^\circ$. The mean Oswestry disability index scores improved significantly both after the operation and at the follow-up visits ($p < 0.05$). Bone union was confirmed in all patients at a mean of 8.6 months post-operation, though this was not achieved until 2 years post-operation in one patient. All 3 patients who had neurological deficits showed great improvement at the last follow-up.

Conclusion: Surgical management using one-stage posterior debridement, interbody fusion, and instrumentation, followed by continuous closed irrigation and drainage, might be an effective treatment option for lumbar postoperative spondylodiscitis.

Level of evidence: Level IV, Therapeutic study.

© 2018 Turkish Association of Orthopaedics and Traumatology. Publishing services by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

Lumbar postoperative spondylodiscitis is a relatively uncommon but severe complication after surgical intervention. It is difficult to diagnose early and is accompanied by a poor long-term prognosis, increased cost, and significant morbidity.¹ Treatment

for the majority of patients with spondylodiscitis includes analgesics, long-term administration of antibiotics, and immobilization.² In some cases, further surgery is required, for example, in cases of failed conservative treatment, severe pain, neurological deficits, abscess formation, and vertebral destruction causing instability or deformity.³ Surgical treatments involving transpedicular drainage, laminectomy and debridement, anterior debridement and fusion, posterior interbody grafting and instrumentation, and anterior debridement and fusion combined with posterior instrumentation have all been reported to be effective, but the optimal approach for treating postoperative spondylodiscitis is still debated.⁴ The aim of this study was to report our experience and evaluate the outcomes of a series of 23

* Corresponding author. Department of Spine Surgery, Research Center of Sports Medicine, Xiangya Hospital, Central South University, Changsha 410008, Hunan, PR China. Tel.: +86 731 89753107. Fax: +86 731 84327332.

E-mail address: chunyueduan@outlook.com (C. Duan).

Peer review under responsibility of Turkish Association of Orthopaedics and Traumatology.

spondylodiscitis patients treated with one-stage posterior debridement, interbody fusion, and instrumentation, followed by continuous closed irrigation and drainage.

Materials and methods

This study was approved by the local Clinical Ethics Committee (No. 200902035).

Patients

Between December 2009 and January 2013, 23 patients (13 male and 10 female, mean age 45 years old) were diagnosed with spondylodiscitis in the lumbar region and underwent surgical treatment in our department. The patients' demographic characteristics are summarized in Table 1 and all the patients were diagnosed as lumbar disc herniation during the index procedures. The diagnosis of postoperative spondylodiscitis was based on the following parameters: clinical manifestation; laboratory examination, including blood cell count analysis, erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP) level; and radiographic studies such as plain X-rays, computed tomography (CT), and magnetic resonance image (MRI). Once spondylodiscitis was strongly suspected, blood samples were obtained for microculture and treatment was initiated immediately, consisting of intravenous antibiotics empirically, analgesia, and complete bed rest.

Because of the seriousness of this complication, our hospital did not delay the diagnosis in any patients. However, some cases were referred from other hospitals, so the interval from presentation to definite diagnosis ranged from 3 days to 4 weeks. For all patients, the surgery indications were definite, including intolerable pain, potential instability, kyphosis caused by vertebral body destruction, progressive neurologic deficits, and unsatisfactory conservative treatment.

Surgical procedure

The operation was performed with the patient under general endotracheal anesthesia and in the prone position. Using a posterior midline approach to the spine, the pedicle screws were

implanted and the entire posterior spinal elements and ligamentum flavum were excised to reveal the dura sac. When the neural structures, including the dura, descending nerve roots, and nerve root exits, were exposed, the posterior longitudinal ligament was lifted out carefully and the affected intervertebral disc was exposed. All of the inflammatory disc tissues that could be found, along with the endplate cartilage, were debrided down to healthy bleeding bone. Then, we performed the interbody fusion by inserting an appropriate iliac-bone allograft into the intervertebral disc. The deformity was corrected by installing pre-bent rods. Before closing the incision tightly, one silicone irrigation tube (diameter = 0.3 cm) was inserted into the affected disc space, and two drainage tubes (diameter = 0.5 cm) were placed in the left and right sides of the vertebral plate outside the vertebral canal. All three tubes were unthreaded from healthy skin away from the incision and fixed firmly. Tissue samples resected during the operation were sent for microbiological evaluation and pathological analysis (Fig. 1).

Postoperative procedure

The irrigation began after the operation with a flushing fluid that consisted of 500 ml normal saline and 80,000 U gentamicin (or antibiotic, according to the microbiological results). When the systemic and local symptoms disappeared, the drainage liquid was clear, and the drainage liquid culture was negative on three assessments, irrigation was suspended for 2 days. If the symptoms did not recur, the irrigation tube could be removed. The drainage tubes were removed after another 2 days of observation if there were no complications. A broad-spectrum or sensitive antibiotic was chosen based on a drug sensitivity test and was administered intravenously for 2–3 weeks until the levels of inflammatory markers decreased to normal values, followed by oral antibiotics for an additional 2–3 weeks. Patients were encouraged to mobilize after the removal of the drainage tubes.

Follow-up assessments and statistical analysis

Patients were followed up for 24–36 months (mean 27 months). The visual analog scale (VAS) was used to evaluate preoperative and

Table 1
Demographics and Characteristics of 23 patients with lumbar spondylodiscitis.

Case no.	Gender	Age	Level	Operation time (min)	Blood loss (ml)	Presumed cause	Culture Findings	Follow-up (months)
1	M	35	L5/S1	160	500	chemonucleolysis	negative	30
2	F	60	L4/5	170	400	radiofrequency ablation	E.coli	24
3	F	41	L4/5	150	500	laminectomy	MRSA	26
4	M	17	L5/S1	160	300	chemonucleolysis	negative	24
5	M	59	L3/4	150	400	minimally invasive surgery	negative	22
6	F	46	L5/S1	200	1300	radiofrequency ablation	negative	36
7	M	53	L5/S1	140	550	radiofrequency ablation	MRSA	28
8	F	61	L4/5	210	350	laminectomy	S.epidermidis	28
9	M	32	L5/S1	180	450	minimally invasive surgery	negative	26
10	M	60	L4/5	140	500	chemonucleolysis	MSSA	33
11	F	49	L4/5	140	600	radiofrequency ablation	MRSA	28
12	M	55	L4/5	120	450	minimally invasive surgery	negative	25
13	M	25	L5/S1	210	1100	laminectomy	negative	27
14	M	44	L5/S1	150	800	laminectomy	S.epidermidis	29
15	F	39	L4/5	220	650	radiofrequency ablation	negative	28
16	M	47	L5/S1	160	550	radiofrequency ablation	E.coli	25
17	M	57	L4/5	210	400	radiofrequency ablation	negative	24
18	F	36	L4/5	240	950	chemonucleolysis	MRSA	27
19	F	49	L3/4	180	800	laminectomy	negative	24
20	M	53	L4/5,L5/S1	250	650	chemonucleolysis	MSSA	26
21	M	60	L5/S1	200	1000	radiofrequency ablation	Corynebacterium	33
22	F	34	L2/3	180	700	minimally invasive surgery	S.epidermidis	26
23	F	44	L4/5	180	350	minimally invasive surgery	negative	27

M = male; F = female; MRSA = methicillin-resistant *S. aureus*; MSSA = methicillin-sensitive *S. aureus*.

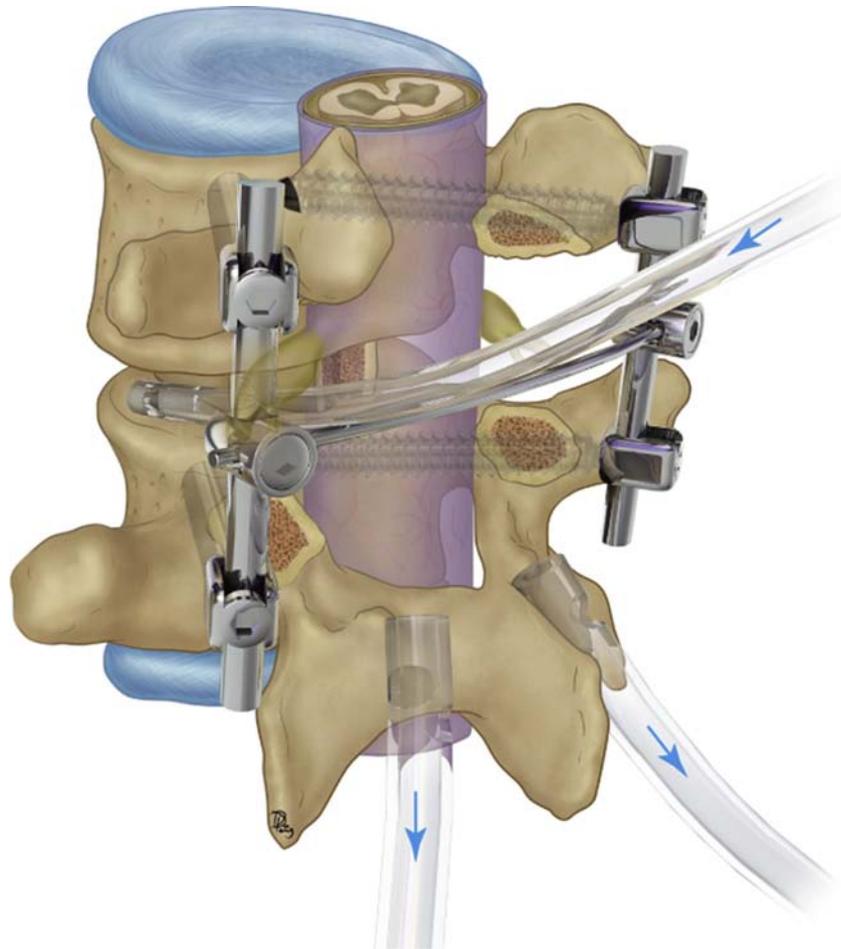


Fig. 1. Illustration of surgical management and the irrigation and drainage system for lumbar spondylodiscitis (the arrows pointed the direction of flow).

postoperative pain, which could also reflect the clinical outcomes. We assessed functional outcome using the Oswestry disability index (ODI) score. Fusion of the bone graft was detected via radiographs or CT, according to the methods described by Lee et al.⁵ The lumbar lordosis angle (LLA), subtended through the superior end-plate of T12 with the upper end-plate of S1,⁶ was measured on lateral plain-film radiographs before and after surgery. Additionally, ESR and CRP, reflecting inflammation, were monitored periodically.

All statistical analyses in this study were performed using the SPSS 13.0 software program (SPSS Inc, Chicago, Ill, USA). Postoperative ESR, CRP, LLA, ODI scores, and VAS scores were compared to their respective preoperative values using paired t tests. The significance level was set at $p \leq 0.05$.

Results

The chief complaints were anxiety and severe disabling back pain (mean preoperative VAS score was 7.52 ± 1.12). The pain was continuous, could not be relieved after resting in bed, and sharpened while turned over. In 19 cases (82.6%), the pain alleviated slightly in the daytime and worsened at night, and there were 14 patients (60.9%) who suffered a radiating pain to the buttocks, thighs, or groin. On examination, all of the patients had limitations in movement, and the straight leg raising tests (SLRT) were positive at 10° – 45° . The preoperative values of ESR and CRP were 69.25 ± 6.89 mm/h and 71.72 ± 10.73 g/ml, respectively. Three patients had neurological deficits, including motor weakness and

sensory alterations. Epidural abscess was showed in 15 (65.2%) in 15 patients and fever lower than 38.5°C was present in 10 (43.5%) patients. In this study, the presumed causes of spondylodiscitis included radiofrequency ablation, chemonucleolysis, laminectomy, and minimally invasive lumbar surgery (Table 1).

The mean operation time was 178.26 ± 34.33 min, and the volume of blood loss during surgery was 619.57 ± 263.17 ml. The symptoms in all patients, especially the back pain, were significantly relieved 1 week after surgery, and patients were satisfied with their clinical results. The mean VAS score 2 weeks post-operation decreased to 2.48 ± 0.67 . The mean ODI score and LLA improved significantly after the operation (Fig. 2). In addition, the ESR and CRP values returned to normal levels in 2–3 weeks after the surgery in all patients (Table 2). The neurologic symptoms of the three patients who suffered neurological deficits preoperative improved completely in the final follow-up.

Pathological analysis of all samples revealed inflammation, but positive microbial detection was identified in only 12 (52.2%) cases, most likely due to the use of antibiotics. The most common type of bacteria was *Staphylococcus aureus* ($n = 6$, including 4 MRSA and 2 MSSA), followed by *Staphylococcus epidermidis* ($n = 3$), *Escherichia coli* ($n = 2$), and *Corynebacterium* ($n = 1$).

No complications associated with irrigation with gentamicin or instrumentation occurred in 22 patients, but one patient developed a dorsal dermal sinus. Bone fusion was completed in 8.61 ± 3.76 months after the operation (Fig. 3), though this was not achieved for one patient until 2 years after surgery (Fig. 4). The VAS scores,

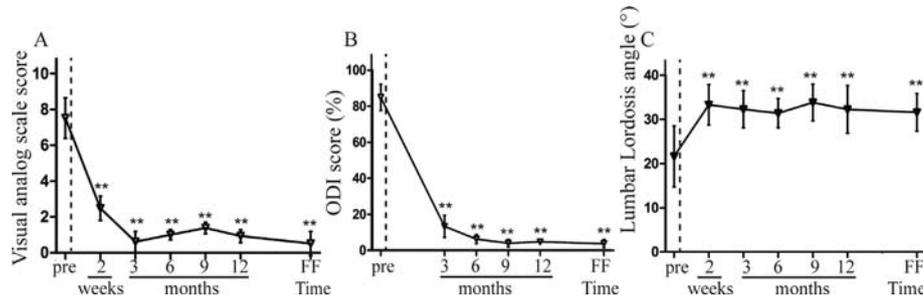


Fig. 2. Summary of changes in visual analog (VAS) scores (A), Oswestry disability index (ODI) scores (B) and lumbar lordosis angle (LLA) (C) from preoperative to postoperative and final follow-up (pre = preoperative; FF = final follow-up; the dotted line indicates the operation time). ** indicates a significant difference compared with preoperative, $p < 0.01$.

Table 2
Preoperative, 2-week postoperative, 3-month postoperative and final follow-up monitoring of ESR, CRP.

	Preoperative	Postoperative (2 w)	Postoperative (3 m)	FF
ESR (mm/h)	69.25 ± 6.89	15.53 ± 1.95**	9.60 ± 1.38**	10.26 ± 3.84**
CRP (mg/L)	71.72 ± 10.73	7.61 ± 2.31**	7.47 ± 2.15**	7.19 ± 3.41**

** $P < 0.01$, compare with preoperative, FF = final follow-up; w = weeks; m = months.

ODI scores, LLA, ESR, and CRP levels remained stable with no evidence of recurrence for any of the 23 patients through the final follow-up.

Discussion

Postoperative spondylodiscitis, described for the first time in 1955,⁷ may be caused by a septic or aseptic infection after lumbar surgery.⁸ The major risk factors in our patients was un-standard

lumbar puncture, such as radiofrequency ablation and chemonucleolysis. A total of 13 of 23 patients had received an lumbar puncture before the infection developed. Besides, patient had comorbidities such as diabetes was also a risk factor. Because the consequences of postoperative spondylodiscitis are severe, including failed back syndrome, a compromised central canal, and alignment abnormalities, early diagnosis and intervention are crucial. In this study, though a postoperative complication (dorsal dermal sinus) was observed in one patient and another experienced

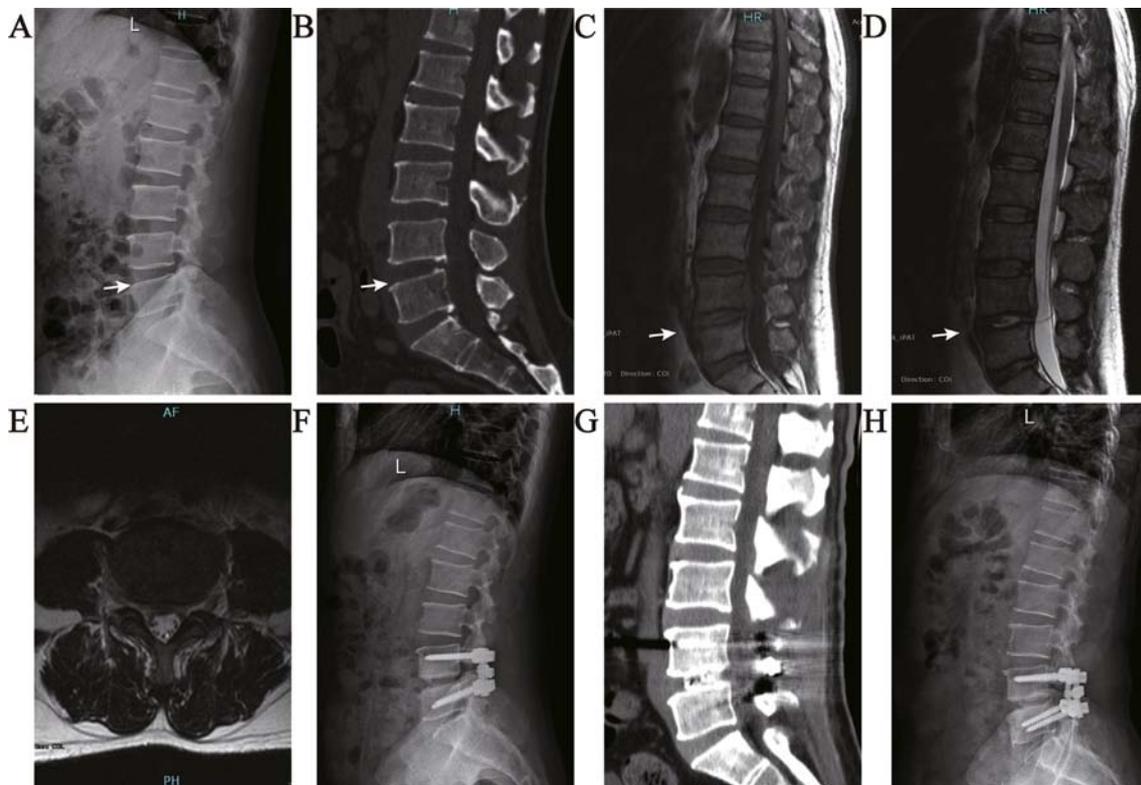


Fig. 3. A 57-year-old man suffered an L4-L5 spondylodiscitis, and the presumed cause might be a radiofrequency ablation several weeks ago. (A–B) pre-operative radiographs, and CT images showed there was no obvious change in L4-L5 disc interspace. (C–E) T1-weighted sagittal and T2-weighted images showed different signals in L4-L5 disc interspace. (F–G) lateral radiograph and CT taken 9 months after surgery showed the allograft bone has united. (H) last follow-up radiograph showed lumbar curvature sustained well.

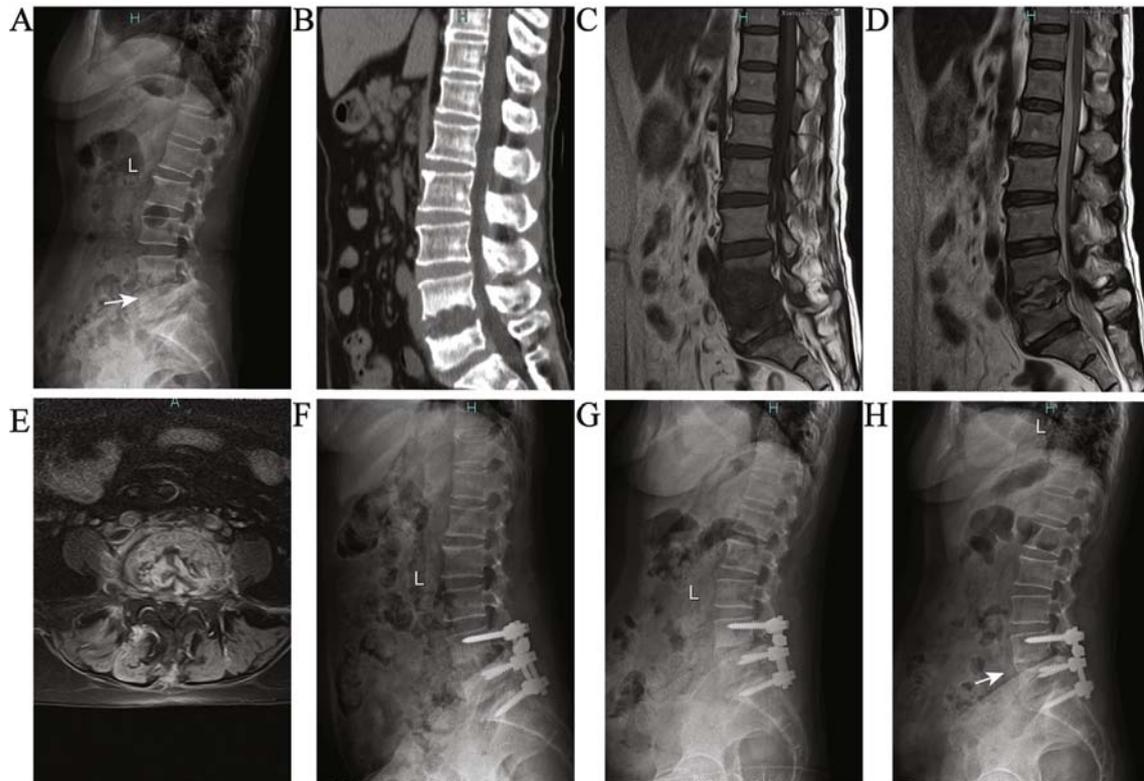


Fig. 4. A 60-year-old woman developed L4-L5 spondylodiscitis with a surgical intervention of radiofrequency ablation several weeks ago. (A–E) pre-operative radiographs, CT and MRI images showed destruction and different signal of the L4-L5 disc interspace. (F–H) post-operative lateral radiographs at 6 months (F), 12 months (G) and 24 months, showing that bone fusion was not achieved until the 24 months.

a lengthy bone fusion time, overall the results demonstrated that the procedure was tolerated and this method is effective for the treatment of lumbar postoperative spondylodiscitis.

In general, back pain is the main symptom of lumbar postoperative spondylodiscitis, which occurs because of, and aggravated in the 10 weeks after lumbar surgery and is not relieved after rest.⁹ Laboratory parameters such as ESR and CRP levels were elevated in most cases. Though Barrey et al¹⁰ suggest that postoperative infection should be considered when the ESR and CRP values are over 45 mm/h and 25 mg/L, respectively, 1 week after lumbar discectomy; these are supportive but not confirmatory conditions for the diagnosis due to their nonspecificity. In addition, percutaneous discal biopsy and culture was recommended to obtain a definitive diagnosis, but the rate of false-negative results was high.¹¹

Upon imaging examination, plain radiograph is the first imaging modality used, but the results are insensitive, especially at the early stage of this disease. Abnormal findings might be observed on the plain radiographs weeks or months later, and include the loss of intervertebral space height and destruction of the affected vertebral end plates.¹² CT is more useful than radiography for observing early changes in the vertebral bodies and end plates, but it is not effective for detecting soft tissue changes, which occur with the initiation of inflammation.¹³ MRI is sensitive enough to observe changes in the early period of postoperative spondylodiscitis (3–5 days),¹³ and the findings involve: (1) a decreased signal on T1-weighted MR images and an increased signal on T2-weighted MR images of the vertebral bodies and disc nucleus pulposus; (2) stenosis of the disc space; (3) bulging of the paraspinal soft tissue; and (4) decreased bony signal intensity of the adjacent vertebral body on T1-weighted images when gadolinium was used. In a recent systematic review, the sensitivity, specificity, and veracity were 93%, 97%, and 95%, respectively.¹⁴ MRI is the radiographic imaging

modality of choice for the early diagnosis of postoperative spondylodiscitis. In our department, if postoperative spondylodiscitis was highly suspected, MRI was recommended, as it is extremely important to diagnose spondylodiscitis early.

Currently, no gold standard treatment for postoperative spondylodiscitis exists. Conservative treatment still dominates for most surgeons and hospitals in the country, which consists of long term administration of antibiotics and immobilization of the affected spinal column.² Because the definitive organism is unknown, the antibiotics were administered empirically, and the results were not satisfactory in some cases. Furthermore, due to the poor vascularity of the discs and slow self-absorption of the inflammatory necrosis, the recovery period is quite long, potentially several months, and might be accompanied by drug side effects.¹⁵ Thus, surgery combined with antibiotics is proposed by an increasing number of surgeons for postoperative spondylodiscitis.¹⁶ Derbent et al¹⁷ reported that the morbidity of remnant back pain for discitis was 26.3% after surgery and 64% after conservative treatment. The goal of surgery is to relieve the symptoms quickly, accelerate intervertebral fusion, shorten the recovery duration, and improve therapeutic efficacy. In our study, the surgery was performed in one stage, which involved aggressive posterior debridement, bone graft reconstruction, instrumentation, and etiological examination.

The use of interbody fusion and instrumentation is still controversial. Emery et al¹⁸ reported that sagittal correction is poor without instrumentation, and therefore a long period of bed rest and a body cast, or even additional posterior surgery, might be required. Internal fixation of the affected vertebral bodies offered early mobilization, which helps control inflammation, shorten bed rest time, and facilitate rehabilitation.¹⁹ Currently, iliac crest bone autograft is still considered the gold standard for lumbar spinal fusion. However, due to the high morbidity rate of continuous

donor site pain, paresthesia, infection, and the rapid development of bone graft substitutes, allograft bone has been used widely in spinal fusion. Compared with other substitutes, allograft bone has osteoinductive properties and is relatively cheap and readily available.²⁰ While it required a longer time to reach bony union than autograft bone, there was no difference in long-term clinical outcomes.²¹ In this study, all patients were given allograft bone into the disc space where necrotic tissue was removed and blood flow is good, combined with pedicle screw fixation. Patient outcomes in this study were satisfactory.

Debridement of all infected bone, plate and disc tissue was able to prevent the accumulation of inflammatory material. Though it is generally accepted that an anterior approach allows direct access to the infected tissues and sufficient debridement,³ the risk of injury to the vasculature is high due to the abundant arteries and veins anterior to the lumbar spine, and it is difficult to operate in the lower lumbar spine.¹⁶ Given the successful use of posterior debridement to treat lumbar spinal tuberculosis,²² we believed it is also appropriate to use this method to treat lumbar postoperative spondylodiscitis. To remove pathogens as thoroughly as possible, we adopted a closed irrigation and drainage technology to wash the disc space persistently, which is typically used in the treatment of osteomyelitis and joint infections. However, in the past, Rohmiller applied a closed suction-irrigation system in 17 patients with postoperative infection after spinal instrumentation,²³ and Mauer treated spinal epidural empyema with limited operation and continuous irrigation and drainage²⁴; both produced excellent results. Some surgeons recommend microsurgery for the management of postoperative spondylodiscitis, but we believe that the infected wound should be opened, the pus should be drained, and the necrotic tissue should be removed.

There are some limitations in this study. When the vertebral area was significantly destroyed, interbody fusion was difficult and might damage the neural structures or vessels, requiring more attention and patience. Allograft bone graft might require a longer time to reach bony union than autograft bone. During the irrigation period, it is difficult for patients to turn over alone, and assistance from a nurse is required. Furthermore, the sample size in this study was small, and a larger number of patient is needed in the next stage.

In conclusion, this one-stage posterior procedure might be effective in the treatment of postoperative spondylodiscitis. This procedure was associated with dramatically alleviated symptoms, especially back pain, immediate postoperative stability and early ambulation, which decreases hospitalization, rehabilitation, antibiotic course and postoperative morbidity. Nevertheless, further study with a larger sample size and longer follow-up is needed.

References

- Gerometta A, Bittan F, Rodriguez Olaverri JC. Postoperative spondylodiscitis. *Int Orthop*. 2012;36(2):433–438.
- Santhanam RK, Lakshmi A. Retrospective analysis of the management of postoperative discitis: a single institutional experience. *Asian Spine J*. 2015;9(4):559–564.
- Wang X, Tao H, Zhu Y, et al. Management of postoperative spondylodiscitis with and without internal fixation. *Turk Neurosurg*. 2015;25(4):513–518.
- Lee JS, Suh KT. Posterior lumbar interbody fusion with an autogenous iliac crest bone graft in the treatment of pyogenic spondylodiscitis. *J Bone Joint Surg Br*. 2006;88(6):765–770.
- Lee CK, Vessa P, Lee JK. Chronic disabling low back pain syndrome caused by internal disc derangements. The results of disc excision and posterior lumbar interbody fusion. *Spine (Phila Pa 1976)*. 1995;20(3):356–361.
- Dubouset J. Treatment of spondylolysis and spondylolisthesis in children and adolescents. *Clin Orthop Relat Res*. 1997;(337):77–85. <https://doi.org/10.1097/00003086-199704000-00010>.
- Ford LT, Key JA. Postoperative infection of intervertebral disc space. *South Med J*. 1955;48(12):1295–1303.
- Marmelstein D, Homagk N, Hofmann GO, et al. Adjuvant systemic antibiotic therapy for surgically treated spondylodiscitis. *Z Orthop Unfall*. 2015;153(2):165–170.
- Piotrowski WP, Krombholz MA, Muhl B. Spondylodiscitis after lumbar disk surgery. *Neurosurg Rev*. 1994;17(3):189–193.
- Barrey C, Launay O, Freitas E, et al. The follow-up of patients with postoperative infection of the spine. *Eur J Orthop Surg Traumatol*. 2013;23(Suppl. 1):S29–S34.
- Rao PJ, Phan K, Maharaj MM, et al. Histological analysis of surgical samples and a proposed scoring system for infections in intervertebral discs. *J Clin Neurosci*. 2016;30:115–119.
- Go JL, Rothman S, Prosper A, et al. Spine infections. *Neuroimaging Clin N Am*. 2012;22(4):755–772.
- Mazzie JP, Brooks MK, Gnerre J. Imaging and management of postoperative spine infection. *Neuroimaging Clin N Am*. 2014;24(2):365–374.
- Diehn FE. Imaging of spine infection. *Radiol Clin N Am*. 2012;50(4):777–798.
- Adam D, Papacocea T, Hornea I, et al. Postoperative spondylodiscitis. A review of 24 consecutive patients. *Chirurgia (Bucur)*. 2014;109(1):90–94.
- Endres S, Wilke A. Posterior interbody grafting and instrumentation for spondylodiscitis. *J Orthop Surg (Hong Kong)*. 2012;20(1):1–6.
- Derbent A, Yilmaz B, Uyar M. Chronic pain following spine surgery. *Agri*. 2012;24(1):1–8.
- Emery SE, Chan DP, Woodward HR. Treatment of hematogenous pyogenic vertebral osteomyelitis with anterior debridement and primary bone grafting. *Spine (Phila Pa 1976)*. 1989;14(3):284–291.
- Przybylski GJ, Sharan AD. Single-stage autogenous bone grafting and internal fixation in the surgical management of pyogenic discitis and vertebral osteomyelitis. *J Neurosurg*. 2001;94(1 Suppl):1–7.
- Nickoli MS, Hsu WK. Ceramic-based bone grafts as a bone grafts extender for lumbar spine arthrodesis: a systematic review. *Global Spine J*. 2014;4(3):211–216.
- Gibson S, McLeod I, Wardlaw D, et al. Allograft versus autograft in instrumented posterolateral lumbar spinal fusion: a randomized control trial. *Spine (Phila Pa 1976)*. 2002;27(15):1599–1603.
- Xu Z, Wang X, Shen X, et al. One-stage lumbopelvic fixation in the treatment of lumbosacral junction tuberculosis. *Eur Spine J*. 2015;24(8):1800–1805.
- Rohmiller MT, Akbarnia BA, Raiszadeh K, et al. Closed suction irrigation for the treatment of postoperative wound infections following posterior spinal fusion and instrumentation. *Spine (Phila Pa 1976)*. 2010;35(6):642–646.
- Mauer UM, Kunz U. Spinal epidural empyema. Limited surgical treatment combined with continuous irrigation and drainage. *Unfallchirurg*. 2007;110(3):250–254.