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Editorial Board Member of *World Journal of Orthopedics*, Kai Cao, MD, PhD, Professor, Department of Orthopaedics, The First Affiliated Hospital of Nanchang University, Nanchang 330002, Jiangxi Province, China. kaichaw@126.com

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ORIGINAL ARTICLE

Retrospective Cohort Study

Impact of computed tomography/magnetic resonance imaging registration on rehabilitation after percutaneous endoscopic decompression for lumbar stenosis: Retrospective study

Xiao-Bo Guo, Jin-Wei Chen, Jun-Yang Liu, Jiang-Tao Jin

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Xiao-Bo Guo, Jin-Wei Chen, Jun-Yang Liu, Jiang-Tao Jin, Department of Orthopedics, Jincheng General Hospital, Jincheng 048006, Shanxi Province, China

Corresponding author: Jiang-Tao Jin, MD, Chief Doctor, Department of Orthopedics, Jincheng General Hospital, Chang'an Road, Jincheng 048006, Shanxi Province, China. 44723733@qq.com

Abstract

BACKGROUND

Percutaneous endoscopic lumbar decompression (PELD) shows promise for lumbar spinal stenosis (LSS) treatment, but its use is limited by the disease's complexity and procedural challenges.

AIM

In this study, the effects of preoperative planning and intraoperative guidance with computed tomography (CT)/magnetic resonance imaging (MRI) registration techniques on PELD for LSS and postoperative rehabilitation outcomes were evaluated.

METHODS

This retrospective study was conducted with data from patients who underwent PELD for LSS between January 2021 and December 2023. Patients were assigned to preoperative CT/MRI registration and control groups. Data collected included the operative time, length of hospital stay, visual analog scale (VAS) scores for low back and leg pain, and the Japanese Orthopaedic Association (JOA) lumbar spine score. Differences between groups were assessed using Student's *t* test.

RESULTS

Data from 135 patients (71 in the CT/MRI registration group, 64 in the control group) were analyzed. The operative time was significantly shorter in the CT/MRI registration group (P = 0.007). At 2 months postoperatively, both groups showed significant reductions in VAS leg and low back pain scores (all P < 0.001) and improvements in the JOA score (both P < 0.001). No complication or death occurred. Preoperatively, pain and JOA scores were similar between groups (P = 0.830, P = 0.470, and P = 0.287, respectively). At 2 months postoperatively, patients in the CT/MRI registration group reported lower leg and low back pain levels (P

< 0.001 and *P* = 0.001, respectively) and had higher JOA scores (*P* = 0.004) than did patients in the control group.

CONCLUSION

Preoperative CT/MRI registration for PELD for LSS reduced the operative time and VAS pain scores at 2 months and improved JOA scores, demonstrating enhanced effectiveness and safety.

Key Words: Endoscopy; Spinal stenosis; Lumbar vertebrae; Tomography; X-Ray computed; Magnetic resonance imaging

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Core Tip: This retrospective analysis showed that computed tomography (CT)/magnetic resonance imaging (MRI) registration for percutaneous endoscopic lumbar decompression (PELD) for lumbar spinal stenosis (LSS) treatment significantly reduced visual analog scale pain scores and improved Japanese Orthopaedic Association scores at 2 months postoperatively compared with the control. The control and registration groups showed notable symptom relief with no complications. These findings suggest that CT/MRI registration enhances the safety and effectiveness of PELD for LSS, and improves postoperative outcomes.

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INTRODUCTION

Lumbar spinal stenosis (LSS) involves a series of structural changes in the intervertebral disc, ligamentum flavum, and facet joints that results in the narrowing of the space around the spinal nerve vessels and the compression of the nerve root, leading to symptoms such as lumbar and leg pain and walking disorders[1,2]. The treatment of LSS is currently controversial, with conservative and surgical options available.

In recent years, with the development of minimally invasive spinal instrumentation techniques and concepts, minimally invasive spinal surgery has become a mainstream approach. Among techniques, percutaneous endoscopic lumbar decompression (PELD) has developed most rapidly. This technique has unique advantages: It can be performed under local anesthesia to avoid general anesthesia-related complications[3,4]; it enables the preservation of the lamina, causes minimal joint damage, and contributes to the maintenance of spinal stability[5,6]; it reduces the postoperative incidence of fixation-related complications[7]; and it is associated with less trauma, more rapid recovery, shorter hospital stays, and lower operation costs[8-11]. Numerous reports describe the use of PELD for the treatment of LSS, with remarkable therapeutic effect[7,12,13].

However, the adoption of endoscopic spinal techniques necessitates a learning period for surgeons to acquire proficiency and achieve optimal clinical outcomes[14-16]. The learning curve associated with spinal endoscopy is influenced by various factors, including the surgeon's experience, case and anatomical structure complexity, and technological advancements. Comprehensive preoperative imaging examination, including x-ray, computed tomography (CT), and magnetic resonance imaging (MRI) studies, is needed to evaluate the location and extent of the affected area and its relationship to adjacent structures, providing detailed positioning information for surgical manipulation[17-20]. Preoperative planning for PELD is crucial. Due to the sensitivity of MRI for soft-tissue differentiation and CT for bone structure differentiation, as well as the three-dimensional reconstruction capability, the combined use of the two modalities in such planning can leverage their respective advantages.

Since 2021, we have been using CT/MRI registration techniques for preoperative planning and intraoperative guidance for PELD. This method enables the more accurate determination of lesion location, design of the optimal surgical path, and accurate navigation during the operation. The aim of this study is to assess the efficacy of CT/MRI registration in enhancing patient recovery following treatment for LSS with PELD.

MATERIALS AND METHODS

Study design and patients

This study was approved by Jincheng General Hospital's Medical Ethics Committee (No. LL2024012201) and was conducted in accordance with the Declaration of Helsinki. Data on 135 patients with LSS who underwent PELD surgery in our hospital between January 2021 and December 2023 were collected retrospectively. The sample comprised 72 males and 63 females aged 14-85 years (mean ± SD, 57.24 ± 13.67 years). According to whether CT/MRI registration was used for preoperative planning, the patients were assigned to CT/MRI registration and control groups.

Inclusion and exclusion criteria

The inclusion criteria were: (1) Presentation with low back pain and intermittent claudication or dysfunction that met the diagnostic criteria for LSS; (2) Performance of MRI and CT examination and availability of complete radiographic data; (3) Failure to respond to conservative treatment for 3 months or presence of severe symptoms requiring surgical treatment; and (4) Availability of complete clinical and postoperative follow-up data.

The exclusion criteria were: (1) Presentation with radiculopathy and diagnosis of lumbar disc herniation (LDH); (2) Inconsistency of clinical symptoms with radiographic images; and (3) Lumbar instability, lumbar spondylolisthesis, lumbar infection, or tumor.

CT/MRI registration for preoperative planning

CT and MRI examinations were performed with the patient in the supine position. A 64-slice spiral CT scanner (Siemens Healthineers, Erlangen, Bavaria, Germany) was used to obtain axial thin-slice digital imaging and communication (DICOM) data. The scans were performed with a tube current of 250 mA, tube voltage of 120 kV, and slice thickness of 0.5 mm. MRI examinations were performed with a 3.0-T device (Siemens Healthineers, Erlangen, Bavaria, Germany). A body coil was used to obtain axial and sagittal scans of the lumbar vertebrae with a layer spacing of 3 mm. The CT and MRI data were uploaded to the Picture Archiving and Communication System in DICOM format (Figure 1).

For registration, thin-slice axial CT and conventional sagittal T2 MRI data were imported into the E-3D medical system (ver. 20.02; Digital Health and Virtual Reality Research Center, Central South University, Changsha, China). The MR (moving) and CT (fixed) images were registered using the software's multimodal registration function. Functions such as translational rotation, B-spline transformation, and interactive movement rotation were applied. Finally, the manual registration function was used for fine tuning. Then, the transparency of the CT and MRI images was set to 0.6, and the distribution of intervertebral discs and osteophytes was observed from multiple directions (Figure 1).

The software's device function was then used to simulate the placement of the working cannula (7.5 mm outer diameter) for surgery. The transforaminal approach was planned as follows. The head of the working cannula was positioned at the herniated disc while avoiding contact of the cannula body with the outlet root and abdominal organs. The position of the cannula was adjusted repeatedly to minimize the resection of the superior articular process and maximize the endoscopic visual field. The angles of the working cannula in the coronal and sagittal planes of the vertebral body were then calculated. The interlaminar approach was planned as follows. The head of the working cannula was positioned at the herniated disc. The cannula's position was adjusted repeatedly to enable the passage of its body through the maximal laminar space to ensure the maximization of the visual field. The perpendicular distance of the working cannula from the midline of the spinous process and its angle with the body of the fifth lumbar vertebra (L5) in the sagittal plane were then calculated (Figure 1).

Surgical procedure

Three chief physicians with expertise in CT/MRI registration techniques performed the PELD surgeries. Preoperative planning was performed with CT/MRI registration or routinely with CT and MRI data (control). For PELD, a foraminal approach to L3/4 and L4/5 and a foraminal or laminar approach to L5/first sacral vertebra (S1) were used. During the surgery, precise excision was performed based on the preoperatively determined nature, size, and extent of the tissue causing nerve compression. This tissue was removed using an osteotome and forceps, and complete decompression of the nerve was then confirmed endoscopically. The standard for surgical success was the significant reduction of lower-limb numbness and pain.

Outcomes and data collection

The primary outcomes examined in this study were the operative time (from initial needle puncture to skin suturing) and the length of hospital stay. Secondary outcomes were the changes in the 10 cm visual analog scale (VAS) scores (0 = no pain, 10 = severe pain) for leg and low back pain from the preoperative baseline at 2 months postoperatively[21] and the Japanese Orthopaedic Association (JOA) lumbar spine score (0-29, with lower scores indicating more pronounced dysfunction).

Statistical analysis

The statistical analysis was performed using SPSSPRO (https://www.spsspro.com/). Measurement data are expressed as means ± SDs. Differences in these data between groups were examined using Student's *t* test, and differences between the preoperative values and those obtained 2 months postoperatively were evaluated using the paired *t* test. Count data are expressed as numbers, and differences in these data between groups were examined using the Pearson χ^2 test. $P \leq 0.05$ was taken to indicate significance.

RESULTS

Baseline characteristics

Of the 135 patients with LSS included in the study, 71 (34 males, 37 females) were allocated to the CT/MRI registration group and 64 (38 males, 26 females) were allocated to the control group. The sex distribution did not differ significantly between groups (P = 0.182). The mean ages in the CT/MRI registration and control groups were 55.54 ± 14.50 and 59.41 ±

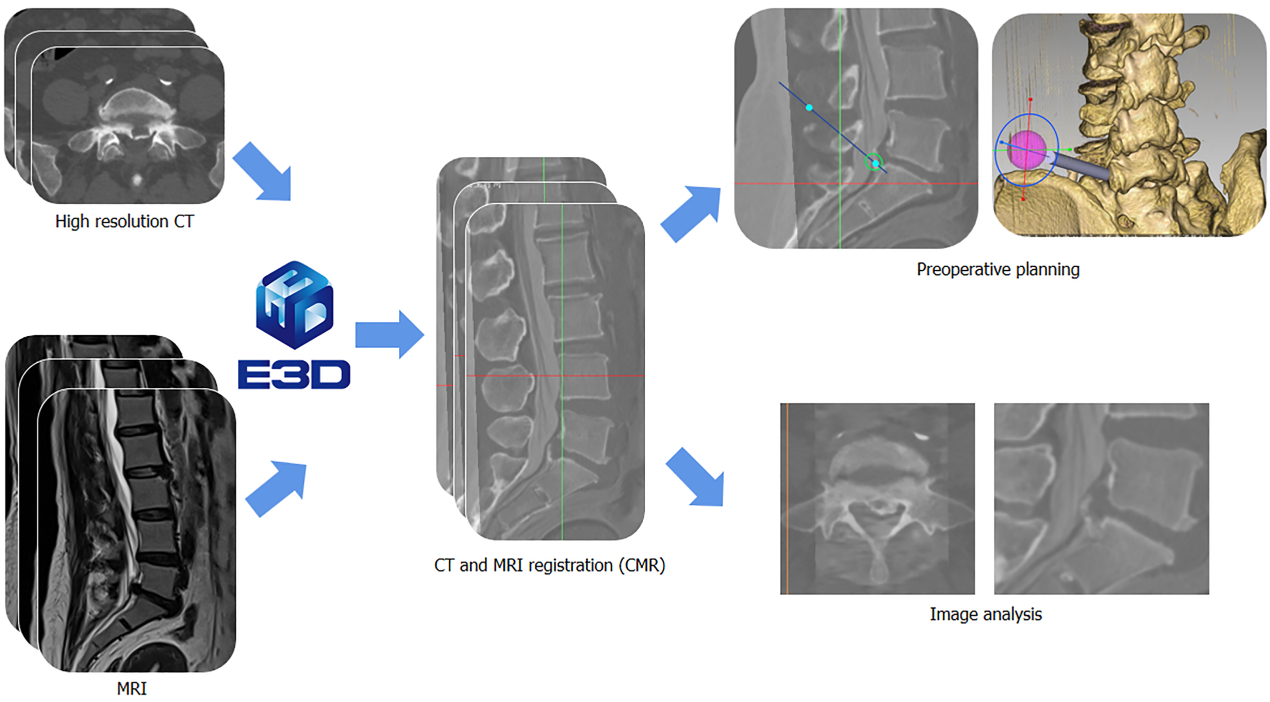

Figure 1 Flowchart of computed tomography/magnetic resonance imaging registration. MRI: Magnetic resonance imaging; CT: Computed tomography; CMR: Computed tomography and magnetic resonance imaging registration.

12.53 years, respectively, with no significant difference between groups (P = 0.126). In the CT/MRI registration group, 27 patients had right lower-limb symptoms, 34 patients had left lower-limb symptoms, and 10 patients had bilateral symptoms. In the control group, 23 patients had right lower-limb symptoms, 31 patients had left lower-limb symptoms, and 10 patients had bilateral symptoms. The symptom distribution did not differ significantly between groups (P = 0.953). The stenosis levels in the CT/MRI registration group were L3/4 (n = 5), L4/5 (n = 30), and L5/S1 (n = 36), and those in the control group were L3/4 (n = 4), L4/5 (n = 40), and L5/S1 (n = 20), with no significant difference between groups (P = 0.056; Table 1).

Primary outcomes

The mean operative times in the CT/MRI registration and control groups was 90.39 ± 12.71 and 98.22 ± 19.92 min, respectively (P = 0.007). The mean lengths of hospital stay in these groups were 6.59 ± 3.29 and was 8.19 ± 6.70 days, respectively, with no significant difference between groups (P = 0.077; Table 2).

Secondary outcomes

At 2 months postoperatively, the VAS leg and back pain scores and the JOA score had decreased significantly from the preoperative baseline in both groups (all P < 0.001). The mean preoperative VAS leg pain score was 8.10 ± 0.74 in the CT/MRI registration group and 8.13 ± 0.68 in the control group, with no significant difference between groups (P = 0.830). At 2 months postoperatively, the mean VAS leg pain score was significantly lower in the CT/MRI registration group than in the control group (2.34 ± 0.83 *vs* 2.94 ± 1.13; P < 0.001). The mean preoperative VAS low back pain score was 3.79 ± 1.22 in the CT/MRI registration group and 3.95 ± 1.42 in the control group, with no significant difference between groups (P = 0.470). At 2 months postoperatively, the mean VAS low back pain score was significantly lower in the CT/MRI registration group than in the control group (1.69 ± 1.02 *vs* 2.33 ± 1.21; P < 0.001). The mean preoperative JOA score was 10.92 ± 2.21 in the CT/MRI registration group and 11.30 ± 1.91 in the control group, with no significant difference between groups (P = 0.287). At 2 months postoperatively, the mean JOA score was significantly higher in the CT/MRI registration group than in the control group (24.27 ± 2.81 *vs* 22.58 ± 3.79; P = 0.004; Table 2).

Typical case 1

Patient 1, a 72-year-old woman, was admitted due to pain, numbness, and intermittent claudication in the right lower limb for more than 10 years, which had been exacerbated for 11 days. The patient had histories of diabetes mellitus, hypertension, brainstem hemorrhage, and cerebral infarction. Physical examination revealed tenderness on the right side of the L5/S1 intervertebral space, and numbness in the right buttock, posterior thigh, posterior calf, and sole of the foot. The right iliopsoas had grade-3 strength and the right gastrocnemius had grade-4 strength. MRI showed spinal canal stenosis at the T12/L1, L4/5, and L5/S1 Levels. CT images reveal osteophyte formation at the anterior and posterior margins of the L1-S1 vertebral bodies, as well as facet joint hypertrophy (Figure 2A). Fusion of the CT and MR images provided clear visualization of the rigid osteophytes and soft intervertebral discs (Figure 2B). It was evident that the compression at the L5/S1 Level was due primarily to pressure from the intervertebral disc.

Table 1 Demographic data, *n* (%)

Category	CT/MRI registration group (*n* = 71)	Control group (*n* = 64)	*P* value
Sex			
Male	34 (48)	38 (59)	
Female	37 (52)	26 (41)	0.182
Age, mean ± SD, year	55.54 ± 14.50	59.14 ± 12.53	0.126
Side			
Right	27 (38)	23 (36)	
Left	34 (48)	31 (48)	
Bilateral	10 (14)	10 (16)	0.953
Level			
L3/4	5 (7)	4 (6)	
L4/5	30 (42)	40 (63)	
L5/S1	36 (51)	20 (31)	0.056

CT: Computed tomography; MRI: Magnetic resonance imaging.

Table 2 Primary and secondary outcomes

Outcome	The CT/MRI registration group (*n* = 71)	The control group (*n* = 64)	Mean difference	*P* value
Surgery time (minute)	90.39 ± 12.71	98.22 ± 19.92	-7.82	0.007
Hospital stay (day)	6.59 ± 3.29	8.19 ± 6.70	-1.60	0.077
VAS leg pain preoperative	8.10 ± 0.74	8.13 ± 0.68	-0.03	0.830
VAS leg pain postoperative 2 months	2.34 ± 0.83[a]	2.94 ± 1.13[a]	-0.60	< 0.001
VAS low back pain preoperative	3.79 ± 1.22	3.95 ± 1.42	-0.16	0.470
VAS low back pain postoperative 2 months	1.69 ± 1.02[a]	2.33 ± 1.21[a]	-0.64	0.001
JOA preoperative	10.92 ± 2.21	11.30 ± 1.91	-0.38	0.287
JOA postoperative 2 months	24.27 ± 2.81[a]	22.58 ± 3.79[a]	1.69	0.004

[a]$P < 0.001$, comparisons with preoperative values.
VAS: Visual analog scale; JOA: The Japanese Orthopaedic Association lumbar spine score; CT: Computed tomography; MRI: Magnetic resonance imaging.

Placement planning for the intervention was performed based on the positioning of the intervertebral discs on three-dimensional CT images (Figure 2C). We performed PELD surgery using a transforaminal approach. Following the pre-planned trajectory, we placed a working cannula and removed the compressive disc at L5/S1. We used an endoscopic bone shaver for precise resection during the surgery. At the end of the surgery, endoscopic images showed complete decompression at the S1 Level, and photographs confirmed the removal of the superior articular process and intervertebral disc (Figure 2D). The patient's VAS leg pain score decreased from 8 preoperatively to 2 at 2 months postoperatively, her VAS low back pain score decreased from 5 preoperatively to 2 at 2 months postoperatively, and her JOA score improved from 9 preoperatively to 25 at 2 months postoperatively. The right iliopsoas had grade-4 strength and the right gastrocnemius had grade-4+ strength at 2 months postoperatively.

Typical case 2

Patient 2, a 67-year-old man, was admitted due to low back pain accompanied by bilateral buttock soreness and intermittent claudication for several years, which had worsened in the previous 6 months. The patient had histories of hypertension and cerebral infarction, and had undergone left total hip arthroplasty. Physical examination revealed tenderness in the L4/5 region, radiating pain in the left lower limb, bilateral buttock soreness, and numbness in the anterior and lateral lower leg and foot dorsum that worsened when standing. The left tibialis anterior and extensor hallucis longus had grade-4 strength. The straight leg raising test result was positive for the left side. The patient's symptoms were attributed to the compression of the left L5 nerve. MR images showed spinal stenosis at L1/2, L4/5, and L5/S1. CT images showed osteophyte formation at the anterior and posterior margins of the L1-L5 vertebral bodies and

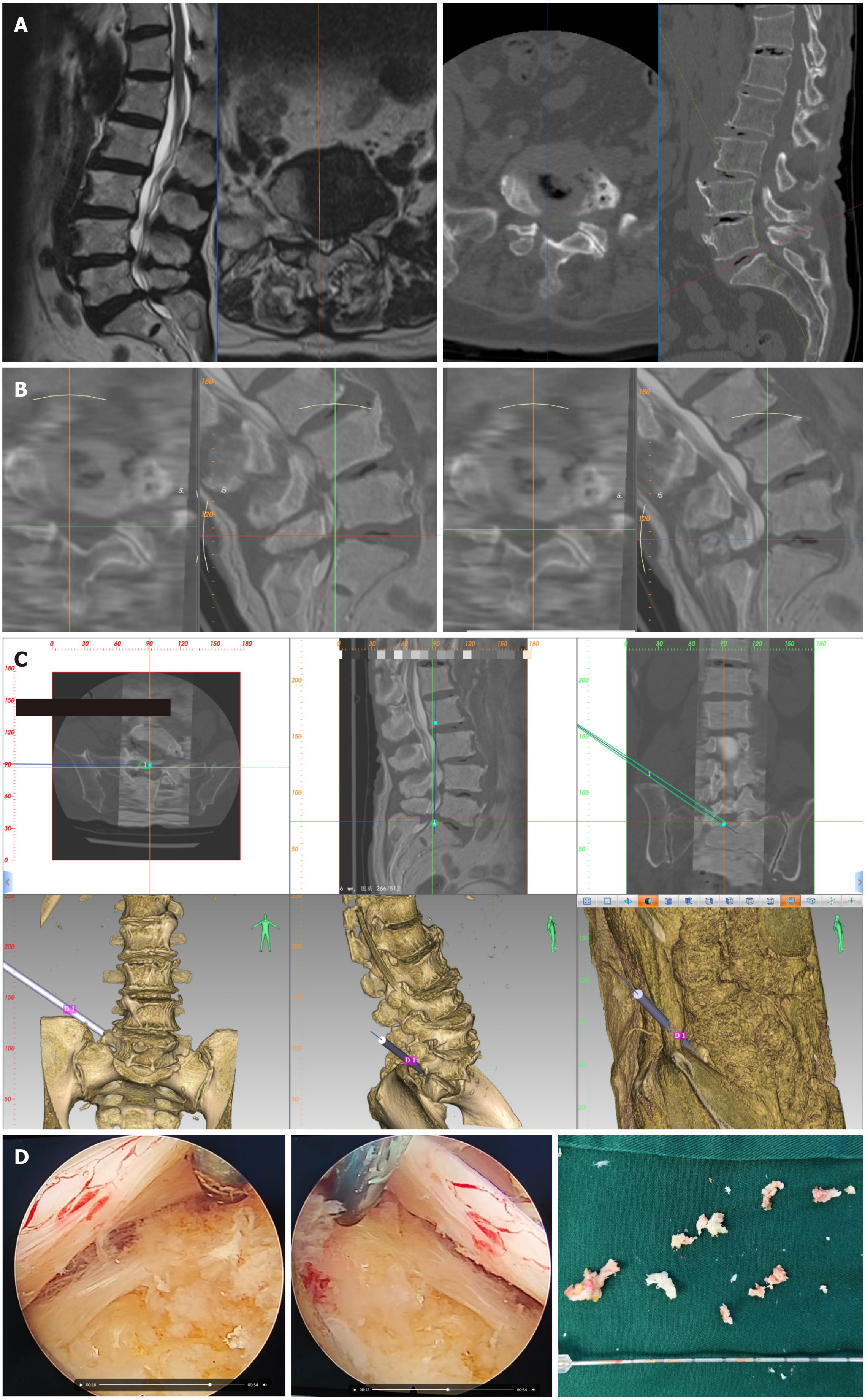

Figure 2 Typical case 1. A: Magnetic resonance imaging and computed tomography images showing lumbar spine stenosis (L5/S1); B: Computed tomography

(CT)/magnetic resonance imaging registration image showing compression of the S1 nerve by its ventral intervertebral disc; C: Based on the compression site, a working cannula was simulated on the three-dimensional CT reconstruction image; D: Endoscopic images showing complete release of the nerves and spinal cord, and photograph showing the extracted intervertebral disc tissue.

facet joints (Figure 3A). The fused CT and MR images demonstrated compression of the left L5 nerve root by the intervertebral disc and superior articular process at the L4/5 intervertebral space (Figure 3B).

Placement planning for the intervention was performed based on the positioning of the intervertebral discs on the three-dimensional CT images (Figure 3C). We performed PELD surgery using a transforaminal approach. Following the pre-planned trajectory, we placed a working cannula and removed the compressive disc at L4/5 and the superior articular process of L5. At the end of the surgery, endoscopic images showed complete relief of the L5 nerve root compression. Photographs confirmed the removal of the intervertebral disc and superior articular process (Figure 3D). The patient's VAS leg pain score decreased from 8 preoperatively to 1 at 2 months postoperatively, his VAS low back pain score decreased from 4 preoperatively to 0 at 2 months postoperatively, and his JOA score improved from 12 preoperatively to 24 at 2 months postoperatively. At 2 months postoperatively, the left tibialis anterior had grade-5 strength and the left extensor hallucis longus had grade-4+ strength.

DISCUSSION

PELD for the treatment of LSS: Current status and our experience

LSS involves the pathological reduction of the area of the spinal canal or nerve root canal due to multiple factors, including the osteoproliferation of the lumbar spinal canal or pathological soft-tissue hypertrophy, leading to compression of the spinal cord and nerve roots and a series of associated symptoms[22,23]. LSS is classified according to the site of onset as central canal, lateral recess, or foraminal stenosis[24,25]. The accurate determination of the structure of compressed nerves is a challenge for physicians. Open decompression has been considered to be the gold-standard surgical option for LSS[26,27], but it has limitations, including extensive trauma, prolonged surgical duration, greater blood loss, and the potential disruption of spinal stability[28-31]. PELD has been used for the treatment of degenerative diseases of the lumbar spine and has been shown to be effective for LSS[28,32,33]. In this study, no significant complication or procedure-related death occurred in either group. We used an endoscopic bone chisel to decompress the preoperatively identified compression sites. Under endoscopy at the ends of the procedures, the compressed nerve roots and dura mater were seen to be full and pulsating with respiration, with no surrounding compressive lesion, demonstrating complete decompression. PELD treatment for LSS is performed under local anesthesia, avoiding general anesthesia risks, especially in elderly patients. The precise excision of joint prominences and bone spurs using an arthroscope avoided the creation of iatrogenic spinal instability.

Although PELD has achieved favorable results in the treatment of LSS, challenges remain. First, due to the presence of factors such as scoliosis, spinal stenosis, ligamentum flavum hypertrophy, and osteophytes in patients with LSS, PELD surgery is much more difficult to perform for LSS than for LDH. The maintenance of a clear field of view in a confined surgical space to effectively manipulate and identify surrounding tissue structures is challenging. Second, LSS is often multilevel, and the identification of the responsible segments is challenging. Third, degenerative LSS is common in elderly patients, who have less surgical tolerance than do younger individuals. For this reason, efforts should be made to minimize the duration of surgery. In this study, based on preoperative imaging, we planned the surgical approaches and trajectories to ensure precise and effective decompression of compressed nerve roots. During the PELD procedures, we used transforaminal and interlaminar approaches to access the targets. By following the pre-planned trajectories, we were able to place the working cannula accurately and remove the compressive discs and superior articular processes. Based on CT/MRI registration images, we preoperatively assessed the extent and nature of nerve compression, and then proceeded with targeted decompression. This approach enabled the direct decompression of the nerve roots, minimizing damage to surrounding tissues.

CT/MRI registration: Application and our experience

In medical image analysis, several images of the same patient are commonly examined together to obtain comprehensive information from multiple aspects, thereby improving medical diagnosis and treatment[34-36]. MRI provides excellent depictions of soft-tissue structures such as discs, ligaments, and nerves, with detailed information about the morphology and signal intensity of these structures, which is crucial for the diagnosis of conditions such as disc herniation, ligament tears, and nerve compression. However, MRI has limitations in the depiction of bony structures, especially when in the presence of significant bone degeneration or deformity. CT is excellent for the visualization of bony anatomy. It produces high-resolution images that accurately depict bone contours, densities, and minute bony abnormalities. CT images can also be used for precise three-dimensional reconstruction, enabling clinicians to obtain a more detailed understanding of the spinal anatomy and pathologies. By registering CT and MRI images, physicians can obtain comprehensive pictures of spinal conditions. This integrated approach enables more accurate diagnosis and treatment planning, potentially leading to better patient outcomes[37-40]. The registration of CT and MRI images also enables surgeons to perform more precise surgical navigation and interventions, minimizing damage to surrounding tissues and nerves. Despite these advantages of CT/MRI registration, its application in PELD surgery remains limited.

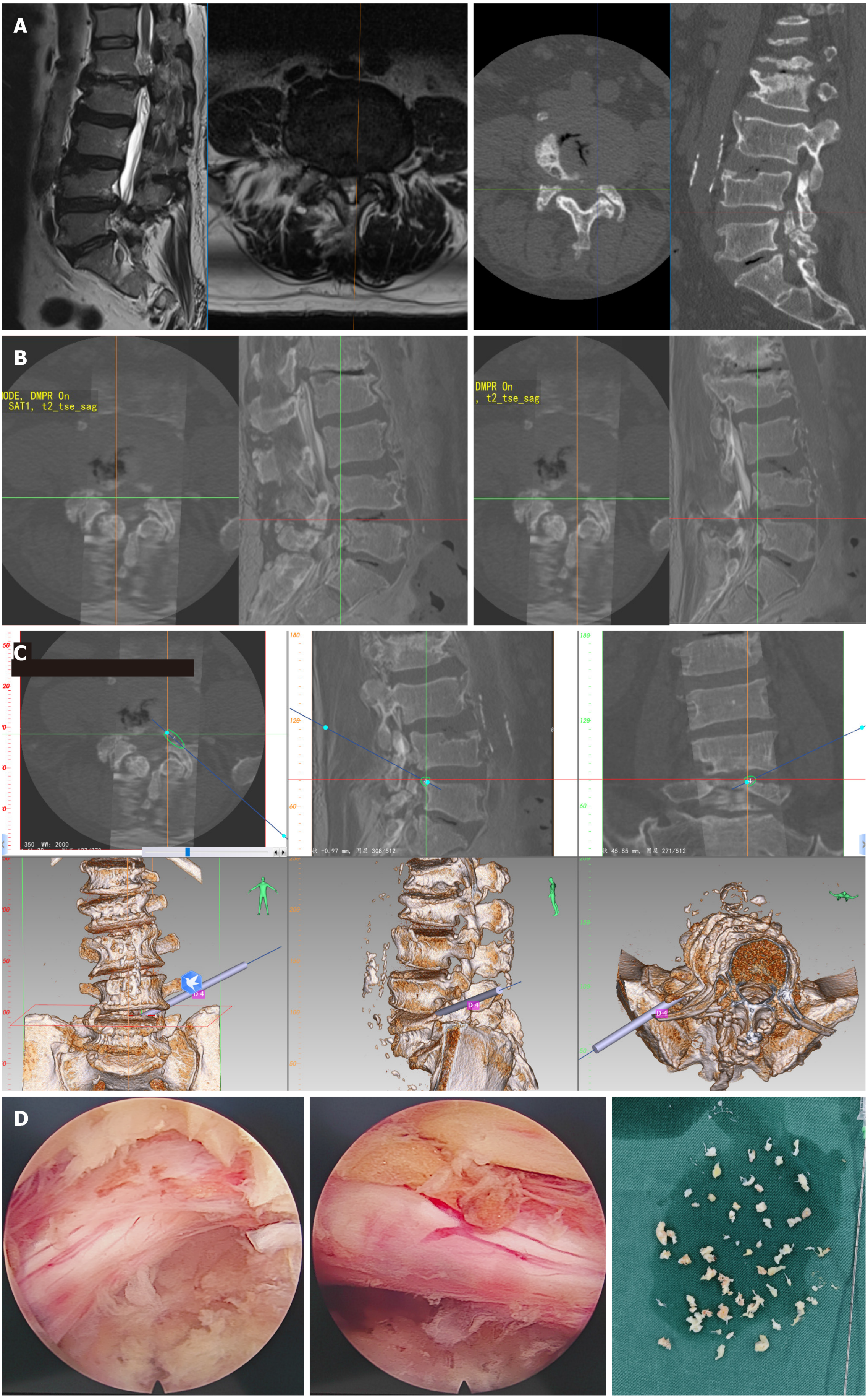

Figure 3 Typical case 2. A: Magnetic resonance imaging and computed tomography images showing lumbar spine stenosis (L4/5); B: Computed tomography

(CT)/magnetic resonance imaging registration image showing that the compression of the L5 nerve arose from the superior articular process and ventral intervertebral disc; C: Based on the compression site, a working cannula was simulated on the three-dimensional CT reconstruction image; D: Endoscopic images showing complete release of the nerves and spinal cord, and photograph showing the removed intervertebral disc and superior articular process.

The first step in the quantitative analysis of multiple images is to achieve strict image alignment, or registration. The authors tested various software programs and algorithms for this study, but none achieved perfect registration the first time and all necessitated manual fine tuning. With the E-3D software, the B-spline transformation method can be used for coarse registration to achieve better results. After successful registration, the dural sac can be reconstructed on a CT image because it is hyperintense on T2 MR images. CT/MRI registration can be used to generate CT myelography-like images[41]. It can directly show whether nerve compression is caused by a bone, disc, or ligament, and it can be combined with three-dimensional technology for more accurate preoperative planning. In this study, we performed three-dimensional reconstruction of the intervertebral discs and lumbar spine after image fusion, and virtually positioned the working cannula to find the optimal path. By integrating CT/MRI registration techniques with 3D surgical planning, we can precisely avoid abdominal organs, accurately target the surgical site, minimize resection of the superior articular process, and reduce the incidence of long-term lumbar instability. In this study, VAS scores for leg and back pain were lower in the CT/MRI registration group than in the control group at the time of surgery and at 2 months postoperatively. Additionally, the JOA score was significantly higher in the CT/MRI registration group than in the control group at 2 months postoperatively. These results reflect the advantages of CT/MRI registration for PELD procedures.

Limitations and prospects

Due to factors such as scanning cost, and time constraints, MRI scans produce significantly fewer layers than do CT scans, which results in imprecise CT/MRI registration. Following automatic registration, manual adjustment is necessary. To enhance the efficiency and accuracy of CT/MR image fusion, deep learning techniques must be employed to optimize the registration algorithm. This research was limited by its retrospective nature and performance with data from a single center. Prospective multicenter studies with larger samples are needed to provide data that can be used to enhance the applicability of CT/MRI registration. In addition, patients were followed for only 2 months in this study. Studies with longer follow-up periods are needed to confirm the advantages of CT/MRI registration. This procedure remains relatively complex, requiring specialized training, and future efforts should focus on the development of more user-friendly tools for CT/MRI registration. Despite the current challenges, however, CT/MRI registration technology shows promise for the three-dimensional reconstruction of anatomical structures such as nerves, cerebrospinal fluid, intervertebral discs, and bones. Its integration with virtual reality technology for intraoperative navigation could improve surgical precision and patient recovery.

CONCLUSION

Preoperative CT/MRI registration for PELD for LSS reduced the operative time and VAS pain scores at 2 months, and improved JOA scores, demonstrating its ability to enhance the effectiveness and safety of this surgical procedure.

FOOTNOTES

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Country of origin: China

ORCID number: Xiao-Bo Guo 0000-0002-3834-1201; Jiang-Tao Jin 0000-0001-7796-5773.

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