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Intraoperative spinal sonography – potential benefits in degenerative spinal disorders

Intraoperačná spinálna sonografia – potenciálny prínos pri degeneratívnych ochoreniach chrbtice

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Abstract
While the modernization of ultrasound devices and the development of miniature probes since the turn of the millennium have improved the visualization of both normal and pathological structures within the spinal canal, the number of publications dedicated to intraoperative spinal sonography in the context of degenerative spinal disorders remains low. Although rarely utilized, intraoperative ultrasound (IOUS) can provide valuable information during surgery for various degenerative spinal pathologies in some cases. In this short communication, we present four illustrative cases that highlight the potential benefits of intraoperative spinal sonography: one case demonstrating the use of IOUS during a decompressive cervical laminectomy, one case illustrating the benefit of IOUS during the excision of a thoracic disc herniation compressing the spinal cord, and two cases of lumbar microdiscectomy performed using IOUS. In each case, sonographic visualization facilitated the course of the surgical procedure to some extent. While spinal IOUS is not an indispensable tool in these diagnoses, in selected cases of degenerative spinal disorders it can help prevent unnecessary dissection, or, conversely, demonstrate that the decompression of neural structures remains suboptimal. Further research is needed to establish the definitive role of IOUS in the surgical management of degenerative spinal disorders.

Key words
intraoperative ultrasound – spinal cord – spinal roots – disc herniation – magnetic resonance imaging

Súhrn
Hoci modernizácia ultrazvukových prístrojov a vývoj miniatúrnych sond po prelome milénia zlepšili vizualizáciu normálnych aj patologických štruktúr v spinálnom kanáli, počet publikácií venovaných využitiu intraoperačnej spinálnej sonografie pri operáciách degeneratívnych ochorení chrbtice zostáva nízky. Napriek tomu, že sa intraoperačný ultrazvuk (intraoperative ultrasound; IOUS) využíva zriedkavo, môže v niektorých prípadoch poskytnúť cenné informácie počas operácií rôznych degeneratívnych spinálnych patológií. V tomto krátkom oznámení prezentujeme štyri ilustračné prípady, ktoré poukazujú na potenciálny prínos intraoperačnej spinálnej sonografie: jeden prípad demonštrujúci použitie IOUS počas dekompresívnej laminektómie krčnej chrbtice, jeden prípad ilustrujúci prínos IOUS počas exstirpácie hernie hrudnej platničky utláčajúcej miechu, a dva prípady lumbálnej mikrodiskektómie vykonanej s využitím IOUS. V každom z prípadov sonografická vizualizácia do určitej miery uľahčila priebeh chirurgického výkonu. Hoci spinálny IOUS pri týchto diagnózach nepredstavuje nevyhnutný nástroj, vo vybraných prípadoch degeneratívnych ochorení chrbtice môže pomôcť predísť zbytočnej preparácii, alebo naopak zobraziť, že dekompresia nervových štruktúr je suboptimálna. Na zhodnotenie skutočného významu IOUS v chirurgickom manažmente degeneratívnych ochorení chrbtice je potrebný ďalší výskum.

Kľúčové slová
intraoperačný ultrazvuk – miecha – miechové korene – hernia medzistavcovej platničky – magnetická rezonancia

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Introduction

While intraoperative ultrasound (IOUS) has become a relatively established tool in cranial surgery over the past decade, its application in spinal procedures remains more limited, and is predominantly reserved for tumorous lesions [1,2]. The use of IOUS in the context of degenerative spinal disorders is far less common; however, it can serve as a valuable adjunct in selected cases [3]. The aim of this short communication is to present four illustrative cases in which the utilization of IOUS positively influenced the surgical course.

Illustrative case 1

A 73-year-old male with a complex medical history including colon cancer with hepatic metastases, liver cirrhosis, esophageal varices, ischemic heart disease and arterial hypertension conveying high cardiovascular risk suffered a fall and subsequently developed paraplegia and severe upper limb paresis, accompanied by sensory loss extending distally from the nipple line. MRI revealed primary cervical spinal canal stenosis, multi-level disc bulging, and compressive myelopathy at the C5–C6 level (Fig. 1). Intravenous corticosteroid therapy and an urgent decompressive laminectomy were in-

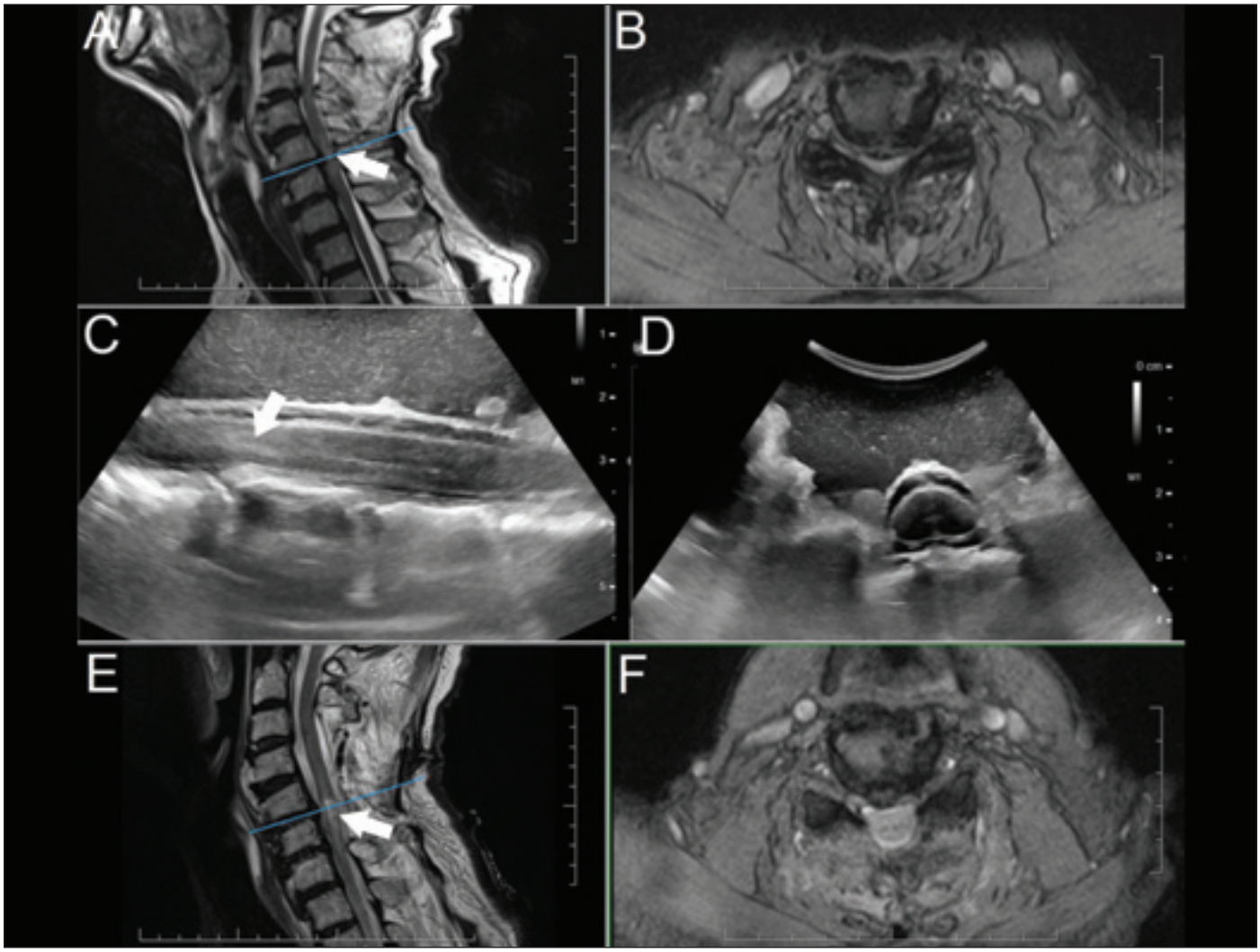


Fig. 1. Case 1. (A) T2-weighted sagittal MRI showing cervical myelopathy due to severe cervical spinal canal stenosis at the C5–C6 level (arrow). (B) T1-weighted contrast-enhanced axial MRI. The level of the axial scan is indicated by the blue line in Fig. 1A. (C) Sagittal intraoperative ultrasound image after sufficient decompression. Note the clear ultrasound hyperechogenicity (arrow). (D) Axial intraoperative ultrasound image after sufficient decompression. Note the normal spinal cord appearance in this scan. (E) Post-operative T2-weighted sagittal MRI showing sufficient decompression. Note the worsening of the myelopathy, which appears more hyperintense compared to the preoperative status (arrow). (F) Corresponding postoperative T1-weighted contrast-enhanced axial MRI. The level of the scan is indicated by the blue line in Fig. 1E.

Obr. 1. Prípad 1. (A) T2-vážený sagitálny obraz MR zobrazujúci cervikálnu myelopatiu v dôsledku závažnej stenózy spinálneho kanála na úrovni C5–C6 (šípka). (B) T1-vážené axiálne zobrazenie MR s kontrastnou látkou. Úroveň axiálneho rezu je označená modrou čiarou na obr. 1A. (C) Sagitálny obraz intraoperačného ultrazvuku po dostatočnej dekompresii. Viditeľná je zreteľná hyperechogenita na ultrazvuku (šípka). (D) Axiálny obraz intraoperačného ultrazvuku po dostatočnej dekompresii. Viditeľný je normálny vzhľad miechy v tomto reze. (E) Pooperačný T2-vážený sagitálny obraz MR zobrazujúci dostatočnú dekompresiu. Viditeľná je progresia myelopatie, ktorá sa javí hyperintenzívnejšia v porovnaní s predoperačným stavom (šípka). (F) Zodpovedajúce pooperačné T1-vážené axiálne zobrazenie MR s kontrastnou látkou. Úroveň rezu je označená modrou čiarou na obr. 1E.

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dicated. Following a C3–C6 laminectomy, an IOUS scan (BK5000 ultrasound system with a BK N13C5 craniotomy transducer, BK Medical Aps, Herlev, Denmark) demonstrated an adequate extent of spinal cord decompression (Fig. 1), thereby obviating the need for further manipulation near the spinal cord. However, the hyperechogenic focus within the spinal cord appeared slightly more prominent than expected based on the preoperative MRI, predicting a complicated neurological recovery (Fig. 1). Postoperative MRI confirmed the ultrasound findings. In the postoperative period, the patient demonstrated only mild neurological improvement: sensation was preserved across his upper extremities, trunk, and lower extremities, and motor function in his upper extremities improved bilaterally in all segments with the exception of finger flexion and extension. The planned posterior stabilization was postponed due to an acute, severe COVID-19 infection.

Illustrative case 2

A 74-year-old male with a history of arterial hypertension and chronic lymphocytic leukemia presented with a five-week history of lower back pain radiating to the lower limbs and progressive paraparesis. On admission, he was non-ambulatory with absent tactile sensation in the lower extremities. MRI of the thoracic spine revealed a right-sided lateral disc herniation and spinal stenosis at the T10-11 level, causing severe spinal cord compression. A posterior decompressive T10 laminectomy was indicated. The herniated thoracic disc was approached lateral to the dura (without the need for dural manipulation) via a posterior transfacet pedicle-sparing approach, as described by Nishimura and colleagues [4]. Following a seemingly adequate discectomy, IOUS (using a BK X18L5s hockey stick transducer) revealed persistent spinal cord compression caused by a residual disc herniation; the remaining disc material was subsequently removed piecemeal (Fig. 2). Postoperatively, the patient was successfully mobilized, regaining ambulatory status, and reported improvement of the sensation in his lower extremities.

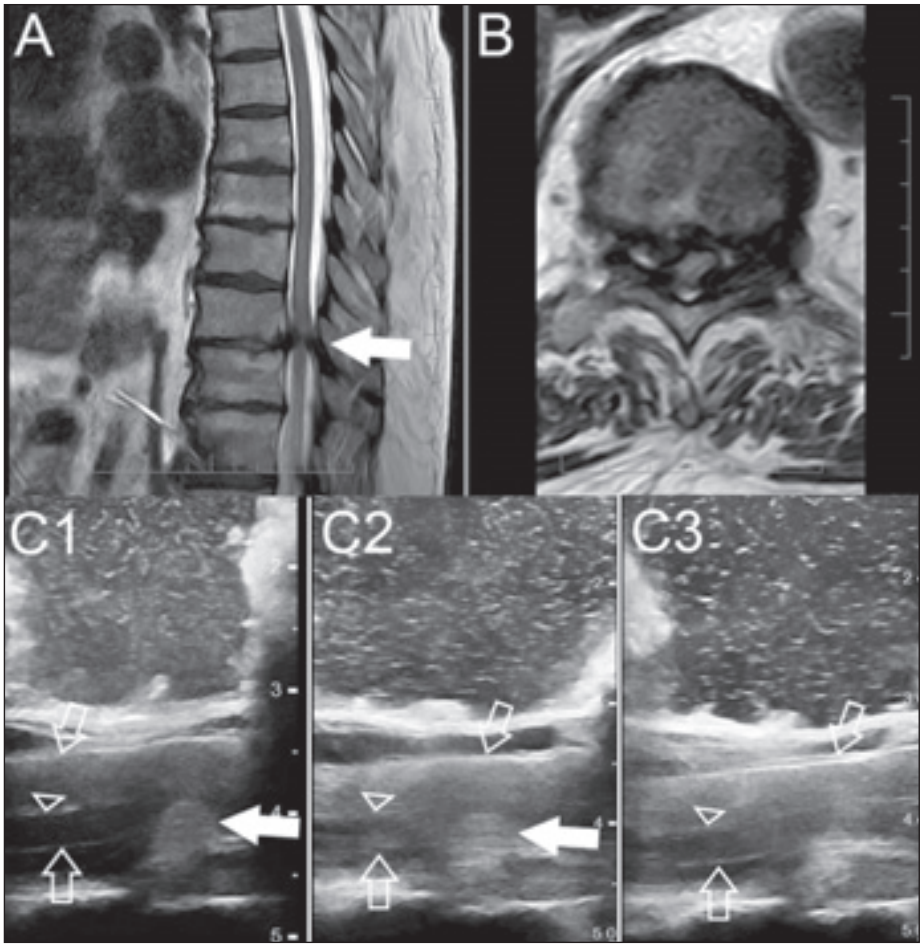


Fig. 2. Case 2. (A) Sagittal T2-weighted MRI scan showing a disc herniation and spinal stenosis at the T10–T11 level, causing severe spinal cord compression. (B) Corresponding T2-weighted axial MRI scan at the T10–T11 level. (C1) Intraoperative ultrasound image showing the situation after laminectomy and prior to discectomy. Open arrows = anterior and posterior spinal cord margins. Arrowhead = central canal of the spinal cord. Note the disc herniation clearly compressing the spinal cord (white arrow). (C2) Situation following partial discectomy (evaluated by the surgeon as sufficient prior to ultrasound scanning). Intraoperative ultrasound clearly demonstrates residual disc material (white arrow). Open arrows = anterior and posterior spinal cord margins; arrowhead = central canal. (C3) Situation after discectomy; note the sufficient decompression of the spinal cord. Open arrows = anterior and posterior spinal cord margins; arrowhead = central canal.

Obr. 2. Prípad 2. (A) Sagitálny T2-vážený obraz MR zobrazujúci herniu medzistavcovej platničky a spinálnu stenózu na úrovni Th10–Th11, ktoré spôsobujú závažnú kompresiu miechy. (B) Zodpovedajúce T2-vážené axiálne zobrazenie MR na úrovni Th10–Th11. (C1) Obraz intraoperačného ultrazvuku zobrazujúci situáciu po laminektómii a pred diskektómiou. Obrysové šípky = predný a zadný okraj miechy. Hrot šípky = centrálny kanál miechy. Viditeľná je hernia platničky zreteľne komprimujúca miechu (biela šípka). (C2) Situácia po čiastočnej diskektómii (pred sonografickým vyšetrením zhodnotená operatérom ako dostatočná). Intraoperačný ultrazvuk jednoznačne zobrazuje reziduálny materiál platničky (biela šípka). Obrysové šípky = predný a zadný okraj miechy; hrot šípky = centrálny kanál. (C3) Situácia po diskektómii; viditeľná je dostatočná dekompresia miechy. Obrysové šípky = predný a zadný okraj miechy; hrot šípky = centrálny kanál.

Illustrative case 3

A 47-year-old male with a history of arterial hypertension presented with severe bilateral radicular pain radiating down the posterior aspects of the lower limbs, accompanied by severe bilateral peroneal nerve paresis of three weeks' duration. The patient had previously undergone repeated spinal ozone therapy at an outside facility, without clear clinical benefit. Preoperative MRI revealed a massive, caudally migrated medial disc extrusion at the L4–L5 level. An urgent decompression and discectomy

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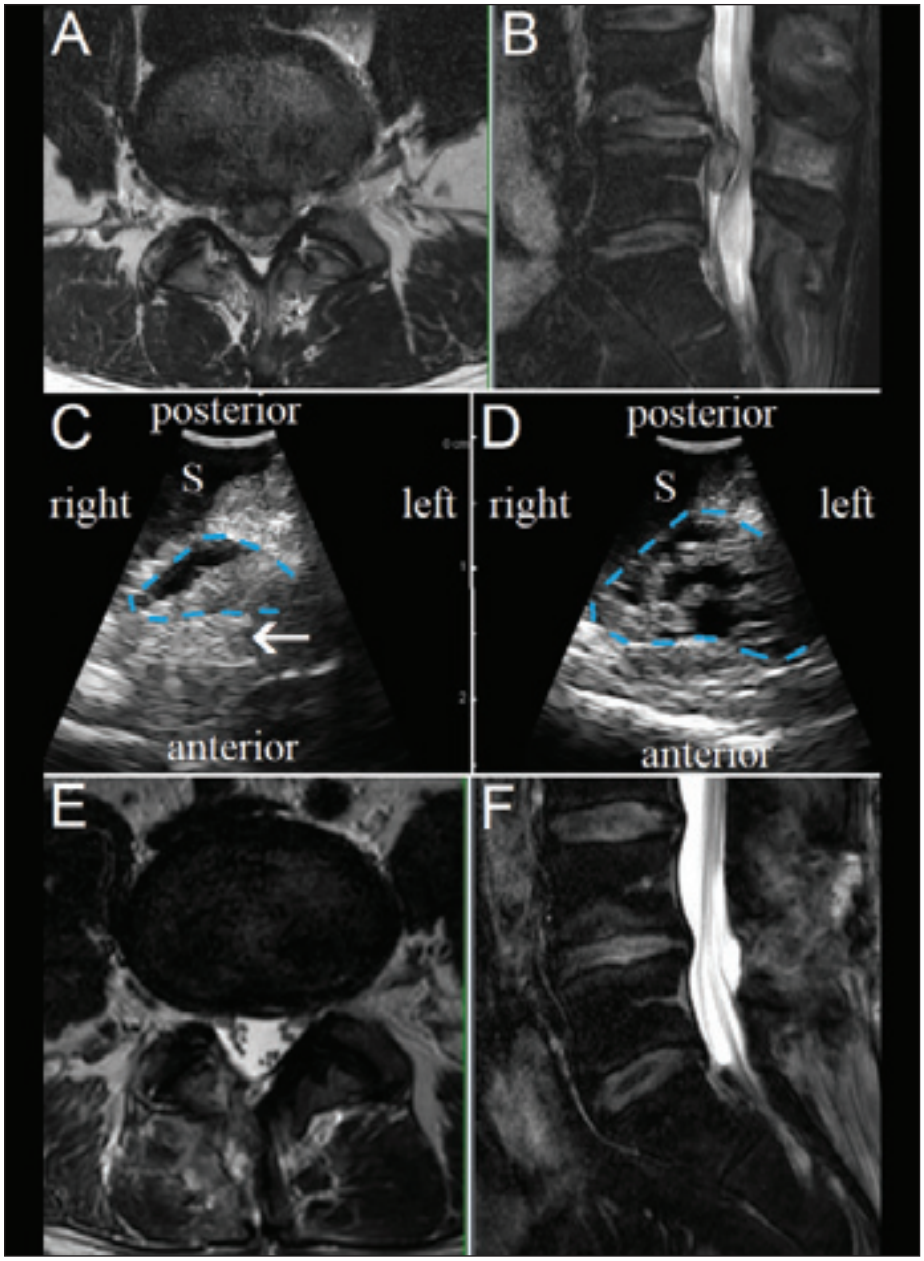


Fig. 3. Case 3. (A, B) Preoperative axial (A) and sagittal (B) T2-weighted MRI scans showing a large medial L4–L5 disc herniation causing significant dural sac compression and severe bilateral L5 motor deficit. (C) Intraoperative ultrasound image using a miniature probe performed following a partial L4 and L5 hemilaminectomy. S = saline; arrow = disc herniation; blue dashed line = dural sac. Note that the nerve roots are compressed and cannot be individually visualized. (D) Intraoperative ultrasound image performed after microdiscectomy. S = saline; blue dashed line = expanded dural sac. The nerve roots are now distinctly visualized, and no residual disc fragment is present. (E, F) Postoperative axial (E) and sagittal (F) T2-weighted MRI scans.

Obr. 3. Prípad 3. (A, B) Predoperačné axiálne (A) a sagitálne (B) T2-vážené obrazy MR zobrazujúce veľkú mediálnu herniu platničky L4–L5 spôsobujúcu významnú kompresiu durálneho vaku a závažný obojstranný motorický deficit L5. (C) Obraz intraoperačného ultrazvuku s použitím miniatúrnej sondy vykonaný po parciálnej hemilaminektómii L4 a L5. S = fyziologický roztok; šípka = hernia medzistavcovej platničky; modrá prerušovaná čiara = durálny vak. Nervové korene sú stlačené a nedajú sa vizualizovať jednotlivo. (D) Obraz intraoperačného ultrazvuku vyhotovený po mikrodiskektómii. S = fyziologický roztok; modrá prerušovaná čiara = expandovaný durálny vak. Nervové korene sú teraz zreteľne viditeľné, nie je zobrazený žiadny reziduálny fragment platničky. (E, F) Pooperačné axiálne (E) a sagitálne (F) T2-vážené obrazy MR.

were indicated. Intraoperatively, the surgical approach was complicated by dense epidural adhesions. Given the large medial nature of the herniation and the bilateral symptomatology, there was a preoperative discussion regarding the optimal side for the hemilaminectomy to achieve sufficient contralateral decompression. Following the microdiscectomy via a right-sided partial L4 and L5 hemilaminectomy, IOUS was utilized to evaluate the spinal canal using a miniature ultrasound probe (BK N11C5s "burr hole" transducer). The IOUS clearly demonstrated adequate decompression of the contralateral side, obviating the need for further surgical exploration using curved microdissectors (Fig. 3). Postoperatively, the patient was successfully mobilized, reporting significant relief of his bilateral radicular pain, and the paresis fully resolved.

Illustrative case 4

A 50-year-old female, who had initially received care abroad following multiple prior administrations of ozone therapy, was admitted with severe left-sided S1 radiculopathy and cauda equina syndrome of four days' duration. This manifested as saddle anesthesia and urinary retention (requiring urinary catheter placement at the referring facility). Preoperative MRI revealed a voluminous disc extrusion at L5–S1 and a smaller herniation at L4–L5. She underwent an urgent left-sided hemilaminectomy at L5 with a partial hemilaminectomy at L4 and S1. After the L4–L5 discectomy, dense epidural adhesions were encountered at the L5–S1 level – the S1 root was unidentifiable, and the dural sac was severely adherent to the ventral spinal canal. Following the initial extraction of a large sequester, IOUS using a miniature probe (BK N11C5s "burr hole" transducer) revealed a relatively large residual herniation fragment that had been previously obscured by the adhesions (Fig. 4). This fragment was subsequently identified and removed in four smaller pieces. In the immediate postoperative period, the patient experienced significant relief of her radicular pain, though her sphincter deficits initially persisted. At the one-year postoperative follow-up, the patient was fully ambulatory, reporting mild residual numbness in the left S1 dermatome, intact bowel control, and the ability to sense bladder filling and urinate voluntarily, although occasional stress incontinence occurred during heavy physical exertion.

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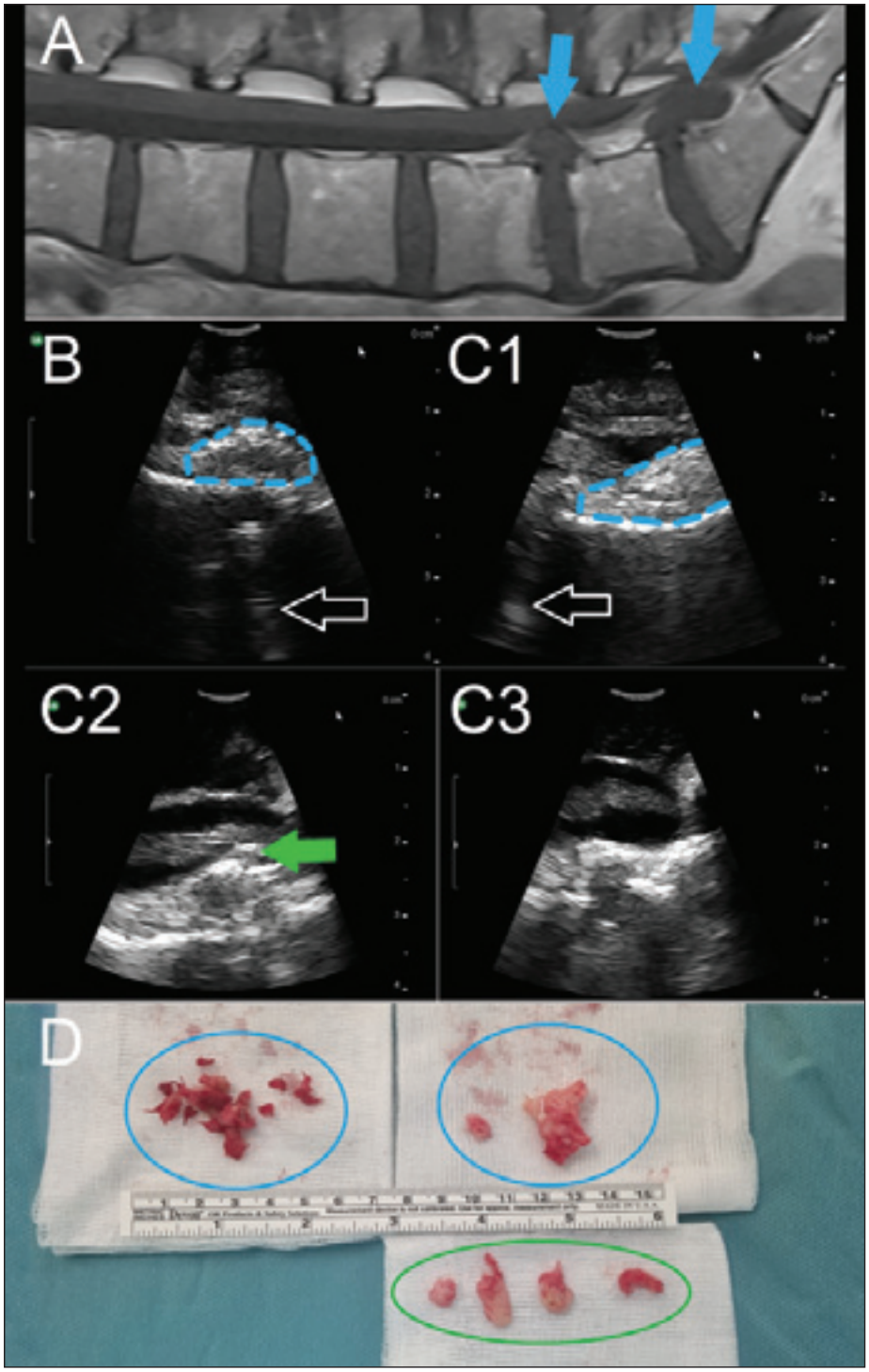


Fig. 4. Case 4. (A) Lumbar spine sagittal T1--weighted MRI image showing disc herniations at the L4–L5 and L5–S1 levels (blue arrows). (B) Intraoperative ultrasound visualization of the L4–L5 disc herniation; open arrow = L4–L5 intervertebral disc space. (C1) Herniated disc at L5–S1; open arrow = L5–S1 intervertebral disc space. (C2) Residual disc fragment compressing the S1 nerve root (green arrow), identified only after the surgeon was initially convinced the discectomy was sufficient. (C3) Intraoperative ultrasound visualization demonstrating sufficient S1 nerve root decompression. (D) Macroscopic disc material: Blue ovals = disc material removed from the L4–L5 and L5–S1 herniations using standard microsurgical techniques. Green oval = residual disc material identified utilizing intraoperative ultrasound.

Obr. 4. Prípad 4. (A) Sagitálny T1-vážený obraz MR driekovej chrbtice zobrazujúci hernie medzistavcových platničiek na úrovniach L4–L5 a L5–S1 (modré šípky). (B) Intraoperačná ultrasonografická vizualizácia hernie platničky L4–L5; obrysová šípka = medzistavcový priestor L4–L5. (C1) Herniovaná platnička na úrovni L5–S1; obrysová šípka = medzistavcový priestor L5–S1. (C2) Reziduálny fragment platničky utláčajúci nervový koreň S1 (zelená šípka), identifikovaný až po tom, ako bol operatér pôvodne presvedčený o dostatočnosti diskektómie. (C3) Intraoperačná ultrasonografická vizualizácia operačného poľa demonštrujúca dostatočnú dekompresiu nervového koreňa S1. (D) Makroskopický materiál platničky: Modré ovály = materiál platničky odstránený z hernií L4–L5 a L5–S1 štandardnými mikrochirurgickými technikami. Zelený ovál = reziduálny materiál platničky identifikovaný pomocou intraoperačného ultrazvuku.

Discussion

The first report addressing the intraoperative use of ultrasound in spinal surgery was published by Reid in 1978 [5], describing the ultrasound visualization of a cervical spinal cord tumor. In the 1980s, in addition to ultrasound-guided procedures for neoplastic spinal lesions, utilization of IOUS during surgery for degenerative disorders such as lumbar disc herniation was described [6,7]. Shortly thereafter, intraoperative ultrasound-guided surgeries for both neoplastic and degenerative spinal disorders were described in the former Czechoslovakia by a group led by Prof. Fagula and Prof. Šulla [8,9]. Throughout the 1980s and 1990s, the quality of ultrasound imaging was insufficient for adequate visualization of the relatively delicate structures of the spinal canal.

After the turn of the millennium, improvements in the quality of ultrasound systems and the miniaturization of ultrasound probes led to more frequent use of intraoperative spinal ultrasonography during tumor surgeries [1,10,11]. Although IOUS is currently utilized far more frequently for neoplastic lesions of the spine and spinal cord than for degenerative pathologies, it can serve as a helpful adjunct in se-

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lected cases of degenerative disorders as well [3].

First, it may be used to verify the extent of spinal cord decompression in patients with cervical spinal stenosis and myelopathy [12–15]. In these cases, ultrasound not only displays the extent of decompression (and thus its sufficiency) but may also provide intraoperative prognostic indications regarding postoperative neurological recovery. Chen and colleagues [16] found that the extent of spinal cord hyperechogenicity after decompression significantly correlated with the postoperative functional status of the spinal cord (i.e., the likelihood of a postoperative neurological deficit). In our case, the appearance and extent of cervical spinal cord hyperechogenicity indicated limited potential for neurological improvement. However, further studies are necessary to assess whether the routine use of IOUS has the potential to improve patient prognosis.

Second, IOUS may be successfully utilized during the resection of thoracic disc herniations, especially via posterolateral approaches [3,4,17–19], where a well-known limitation is the poor visualization of close-to-midline herniations [20]. Advances in IOUS, however, have improved the visualization of ventral pathologies, obviating the need for any significant thecal sac retraction [19]. Recently, the advantages of IOUS utilization during a lateral extracavitary approach in thoracic disc herniation surgery were also described; IOUS was used to confirm complete decompression over the spinal cord and to rule out the presence of unnoticed fragments [20]. In our case 2, who was operated on via a transfacet pedicle-sparing approach, IOUS significantly contributed to a successful surgical course by demonstrating persistent spinal cord compression at a point when an experienced spinal surgeon (J.M.) considered the anterior decompression to be sufficient (Fig. 2). Although traditional thoracic discectomy will likely be replaced by full endoscopic thoracic discectomy in a large proportion of patients – due to the minimally invasive nature of the endoscopic approach – spinal endoscopy is still not available in all centers, and its learning curve is relatively steep [21]. Interestingly, in a recent retrospective multi-center case series and meta-analysis comparing endoscopic approaches with traditional thoracic microdiscectomy, only 41 patients operated on using the endoscopic approach were included (vs. 3,190 patients operated on using traditional thoracic microdiscectomy) [22].

Third, IOUS can offer potential benefits during lumbar microdiscectomies. Although lumbar discectomies are generally considered "simpler" neurosurgical procedures, they still carry a risk of several complications, including inadvertently leaving a resectable sequestered disc fragment in some cases [23–26]. Of note, current IOUS systems appear to possess sufficient imaging quality to enable the visualization of residual lumbar disc material inadvertently left behind, at least in a subset of cases [3]. Aoyama and colleagues [27] examined a cohort of 30 patients with lumbar disc herniation. In two cases, they identified a residual herniated disc that they would not have detected without using ultrasound. Interestingly, dedicated ultrasound miniprobes allow for the visualization of anatomical structures within the spinal canal even during minimally invasive procedures, such as tubular microdiscectomies [28]. New lateral-firing miniprobes can provide striking image quality after insertion into the spinal canal through a small bony window; this approach represents a conceptual shift from conventional extraspinal ultrasound (where a larger bony window is sometimes required) toward an intraspinal imaging paradigm [29]. IOUS may also help establish the intradural location of a lumbar disc herniation, guide the dural opening in these cases and confirm adequate nerve root decompression following discectomy [30]. In both of our illustrative cases of lumbar disc herniation, IOUS provided sufficient imaging of the anatomical structures within the spinal canal (Fig. 3 and 4). In the first lumbar case (case 3), IOUS showed sufficient decompression of the cauda equina nerve roots with no detectable residual disc fragment. In the second patient (case 4), who presented with cauda equina syndrome caused by a two-level lumbar disc herniation and significant epidural fibrosis (likely due to repeated ozone therapy [31]), IOUS helped identify a relatively large residual herniation fragment at the L5–S1 level (compressing the S1 nerve root) that had been previously obscured by the adhesions. The fragment was subsequently located and extracted successfully. Of note, while IOUS is certainly not an indispensable tool during lumbar discectomies, intraoperative video documentation of the absence of residual fragments may assist in differentiating true recurrence from incomplete decompression in cases of suspected ultra-early reherniation.

Lastly, while standard two-dimensional IOUS is currently the only surgically relevant modality, it is not the only sonography-based imaging method potentially applicable during spinal surgery. Initial attempts at three-dimensional sonographic imaging of intradural spinal tumors have been published; however, to date, this remains largely an experimental methodology [32], and is not yet a routine modality in spinal surgery. Another potential application of IOUS involves utilizing intraoperative US-based navigation for pedicle screw insertion, relying on automatic registration between IOUS scans and preoperative CT images [33,34]. In the future, this novel method could theoretically serve as a low-cost, radiation-free alternative to intraoperative CT and fluoroscopy.

Conclusions

Although spinal IOUS is not an indispensable tool in surgery for degenerative spinal disorders, in selected cases, it can help prevent unnecessary dissection; or, conversely, demonstrate that the decompression of neural structures remains suboptimal. Further research is needed to establish the definitive role of IOUS in the surgical management of degenerative spinal disorders.

Ethical principles

The study was conducted in accordance with the Declaration of Helsinki (2013 revision). The study protocol was approved by the institutional ethics committee (Etická komisia UN Bratislava, Nemocnica akad. L. Dérera) on May 28, 2025 (approval number: 11/2025). All patients signed an informed consent form for participation in the study and for the publication of their data and images.

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Conflict of interest

The authors declare they have no potential conflicts of interest concerning drugs, products, or services used in the study.

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Zařazeny budou práce otištěné v číslech 2026/1–6.

Předem děkujeme všem autorům za zaslané příspěvky.