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Special issue

Uniportal endoscopic decompression and debridement for infectious diseases of spine with neurological deficits: a retrospective study in China

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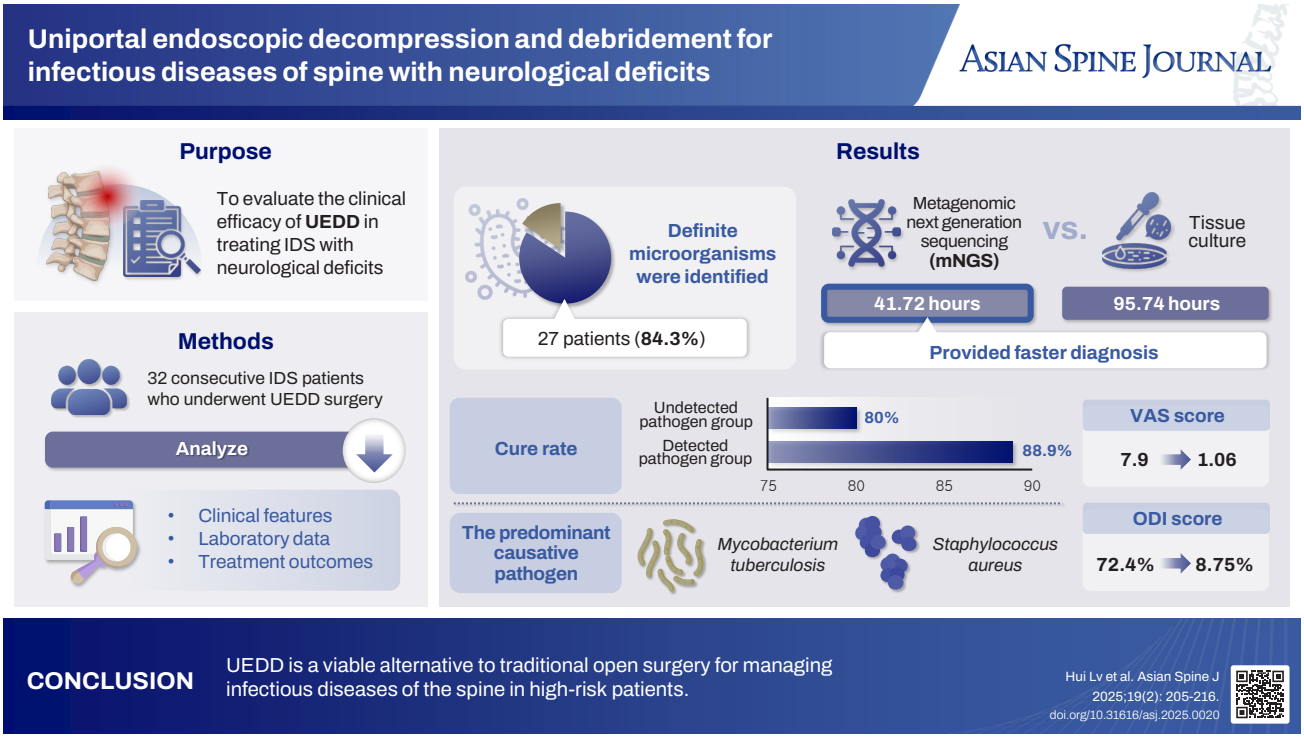

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Uniportal endoscopic decompression and debridement for infectious diseases of spine with neurological deficits: a retrospective study in China

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Study Design: A retrospective study.
Purpose: To evaluate the clinical efficacy of uniportal endoscopic decompression and debridement (UEDD) in treating infectious diseases of the spine (IDS) with neurological deficits.
Overview of Literature: IDS patients with neurological deficits often require urgent surgical decompression. However, the efficacy of UEDD in this complex patient population is not well-characterized.
Methods: This retrospective study analyzed 32 consecutive IDS patients who underwent UEDD surgery. Clinical features, laboratory data (erythrocyte sedimentation rate and C-reactive protein), and treatment outcomes were analyzed.
Results: Definite microorganisms were identified in 27 patients (84.3%), with 24 (88.9%) meeting cure criteria. The cure rate was significantly higher in the detected pathogen group compared to the undetected pathogen group (88.9% vs. 80%; χ^2=19.36, p<0.0001). Metagenomic next generation sequencing (mNGS) provided faster diagnosis (41.72±6.81 hours) compared to tissue culture (95.74±35.47 hours, p<0.05). The predominant causative pathogen was *Mycobacterium tuberculosis*, followed by *Staphylococcus aureus*. Significant improvements were observed in Visual Analog Scale pain scores, from a mean of 7.9 preoperatively to 1.06 at 1 year postoperatively. The Oswestry Disability Index revealed a similar trend, showing significant improvement (p<0.05).
Conclusions: UEDD is a viable alternative to traditional open surgery for managing IDS in high-risk patients. UEDD offers a dual therapeutic-diagnostic advantage during the initial admission phase, enabling simultaneous debridement, neurological decompression, and targeted biopsy in a single intervention. Compared with traditional tissue culture, mNGS enables rapid microbiological diagnosis and extensive pathogen coverage.

Keywords: Spondylitis; High-throughput nucleotide sequencing; Endoscopy; Debridement; Infectious bone diseases

Introduction

Infectious diseases of the spine (IDS) encompass a range of musculoskeletal infections caused by pathogenic microorganisms in the intervertebral disc, vertebral body, spinal canal, or the surrounding tissues. These infections account for approximately 2%–7% of all musculoskeletal infections in the body [1-3]. Recent advancements in diagnostic methods for IDS have significantly improved the detection rate of microorganisms [4,5]. A combination of diagnostic modalities such as clinical radiology, microbial culture, molecular assays—including metagenomic next generation sequencing (mNGS)—and histopathology are increasingly being employed in clinical practice. Additionally, improved biopsy techniques, including the use of semirigid grasping forceps, enable the collection of larger specimen volumes, further increasing diagnostic efficacy [6]. Accurate etiological diagnosis of IDS is indispensable in controlling disease progression through personalized anti-infection protocols.

As population ages, specialist surgeons increasingly face the challenge of managing patients with IDS who often have poorly controlled comorbidities, including type 2 diabetes, hypertension, and renal insufficiency, along with complications such as heart disease and cerebral infarction. These patients typically require a prolonged period of management to stabilize their underlying conditions, thereby reducing anesthesia and perioperative risks. Emergent open surgery inevitably increases perioperative mortality [7]. Therefore, in IDS cases with neurological deficits warranting urgent surgery, a difficult decision arises regarding whether to prioritize preserving neurological function or proceeding with safe surgical intervention. This dilemma highlights the critical need for developing safe and effective debridement and decompression procedures tailored to patients with compromised systemic health and neurologic deficit.

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Minimally invasive techniques have revolutionized surgical practice [8,9], with percutaneous endoscopy technology undergoing rapid advances over the past 2 decades. Spinal endoscopy, in particular, has become a widely accepted modality in clinical settings [10,11], offering numerous benefits, including reduced tissue damage, local anesthesia feasibility, enhanced perioperative safety, and effective drainage and irrigation of paravertebral and epidural spaces. Kim et al. [12] demonstrated the effectiveness of endoscopic treatment for thoracic spinal myelopathy in a 73-year-old patient with multiple comorbidities, including a severe kyphotic deformity (120°) resulting from spinal tuberculosis. This successful outcome underscores the potential of spinal endoscopic techniques as a viable alternative to traditional open decompression and fixation surgeries. We believe that endoscopic techniques may be particularly beneficial in managing IDS patients with multiple comorbidities and neurologic deficits. However, there is a lack of evidence regarding the efficacy and safety of spinal endoscopy in patients with IDS complicated by neurological deficits and multiple comorbidities. This study aimed to address this knowledge gap by investigating the effectiveness and safety of uniportal endoscopic decompression and debridement (UEDD) in this complex patient population.

Materials and Methods

This retrospective study was conducted at two-center hospital with the approval of the Institutional Review Board (IRB) of Jiangbei Branch of Southwest Hospital, 958th Hospital of the PLA Army (2024-KY003). Due to the retrospective nature of the study, the need to obtain the informed consent was waived by the IRB of 958th Hospital of the PLA Army. The American Society of Anesthesiologists (ASA) physical status classification system was used to assess comorbidities associated with IDS. The inclusion criteria consisted of the following conditions. Patients with ASA grades III and IV were included to evaluate the safety of spinal endoscopic technique. Additionally, the neurological function assessment developed by the American Spinal Cord Injury Association (ASIA) served as an inclusion criterion for patients with ASIA grade D or lower. Patients who underwent spinal endoscopy for non-infectious indications were excluded. An electronic database search was conducted to collect data regarding demographic characteristics, clinical manifestations, radiological manifestations, laboratory tests, microbiological cultures, histopathological examinations, and mNGS test results.

Surgical techniques

Patient positioning

All procedures were performed by a single experienced surgeon. With the patient in a prone position on a radiolucent table, the target vertebral interval was identified using C-arm fluoroscopy. The target vertebral space and pedicle positions of the upper and lower vertebral bodies were marked on the body surface under fluoroscopic guidance (Fig. 1H–J).

Working channel establishment

Following standard skin sterilization and draping, local anesthesia was administered in a layered fashion. A 5 mL dose of superficial skin anesthetic was followed by layer-by-layer administration of 10 mL of 2% lidocaine, 10 mL of ropivacaine, and 10 mL of 0.9% saline. The deep fascia and the peri foraminal area were anesthetized with a puncture needle. After achieving satisfactory local anesthesia, an 8 mm incision was made approximately 3 cm lateral to the right posterior median spinous process. An orthopedic drill sighting device was inserted into the area outside the foramen, and a confirmatory X-ray was performed to ensure the dilator tip was positioned in the foraminal area outside the target intervertebral space. The endoscope (SPINENDOS GmbH, Munich, Germany) was then inserted directly into the superior and inferior articular processes outside the target intervertebral space via a working cannula (Fig. 1F–G).

Foraminoplasty, debridement, and decompression

A representative case involving the T9/10 intervertebral space is presented (Fig. 1A–E). The procedure commenced after channel placement. A radio frequency bipolar electrode was employed to stop bleeding, and the soft tissue in the visual field was cleared to expose the upper and lower articular processes. The lateral edge of the T9 inferior articular process was removed using the radio frequency bipolar electrode, followed by excision of the inferior articular process of T9 with a trephine. A grinding drill was then used to dissect the superior articular process of T10 (Fig. 1K–M). After removing the ligamentum flavum, the working cannula was gently inserted into the spinal canal, revealing a large amount of inflammatory granulation tissue under the endoscope. A Kerrison rongeur and a high-speed burr were employed to gradually enlarge the bone channel while controlling any bleeding with the radio frequency bipolar electrode. A neurosurgery dissector was then used to probe the posterior wall of the vertebral body, carefully exploring the dural sac for ventral compression.

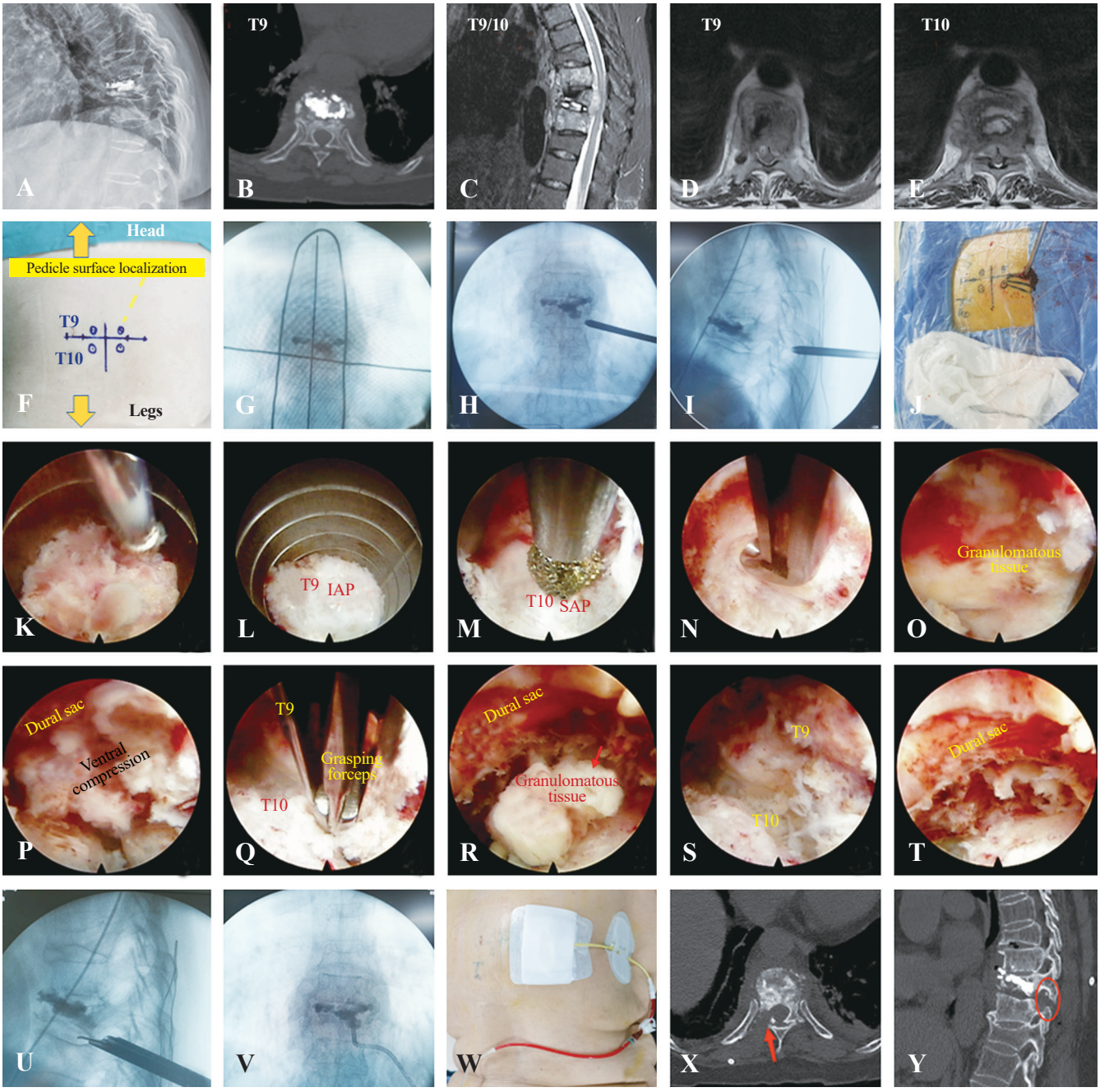

Fig. 1. Typical case involves a 76-year-old female diagnosed of spinal tuberculosis who was misdiagnosed as having an osteoporotic compression fracture after undergoing percutaneous vertebroplasty. The patient's initial American Spinal Cord Injury Association (ASIA) grade was B before surgery. Following the uniportal endoscopic decompression and debridement via a transforaminal approach, the patient's ASIA grade improved to C. At the 1-year follow-up, the patient achieved an ASIA grade of E. **(A–E)** Preoperative X-ray, computed tomography (CT), and magnetic resonance imaging radiographic examination revealed bone destruction of the T9–10 vertebrae and formation of a ventral epidural abscess that compressed the spinal cord. **(F–G)** Marked lines for the target intervertebral disc were obtained by C-arm fluoroscopy. **(H–J)** Endoscopic working channel establishment. **(K–M)** Soft tissue cleaning and foraminoplasty with a trephine and high-speed grinding drill. **(N–P)** Intraspinal exploration of the anatomical relationship between abscess and dural sac. **(Q–S)** Endoscopic decompression and debridement by grasping ventral epidural abscess and suspected infected tissue. (T) Final exploration after ventral dural sac decompression. **(U–W)** A negative pressure drainage tube was placed into the target disc space with confirmation of fluoroscopy. **(X, Y)** Postoperative CT revealed foraminoplasty of the T9–10 vertebrae (red arrow and circle). IAP, inferior articular process. SAP, superior articular process.

The dural sac in this case was found to be severely compressed by the proliferating granulomatous tissue (Fig. 1N–P). Nucleus pulposus forceps and Kerrison rongeur were alternately used to clear the ventral inflammatory tissue and decompress the dural sac. This procedure exposed the intervertebral space for disinfection and allowed for the careful cleaning of inflammatory tissue in the spinal canal, extending from the upper edge of the

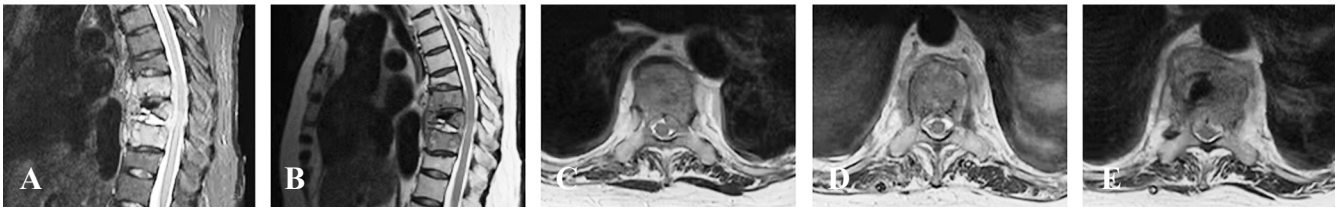

Fig. 2. Postoperative sagittal and axial magnetic resonance imaging (MRI). **(A–E)** Postoperative MRI revealed a significant decrease in the size of the ventral epidural abscess, along with an increase in the area of the dural sac.

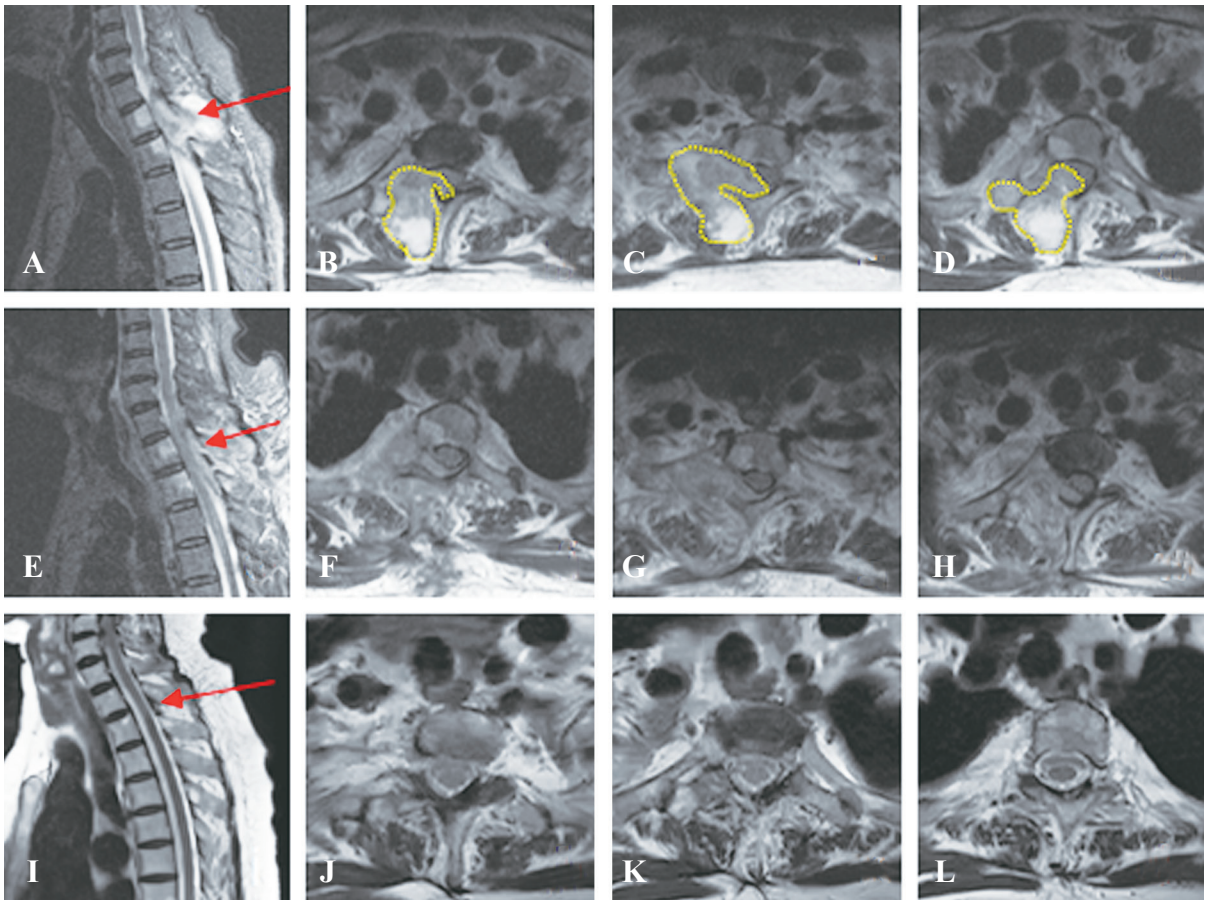

Fig. 3. A typical case involved: A 67-year-old woman diagnosed of thoracic tuberculous infection, which resulted in a dorsal epidural abscess compressing the spinal cord. The patient presented with a preoperative American Spinal Cord Injury Association (ASIA) grade of C. Uniportal endoscopic decompression and debridement (UEDD) procedure was conducted via an interlaminar approach. At the 1-year follow-up, the patient had improved to an ASIA grade of E. **(A–D)** Preoperative sagittal and axial magnetic resonance imaging (MRI) indicated the presence of a dorsal epidural abscess that was pressing on the spinal cord (arrow). The extent of the abscess is depicted by the yellow dotted line. **(E–H)** After UEDD, the spinal cord was successfully decompressed, resulting in an increased area of the dural sac (arrow). **(I–L)** At the 1-year follow-up, the MRI revealed normal spinal cord morphology and there was no inflammatory tissue in the spinal canal (arrow).

pedicle in the T10 vertebral body to the lower edge of the pedicle in the T9 vertebral body, along the posterior edge of the vertebral body. All inflammatory tissues suspected of infection were excised. These included the paravertebral muscles, necrotic tissue, intervertebral discs, granulation tissue, and disrupted vertebral bodies (Fig. 1Q–S). When the dura shows signs of adhering inflammatory tissue, gentle and careful manipulation are crucial. In this case, the gap between normal dural tissue and the inflammatory tissue was identified, and inflammatory tissue was delicately removed with nucleus pulposus forceps. To avoid damage, aggressive cleaning was avoided, especially when inflammatory tissue was difficult to separate. If the dural sac ruptures, it may lead to intraspinal infection, resulting in catastrophic iatrogenic complications, including potential intracranial infection. Intraoperative irrigation typically requires more than 3 L of saline. Successful decompression was confirmed by visible pulsation of the dural sac (Fig. 1T). Finally, a negative pressure drainage tube (di-

ameter, 3.2 mm) was placed into the target disc space, confirmed via fluoroscopy. The tube was secured with sutures and dressed with a sterile dressing (Fig. 1U–W).

The second phase of bone graft fusion and internal fixation

Spinal instability following spinal endoscopy can manifest as mechanical pain symptoms, such as discomfort when turning over or getting out of bed. Vertebral body destruction, particularly with vertebral height loss of more than 50% observed in radiological assessments, can also occur. Notably, the Spinal Instability Neoplastic Score (SINS) is a valuable tool for the quantitative assessment of spinal stability, with a score exceeding 13 indicating the necessity for secondary fixation surgery [13]. In such cases, open procedures, including secondary pedicle screw stabilization and intervertebral fusion surgery, are essential. In the present study, 16 patients underwent secondary bone graft fusion and pedicle screw stabilization. Typical cases of the transforaminal approach for UEDD are shown in Figs. 1 and 2, and the transforaminal approach is illustrated in Fig. 3.

Postoperative management

Intraoperative specimens were collected for histochemical staining, microbiological culture, and mNGS. Caseous tissues suspected of tuberculosis infection were analyzed using X-pert or mNGS to confirm the presence of the rifampicin resistance-determining region. Conservative anti-infection treatment is critical to follow-up care for patients exhibiting spinal stability. An intravenous antibiotic regimen was administered for 2 to 4 weeks, depending on the results of microbial mNGS and cultures, followed by oral administration for an additional 6 to 8 weeks. However, oral administration of drugs for TB should last no less than 9 months. Once initially controlled, a downward trend in infection markers and a 24-hour drainage volume of less than 20 mL is an indication for removal of the drainage tube. Additionally, the patient should wear a rigid brace for 3 months.

For patients with spinal instability, the treatment strategy primarily focuses on anti-infection therapy, with surgical intervention serving as an essential adjunct. The timing of the second operation is critical and typically considered after 2 to 4 weeks of appropriate antibiotic therapy, when levels of C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR) demonstrate significant improvement. During this period, the underlying systemic diseases are often better managed, resulting in an improved ASA classification grade, typically advancing to grade I or II. Following surgery, anti-infective therapy should continue, adhering to the same protocol as conservative treatment.

Outcome assessment

Operative time, duration of drainage tube retention, length of hospital stay, and intraoperative and postoperative complications were recorded. Serological tests, including liver function, ESR, and CRP, were conducted to assess infection control. We also documented postsurgical clinical signs and symptoms, and quantified patients' pain levels using the Visual Analog Scale (VAS) and evaluated their functional status using the Oswestry Disability Index (ODI). The ASIA grading system was employed to assess the recovery of postoperative neurological function.

The criteria for cured infection were as follows: (1) Relief of clinical symptoms, and daily life unaffected by pain at the site of the diseased spine, with a VAS score of <2; (2) normal ESR and CRP levels in two random tests after cessation of oral antibiotics; (3) postoperative computed tomography (CT) indicating intervertebral bone fusion or magnetic resonance imaging confirming the disappearance of the high-intensity infected area in the T2 image.

Statistical analysis

Continuous variables were presented as mean±standard deviation and between-group differences were assessed using the *t*-test (IBM SPSS ver. 21.0; IBM Corp., Armonk, NY, USA). Categorical variables were presented as frequency (percentage) and between-group differences were assessed using the chi-square test or Fisher's exact test. All *p*-values <0.05 were considered indicative of statistical significance.

Results

Thirty-two consecutive IDS patients with neurological deficits and multiple comorbidities who underwent UEDD surgery were included in this study. The mean age of patients in this series was 67.8 years, and the majority were male. Type 2 diabetes was the most common comorbidity. Twenty-five patients were classified as ASA grade III and seven patients as ASA grade IV. Prior to admission, 21 patients had received occasional antibiotic therapy, six patients had undergone only symptomatic treatment with oral non-steroidal anti-inflammatory drugs, and five patients had received diagnostic antituberculosis therapy. The demographic

Table 1. Patient demographics and comorbidities

Characteristic	Value
Age (yr)	67.8±19.0
Gender	
Male	21 (65.6)
Female	11 (34.4)
ASA grade	
III	25
IV	7
Smoker	13 (40.6)
Steroid use	7 (21.9)
Body mass index (kg/m^2)	23.7±5.8
Symptom onset to admission (mo)	11.8±22.8
Comorbidity	
Diabetes mellitus	22 (68.8)
Hypertension	18 (56.2)
Heart disease	14 (43.8)
Renal failure	11 (34.4)
Hepatopathy	10 (31.3)
Cerebral infarction	8 (25.0)
Pneumonia	5 (15.6)
Active malignancy	3 (9.3)
Follow-up (mo)	13.4±5.5

Values are presented as mean±standard deviation or number (%).
ASA, American Society of Anesthesiologists.

Table 2. Patient clinical and radiological characteristics and surgical information

Variable	Value
The location of the epidural abscess	
T1–T2	1
T3–T4	1
T9–T10	1
T11–T12	2
T12–L1	3
L1–L2	4
L2–L3	2
L3–L4	9
L4–L5	7
L5–S1	2
Location of abscess relative to thecal sac	
Dorsal	8
Ventral	18
Circumferential	6
Clinical symptoms	
Neurological deficits	32
Severe back pain	29
Fever	16
Weight loss	15
Radicular pain in the lower extremities	14
Numbness of lower limbs	13
Night sweats	6
Paralysis	2
Degree of segmental kyphosis (°)	
Thoracic	35.2
Lumbar	4.7
Height of vertebral destruction	
<1/2 collapse	29
No collapse	3
Operative duration (min)	151.4±94.7
Operative approach	
Interlaminar approach	11
Transforaminal approach	21
Secondary fixation and fusion	16
Remission of the abscess	32

Values are presented as number of patients or mean±standard deviation.

and clinical characteristics of these patients are summarized in Table 1.

In our series, infections in the lumbar spine were the most prevalent, followed by the thoracic spine. Specifically, the L3–4 and L4–5 segments were most affected in these regions. Severe back pain was the most common symptom. Epidural compression was predominantly observed on the ventral side, accounting for 56.3% of cases. Radiological assessments revealed a mean preoperative kyphotic angle of 35.2° in the thoracic focal segment, and a mean Cobb angle of 4.7° in the lumbar segment. The extent of vertebral bone destruction in all patients was less than half (Table 2).

The mean operation time was 151.4 minutes (range, 60–320 minutes), the mean length of hospital stay was 39.3 days (range, 15–83 days), and the mean duration of drainage was 11.8 days (range, 7–16 days). Only two patients had postoperative paresthesia of the lower limbs (Table 3).

Microbiological identification revealed definitive causative agents in 27 patients. Five patients did not receive an etiological diagnosis and were treated with empiric broad-spectrum antibiotics, typically a combination of vancomycin and a fluoroquinolone. The treatment outcome was favorable, with 28 patients meeting the criteria for being cured. Among patients with detectable bacteria, 24 individuals (88.9%) were successfully cured. Conversely, among patients with no detect-

Table 3. Patients ASIA grade postoperatively

Variable	No. of cases	ASIA grade				
		A	B	C	D	E
Preoperative	32	0	3	8	21	0
Postop 2 day	32	0	2	6	16	8
Discharge	32	0	1	3	6	22
Postop 3 mo	32	0	1	1	2	28
Postop 1 yr	32	0	0	0	1	31

ASIA, American Spinal Cord Injury Association; Postop, postoperative.

Table 4. Comparison of clinical and laboratory indexes at different outpatient service postoperatively

Variable	ESR (mm/hr)	CRP (mg/L)	VAS	ODI (%)
Preoperative	64.53±26.50	37.75±34.75	6.94±1.13	72.39±7.95
Postop 1 mo	50.21±21.77[a)]	24.76±18.41[a)]	2.8±0.81[a)]	48.56±5.19[a)]
Postop 6 mo	26.19±17.56[b)]	10.41±5.28[b)]	1.69±0.53[b)]	18.13±3.74[b)]
Postop 1 yr	12.78±5.37[c)]	4.13±2.14[c)]	1.06±0.72[c)]	8.75±1.36[c)]
p-value	<0.001*	<0.001*	<0.001*	<0.001*

Values are presented as mean±standard deviation.
ESR, erythrocyte sedimentation rate; CRP, C-reactive protein; VAS, Visual Analog Scale; ODI, Oswestry Disability Index; Postop, postoperative.
*p<0.05. [a),b),c)]indicates the difference was statistically significant compared with preoperative.

able bacteria, 4 (80%) were cured. Statistical analysis revealed a significant difference in cure rate between the group with detected pathogens and group with undetected pathogen (80% versus 88.9%; χ^2=19.36, p=0.000). Three patients experienced inadequate infection control, although continued antibiotic administration halted the spread of the infection. One of these cases lacked a definitively identified causative organism, while two cases of tuberculosis developed multi-drug resistance due to poor medication compliance.

Neurological deficits improved over time, as assessed by the ASIA grading system, with detailed results presented in Table 3. Pain levels, as measured by the VAS pain scores, consistently decreased from a mean of 7.9 preoperatively to 1.06 at the final follow-up. ODI demonstrated similar trends, with differences reaching statistical significance (p<0.05). Serum CRP levels decreased from an average preoperative value of 37.75±34.75 to 24.76±18.41 mg/L at 1 month postoperatively, 10.41±5.28 mg/L at 6 months postoperatively, and 4.13±2.14 mg/L at the last follow-up. ESR levels decreased more gradually over time (Table 4).

Tissue cultures were positive in 11 patients, while mNGS results were positive in 21 patients. Notably, there were two false-positive tissue culture results compared to four false-positive mNGS results. The average

Table 5. Spectrum of microbiological test results in spondylodiscitis

	Final identification	Culture	mNGS
Mycobacterium tuberculosis	12	3	10
Staphylococcus aureus	7	4	4
Escherichia coli	2	2	1
Staphylococcus epidermidis	2	1	2
Mycobacterium Avium Complex	1	0	1
Cryptococcus	1	0	1
Aspergillus terreus	1	0	1
Aspergillus flavus	1	1	1

mNGS, metagenomic next generation sequencing.

time to obtain a positive result from tissue culture was significantly longer, at 95.74±35.47 hours, compared to 41.72±6.81 hours for mNGS (p<0.05). *Mycobacterium tuberculosis* was the most common causative pathogen identified, followed by *Staphylococcus aureus*. Detailed strain information is provided in Table 5.

After drain removal, two patients experienced poor wound healing at the local drainage site, but eventually achieved healing following repeated dressing changes. One patient developed a pulmonary infection accompanied by pleural effusion, which responded well to anti-infective treatment. Drug-related hepatic dysfunction occurred in two cases of tuberculosis and one case of *Aspergillus terreus* infection. In these cases, we modified the antibiotic regimen and administered hepatoprotective therapy to manage the adverse effects.

Discussion

The key finding of this study was that UEDD combined with subsequent antibiotic therapy achieved satisfactory efficacy (87.5% cure rate) in IDS patients with neurological deficits and multiple comorbidities, consistent with previous literature reports [14]. Moreover, UEDD offered a dual therapeutic-diagnostic advantage over traditional percutaneous biopsy during the initial admission phase, enabling simultaneous debridement, neural decompression, and targeted biopsy in a single intervention. This integrated approach facilitated timely neurological recovery through effective decompression of infected and inflamed tissues, and also accelerated etiological diagnosis through direct visualization and precise specimen collection. By overcoming the limitations of conventional biopsy methods, especially in cases requiring urgent intervention for neurological preservation, UEDD represents a major advancement in the management of spinal infections, combining

therapeutic efficacy with diagnostic precision to optimize patient outcomes.

Despite its growing acceptance, spinal endoscopy in patients with IDS remains a topic of debate [15]. A major concern is the limited scope of endoscopic debridement, and that the use of irrigated saline can potentially facilitate the spread of infection. However, this study demonstrates that endoscopy can achieve therapeutic outcomes comparable to open surgery. This may be attributable to several factors. First, anti-infective antibiotic therapy is the cornerstone of IDS treatment, and a sensitive antibiotic regimen is crucial for successful treatment. In this study, emergency UEDD played a crucial role in improving neurological function by decompressing the spinal cord, while also enabling the collection of samples for comprehensive testing to identify pathogenic microorganisms. Subsequently, we formulated personalized antibiotic regimens based on the drug sensitivity testing results. Consistent with our findings, Pola et al. [16] identified microbiological diagnosis as a primary predictor of treatment success in their multifactorial analysis of 207 patients with pyogenic spondylodiscitis. The therapeutic benefits of UEDD extend beyond microbiological diagnosis. This minimally invasive procedure effectively removes necrotic tissue, while irrigation with normal saline and catheter utilization facilitate the discharge of local inflammatory substances and abscesses. By reducing the bacterial load and eliminating bacterial biofilm, UEDD helps reinstate the physiological healing process of acute wounds. Furthermore, local antibiotic injection through the drainage tube can provide additional benefits once a sensitive antibiotic regimen is established, enhancing the overall treatment efficacy. The current study observed no instances of iatrogenic spinal infection associated with standardized saline irrigation protocols, aligning with the established safety profiles in a prior systematic review [17]. This favorable outcome may be attributed to the implementation of two key procedural safeguards in our spinal infection debridement protocol: maintained patency of irrigation outflow channels through real-time pressure monitoring (target <30 mm Hg) and extended postoperative drainage (mean duration, 11.8 days) using negative pressure systems.

The management of IDS primarily centers on targeted antimicrobial therapy, while surgical intervention remains a critical adjunctive approach in selected cases. However, the optimal management strategy for IDS patients presenting with multiple comorbidities remains a subject of ongoing debate within the spine surgery community, particularly regarding the optimal balance between conservative pharmacotherapy and invasive surgical procedures. Jin et al. [18] investigated the risk factors for treatment failure in intervertebral discitis, comparing conservative and surgical approaches. Their study identified epidural abscesses, cervical or thoracic spine involvement, and multi-segment spinal involvement as risk factors for conservative treatment failure. Giampaolini et al. [19] proposed a criterion for surgical intervention in pyogenic spondylodiscitis, recommending surgical debridement after 4 weeks of conservative treatment if inflammatory markers do not significantly decline (ESR <50 mm/hr and CRP <2.7 mg/dL). The universal surgical indications for IDS include neurological deficits, and imaging signs of instability, deformity, or abscesses. Conventional anterior or posterior debridement procedures have been employed for surgically indicated IDS cases, demonstrating favorable outcomes in historical series [20-22]. However, our cohort comprised high-risk patients classified as ASA III or IV, a population with documented perioperative mortality rates ranging from 1.82% to 23.0% [23]. Notably, our series achieved zero perioperative mortality. The UEDD technique may offer a preferential therapeutic option for IDS management particularly in patients with compromised systemic conditions. The minimally invasive nature of UEDD, combined with contemporary diagnostic advancements, makes it an attractive alternative to conservative or open surgical procedures for high-risk patients.

Furthermore, UEDD offers a significant advancement over traditional percutaneous biopsy methods, boasting a dual capacity for neural decompression and precise endoscopic delineation of infected tissue margins. These technical advantages, unattainable through standard needle biopsy techniques, enable more effective infection management. In our clinical experience, patients undergoing UEDD exhibited marked postoperative improvement in axial back pain and radicular lower extremity symptoms. Subsequent pain resolution and functional recovery paralleled effective infection control achieved via continuous drainage and targeted antibiotic therapy.

There is no clear consensus regarding the spinal stability assessment, particularly concerning the ambiguous distinction between stability and instability during spinal infections [24]. Inflammatory stimulation often leads to localized tension in the paravertebral muscles, resulting in insensitivity to mechanical pain symptoms. In the present study, the degree of vertebral collapse was minimal, with destruction of the vertebral body being less than 50% in 23 patients, and no vertebral invasion in nine patients. Notably, none of the cases exhibited radiological signs of subluxation or translation.

Consequently, after excluding mechanical symptoms, the highest SINS score recorded among patients was 12. This finding indicates the crucial role of mechanical pain symptoms in stability assessment. Therefore, in cases of epidural abscess with uncertain spinal stability, aggressive internal fixation combined with fusion surgery may be considered imprudent. Such surgical interventions not only extend the operative time and trauma but also increase perioperative risks. Moreover, in the absence of identified pathogenic bacteria, internal fixation can increase the risk of biofilm formation, particularly by *S. aureus*, which is notorious for readily generating biofilms [25]. This can exacerbate the local inflammatory microenvironment, promote osteoclast differentiation, complicate bone fusion, and potentially lead to pseudarthrosis formation [26,27]. A significant advantage of staged surgery is that the first stage involves endoscopic debridement and decompression. This approach provides several benefits, including restoring spinal cord function, enabling microbiological diagnosis, facilitating drainage of local inflammatory factors, and alleviating pain. In the second stage, a systematic reassessment of spinal stability is conducted for an objective evaluation of mechanical symptoms. Subsequent fusion surgery further helps alleviate the local inflammatory microenvironment, creating conditions conducive to bone fusion and promoting osteoblast differentiation. However, in cases with significant spinal stability loss, open debridement, bone graft fusion, and internal fixation may be necessary. This typically involves situations where vertebral collapse exceeds 50%, accompanied by kyphosis greater than 30°, and spinal subluxation or translation, particularly in the cervicothoracic and thoracolumbar junction regions.

Recent studies have documented satisfactory outcomes of endoscopic treatment for spondylodiscitis. Abreu et al. [15] reviewed 342 patients with spondylodiscitis who underwent endoscopic treatment, noting a failure rate of 0 to 33%. They concluded that endoscopic debridement may be an effective and safe method for treating refractory spondylodiscitis. Yamada et al. [28] reported a cure rate of 82.8% in 64 patients with spondylodiscitis who underwent endoscopic surgery combined with negative pressure drainage. Their analysis identified large abscess cavities and multi-level intervertebral infections as risk factors for failure. In our series, patients with a definitive etiological diagnosis exhibited significantly superior therapeutic outcomes compared to those with undetermined pathogens (88.9% versus 80%), suggesting a crucial role of precise microbiological identification in optimizing treatment efficacy for IDS. This observation highlights the clinical significance of targeted pathogen detection in improving infection resolution rates through individualized antimicrobial stewardship. Furthermore, our series achieved an etiological diagnosis rate of 84.3%, surpassing previously reported rates of 71.1% by Duan et al. [14] and 76% by Polo et al. [29]. This diagnostic superiority may be attributed to several key factors. Primarily, the implementation of mNGS significantly enhanced the detection of pathogenic microorganisms. This advanced technique enables comprehensive identification of suspected microbial species by performing high-throughput sequencing of all nucleic acids in clinical specimens. Unlike conventional culture methods, mNGS even detects residual nucleic acids from nonviable organisms, making its effectiveness independent of pathogen viability. A retrospective cohort analysis by Yin et al. [30] demonstrated the superiority of mNGS over conventional culture methods in detecting pathogens in IDS cases. Their study revealed significantly higher pathogen detection rates using mNGS (88.42%) compared to conventional culture methods (43.16%, $p<0.05$), with mNGS demonstrating a diagnostic sensitivity of 86.44% and specificity of 92.00% [30]. Additionally, biopsy specimen quality appears critical in microbiological identification. Polo et al. [29] reported sensitivity rates of 60.00% for open surgical biopsies versus 46.27% for CT-guided biopsies. Our UEDD technique, analogous to open surgical biopsy in terms of specimen acquisition quality, permits endoscopic-guided retrieval of diagnostically superior tissue samples, as illustrated in Fig. 1R. Notably, our culture-based pathogen detection rate (34.3%) proved lower than that reported in literature. While *Staphylococcus* species predominated in the aforementioned studies [14,29], *M. tuberculosis* was the primary causative organism in our cohort. This observed discrepancy in culture sensitivity likely reflects the more stringent culture requirements and prolonged incubation periods inherent to *M. tuberculosis* isolation. Additionally, physiological saline irrigation during specimen collection may reduce bacterial load in cultured samples, potentially impacting conventional culture sensitivity. Our findings further substantiate the diagnostic superiority of mNGS, which exhibits both reduced processing time and broader pathogen detection spectrum compared to conventional methods. This has important implications for the early implementation of personalized antibiotic regimens. However, clinicians should be aware of the inherent risk of false-positive mNGS results, as documented in our prior investigation [4]. Therefore, positive mNGS

findings should be interpreted in conjunction with radiographic characteristics, clinical manifestations, and serological parameters to optimize diagnostic accuracy.

Some limitations of this study should be acknowledged. First, as a retrospective analysis, it has an inherently low level of evidence and lacks a control group, limiting our ability to demonstrate advantages over traditional open debridement. Second, the relatively small sample size and minimal complication rates precluded further multivariate analysis to identify potential risk factors for treatment failure. The relatively short follow-up period may also have confounded the results, as infections could recur after antibiotic discontinuation, particularly in patients with intracellular infections, like tuberculosis. Additionally, technical bias may have been introduced due to the involvement of different surgeons at the two centers. Finally, we were unable to calculate the sensitivity and specificity of mNGS due to the lack of data on non-spondylodiscitis cases diagnosed using this method.

Conclusions

This study demonstrated that UEDD is a viable alternative to traditional open surgery for managing IDS in high-risk patients. In this study, UEDD achieved a clinical cure rate of 87.5% among individuals presenting with neurological deficits (ASIA grade D or lower) and multiple comorbidities (ASA class III–IV). Furthermore, UEDD offered a dual therapeutic-diagnostic advantage during the initial admission phase, enabling simultaneous debridement, neurological decompression, and targeted biopsy in a single intervention. Moreover, mNGS played a significant role in rapid diagnosis and extensive pathogen coverage, outperforming traditional tissue culture.

Key Points

- Uniportal endoscopic decompression and debridement (UEDD) is a viable alternative to traditional open surgery for managing infectious diseases of the spine in high-risk patients.
- UEDD offers a dual therapeutic-diagnostic advantage during the initial admission phase, enabling simultaneous debridement, neurological decompression, and targeted biopsy in a single intervention.
- Compared to conventional techniques, metagenomic next generation sequencing offers faster turnaround times and broader pathogen detection capabilities.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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The datasets generated and/or analyzed during the current study are not publicly available due to limitations of ethical approval involving the patient data and anonymity but are available from the corresponding author on reasonable request.

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