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Original Article

Preoperative application of CT and MRI registration in lumbar disc herniation endoscopic surgery could improve the postoperative rehabilitation of patients

Xiaobo Guo, Jiangtao Jin, Jinwei Chen, Junyang Liu

Department of Orthopedics, Jincheng General Hospital, Jincheng 048006, Shanxi, China

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Abstract: Background: Percutaneous Endoscopic Lumbar Discectomy (PELD) has emerged as routine treatment for lumbar disc herniation (LDH) due to its minimal invasiveness and quick recovery. However, PELD demands high precision from the surgeon, as the risk of intraoperative complications is substantial, including potential damage to the nerve root and dura, and a higher likelihood of recurrence post-surgery. Thus, preoperative planning utilizing CT and MRI imaging is essential. Methods: In this study, the clinical data of 140 patients treated with PELD for LDH from January 2021 to December 2023 were retrospectively analyzed. Patients were categorized into two groups based on whether CT and MRI registration (CMR) was employed for surgical planning: a CMR group (n=68) and a control group (n=72). Data collected included surgery time, hospital stay duration, and scores from the Visual Analog Scale (VAS) for low back and leg pain, as well as the Japanese Orthopaedic Association Lumbar Spine Score (JOA). Differences between the two groups were assessed using the Student's t-test. Results: No significant difference was found in hospital stay length between the groups (P=0.277). Surgery time was significantly shorter in the CMR group (P<0.001). Prior to surgery, no significant differences in VAS scores for leg and low back pain were observed between the groups (P=0.341 and P=0.131, respectively); however, at 2 months postoperatively, both scores were significantly lower in the CMR group (P<0.001 and P=0.002, respectively). Similarly, no difference in preoperative JOA scores was noted (P=0.750), but at 2 months postoperative, the CMR group exhibited significantly higher scores (P<0.001). Conclusion: Compared with the traditional PELD, the preoperative use of CMR has shown to reduce surgery time, alleviate leg and low back pain, and increase the lumbar JOA score at 2 months after surgery, underscoring its efficacy in enhancing surgical outcomes.

Keywords: Endoscopy, intervertebral disc degeneration, lumbar vertebrae, tomography, X-Ray computed, magnetic resonance imaging

Introduction

Lumbar disc herniation (LDH) is typically characterized by lower back pain and leg pain. Kika Konstantinou et al. reported that the prevalence of sciatica ranged from 1.2% to 43% in different studies [1]. M. A. Stafford reported that the lifetime incidence of sciatica is estimated to be between 13% and 40% [2]. Most people experiencing their first onset of symptoms find relief through bed rest and medication. Nonetheless, some patients experience no improvement or suffer relapses after two months of stringent conservative treatment.

If conservative treatment fails, surgery should be considered [3-5]. The conventional procedures often involve a lumbar laminectomy to remove the intervertebral disc. However, a major drawback associated with this conventional procedure is the destruction of paravertebral muscles and ligaments [6, 7]. In addition, this surgical approach induces extensive surgical scarring and adhesion, which may deteriorate the postoperative clinical outcomes [8, 9]. Percutaneous endoscopic lumbar discectomy (PELD) offers minimally invasive treatment for treating LDH. This technique minimizes damage to intraspinal structures, preserves most of the ligamentum flavum, and reduces the likelihood of perineural scarring and adhesion [10, 11]. As a result, PELD reduces post-operative pain and accelerates recovery [12-14], making

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it an increasingly popular choice for LDH management in recent years.

However, PELD has certain limitations. Firstly, the scope of surgical operation is relatively narrow, as it can only be performed through the intervertebral foramen or between the laminae. For patients with large prominent disc tissue that requires extensive exposure and release, PELD is not convenient and risks missing disc material. Secondly, PELD has a steep learning curve; it necessitates a well-trained surgeon and support team to execute these minimally invasive procedures effectively [15]. Preoperative comprehensive imaging examinations are essential, including X-ray, computed tomography (CT), and magnetic resonance imaging (MRI). These techniques evaluate the location, extent, and relationship of the affected area with adjacent structures, providing detailed positioning information for surgical manipulation.

Since 2021, we have implemented CT and MRI registration (CMR) for pre-operative planning in PELD. This approach allows for more accurate determination of the location of the disc protrusion, optimal surgical pathway design, and accurate intraoperative navigation. This study aims to investigate the application value of CMR for PELD in the treatment of LDH, hopefully to illuminate the potential benefits and enhance understanding of how CMR can improve surgical outcomes in PELD procedures.

Materials and methods

Study design and patient population

This study was approved by Jincheng General Hospital's Medical Ethics Committee (No. LL2024012201) and was conducted in accordance with the Helsinki Declaration. Clinical data of 140 patients with LDH who underwent PELD from January 2021 to December 2023 were retrospectively collected. There were 87 males and 53 females, ranging in age from 12 to 81 years, with an average age of (44.19±14.13) years. According to whether CMR was performed before surgery, the patients were categorized into a CMR group (n=68) and a control group (n=72).

Inclusion criteria and exclusion criteria

Inclusion criteria: 1. Patients presenting with low back pain, radiculopathy, or dysfunction that met the diagnostic criteria for LDH; 2. Patients who had undergone MRI and CT scans with and complete and available radiographic data; 3. Patients who failed to respond to conservative treatment over a 2-month period; 4. Patients with severe symptoms requiring surgical treatment; 5. Patients with available and complete clinical data and postoperative follow-up data; 6. Patients who underwent PELD. Exclusion criteria: 1. Patients exhibiting radiculopathy or dysfunction, accompanied by intermittent claudication and diagnosed with spinal stenosis; 2. Patients with incomplete radiographic data; 3. Discrepancies between clinical symptoms and radiographic finding; 4. Patients who did not undergo PELD; 5. Patients presenting with lumbar instability, lumbar spondylolisthesis, lumbar infection, or tumor.

CMR pre-operative planning

CT examination method: Patients were scanned with a Siemens 64-slice spiral CT scanner in a supine position to obtain axial thin-slice DICOM data. The scanning parameters included a tube current of 250 mA, tube voltage of 120 kV, and slice thickness of 0.5 mm.

MRI scanning method: The Siemens 3.0T MRI scanner was used to obtain MRI imaging in both the axial and sagittal planes of the lumbar vertebrae, with a layer spacing of 3 mm. The acquired CT and MRI data were then uploaded to the Picture Archiving and Communication System (PACS) in the medical digital imaging and communication (DICOM) file format (**Figure 1**).

CMR method: Thin-slice axial CT scan data and conventional MRI T2 sagittal data were imported into E-3D medical system (V20.02) (Digital Health and Virtual Reality Research Center, Central South University). MRI images served as moving images and thin-slice CT images served as fixed images, registered using the software's multimodal registration function. The CMR process includes techniques such as translational rotation, B-spline transformation, and interactive movement rotation, concluding with fine registration using the manual registra-

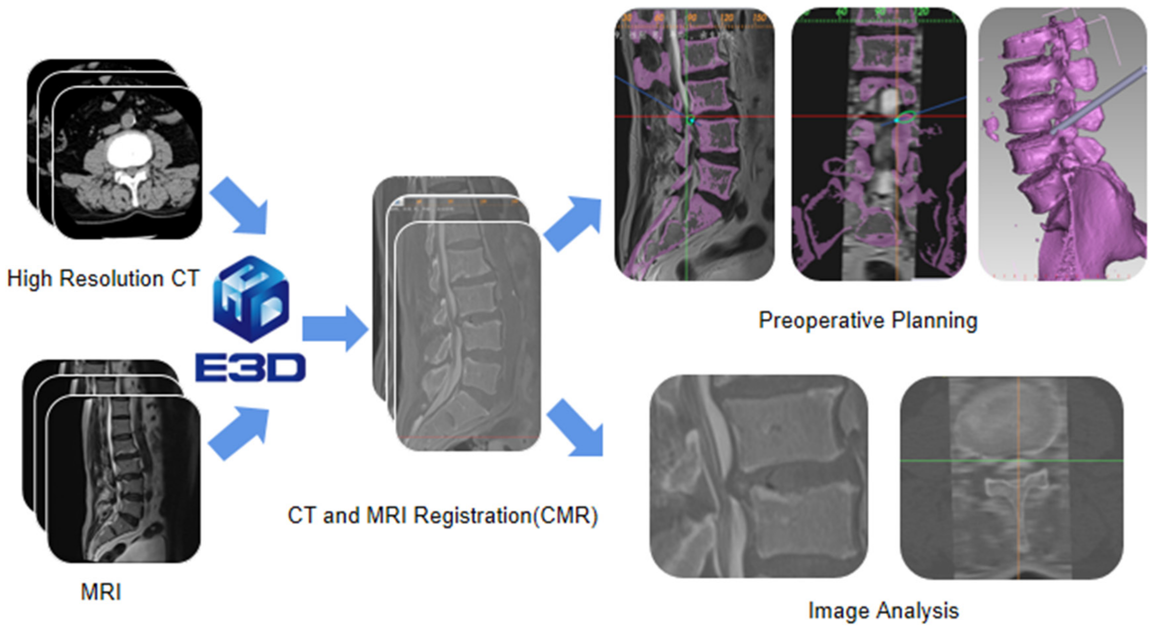

Figure 1. Flowchart of CT and MRI registration (CMR).

tion function. The transparency of CT and MRI images was set to 0.6, and the distribution of intervertebral discs and osteophytes was observed from multiple directions (**Figure 1**).

Simulated surgery: The device function was used to simulate the placement of the working cannula with an outer diameter of 7.5 mm. For the transforaminal approach, the head of the working cannula was positioned at the herniated disc site, ensuring the body of the working cannula avoids the outlet root and abdominal organs. The position was repeatedly adjusted to minimize resection of the superior articular process while maximizing the endoscopic visual field. The angles of the working cannula in the coronal and sagittal planes relative to the vertebral body are then calculated. For the interlaminar approach, the cannula's head is also placed at the herniated disc site, with its body navigating through the maximum space of the laminar space to ensure an optimal field of view. The perpendicular distance from the midline of the spinous process and its angle with the L5 vertebral body in the sagittal plane are also determined (**Figure 1**).

Surgical procedure

The surgical approach in CMR group was preoperatively planned by CMR, while that in the control group was routinely planned by CT or MRI before surgery. Both groups were treated with PELD. For L2/3, L3/4, L4/5 LDH, the foraminal approach was used. For L5/S1 LDH, intervertebral foraminal or interlaminar approach was employed. During the operation, the position and size of the disc, as well as the nerve compression caused by the disc were assessed. The herniated disc was removed using forceps, and then the nerve was inspected endoscopically to ensure it was completely decompressed. The surgery was completed after verifying significant reductions in the patient's pain and numbness.

Outcome measurements

Primary outcomes: Surgical time is defined as the duration from the needle puncture to the suturing of the skin. Additionally, the length of hospital stay was recorded.

Secondary outcomes: The Visual Analog Scale (VAS) was utilized to assess leg pain and low back pain before and 2 months after surgery. The VAS score is represented by a 10 cm line on paper, where one end of the line is marked 0, indicating no pain, and the other end is marked 10, indicating severe pain. Patients were asked to place a mark on the line corresponding to their pain level [16]. The Japanese Orthopaedic Association Lumbar Spine Score (JOA) was also recorded, with a scoring range

Table 1. Demographic data

Category	CMR group (n=68)	Control group (n=72)	*P* value
Gender			
Male	41 (60.0)	46 (63.9)	
Female	27 (40.0)	26 (36.1)	0.661
Age, mean ± SD, y	42.91±14.73	45.40±13.55	0.229
Side			
Right	28 (41.2)	35 (48.6)	
Left	38 (55.9)	37 (51.4)	
Bilateral	2 (2.9)	0 (0)	0.262
Level			
L2/3	0 (0.0)	1 (1.4)	
L3/4	2 (2.9)	1 (1.4)	
L4/5	34 (50.0)	42 (58.3)	
L5/S1	32 (47.1)	28 (38.9)	0.507

from 0 to 29, where lower scores indicate more pronounced dysfunction.

Statistical analysis

Statistical analysis was performed using SPSSPRO (https://www.spsspro.com/). The measurement data were expressed as mean ± standard deviation and the difference between the two groups was compared using the Student t-test. The difference in measurement data at 2 months postoperatively compared to preoperative was evaluated using the paired t-test. The count data were expressed in numbers and the difference between the two groups was analyzed by using the Pearson chi-square test. P≤0.05 was considered as statistical significance.

Results

Demographic data

A total of 140 patients diagnosed with lumbar disc herniation (LDH) were included in this retrospective analysis. The CMR group comprised 68 patients (41 males and 27 females), while the control group consisted of 72 patients (46 males and 26 females). Statistical analysis revealed no significant differences in gender distribution (P=0.661), age distribution (P=0.229), affected lower limb side (P=0.262), or protruding levels of LDH (P=0.507) between the two groups (**Table 1**).

Primary outcomes

Surgical time in the CMR group was significantly shorter than that in the control group (P<0.001). The average length of hospital stay in the CMR group was 6.31±3.08 days, which was comparable to 6.89±3.20 days in the control group (P=0.277, **Table 2**).

Secondary outcomes

Two months postoperatively, the CMR group exhibited a significant reduction in VAS leg pain (P<0.001) and VAS low back pain (P<0.001), as well as a significant increase in JOA scores (P<0.001) compared to preoperative levels. Similarly, the control group showed significant decreases in VAS leg pain and VAS low back pain (P<0.001 for both) and an increase in JOA scores (P<0.001) two months postoperatively.

Comparisons between the two groups revealed that, two months post-surgery, the CMR group experienced significantly lower VAS scores for leg pain (P<0.001) and low back pain (P=0.002), and higher JOA scores (P<0.001) than the control group (**Table 2**).

Typical case #1

Patient #1, male, 44 years old. He was admitted to the hospital due to persistent low back pain and numbness in the left lower limb for six months. Physical examination showed positive Lasegue sign on the left side; numbness in the posterior left calf, thigh, soles, and dorsum of the feet. Strength level of the left extensor longus muscle was graded at 4. MRI: LDH(L3/4). CT: calcification at L3/4 disc (**Figure 2A**). The MRI image served as moving image, and the CT image served as fixed image, facilitating precise registration. After the herniated disc was precisely positioned, a working cannula was simulated on the CT 3D reconstruction image (**Figure 2B**). The extent of soft protrusions and calcifications is precisely shown on the fusion image (**Figure 2C**). Endoscopic image confirmed complete release of the nerves and spinal cord and removal of the herniated disc (**Figure 2D**). The operation lasted 85 minutes. The patient

Table 2. Primary and secondary outcomes

Outcome	CMR group (n=68)	Control group (n=72)	Mean difference	*P* value
Surgery time (min)	88.94±14.30	108.99±19.86	-20.04	<0.001
Hospital stay (day)	6.31±3.08	6.89±3.20	-0.58	0.277
VAS leg pain - preoperative	8.12±0.70	8.00±0.75	0.12	0.341
VAS leg pain - postoperative	2.00±0.95*	2.89±1.11*	-0.89	<0.001
VAS low back pain - preoperative	7.09±1.32	6.75±1.31	0.34	0.131
VAS low back pain - postoperative	1.62±1.11*	2.28±1.32*	-0.66	0.002
JOA-preoperative	11.44±2.36	11.32±2.15	0.12	0.750
JOA-postoperative	24.66±2.94*	22.07±3.40*	2.59	<0.001

Note: VAS: Visual Analog Scale, JOA: The Japanese Orthopaedic Association Lumbar Spine Score. *P<0.001, compare with preoperative values.

was hospitalized for 4 days, with initial VAS leg pain of 9, reduced to 1 two months postoperatively, and the initial VAS low back pain of 8, reduced to 2 two months postoperatively. The JOA score was 8 before surgery and improved to 26 two months after surgery.

Typical case #2

Patient #2, female, 31 years old. She was hospitalized for persistent low back pain and right lower limb pain for 6 years, worsened by numbness for 2 days. Physical examination showed low back tenderness, inducing radiating pain in the right lower limb. Positive right-side Lasegue signs. Numbness was reported in the right back thigh, lateral right calf, and the back of the right foot. The muscle strength of the right hallux long extensor muscle was graded level 4, and the right anterior tibialis muscle strength was level 4. MRI: LDH(L4/5). CT: A small fraction of the calcified discs at L4/5 (**Figure 3A**). The MRI image served as moving image, and the CT image served as fixed image, for the image registration. After the herniated disc was precisely positioned, a working cannula was simulated on the CT 3D reconstruction image (**Figure 3B**). The extent of soft protrusions and calcifications was precisely shown on the fusion image (**Figure 3C**). Endoscopic images confirmed complete release of the nerves and spinal cord and removal of the herniated disc (**Figure 3D**). The operation lasted 124 minutes. The patient was hospitalized for 4 days, with initial VAS leg pain of 8, reduced to 2 two months postoperatively, and the initial VAS low back pain of 7, reduced to 2 two months postoperatively. The JOA score was improved from 15 before surgery to 26 at 2 months after surgery.

Discussion

Imaging techniques play a pivotal role in the management of spinal disorders, proving essential for both diagnosis and treatment. Clinicians commonly rely on preoperative imaging to plan surgical strategies, guide the operative procedure, and tailor treatments to individual patients. Appropriate imaging examination can effectively guide surgical operations and reduce unnecessary damage to nerves and tissues [17-19]. CT imaging is renowned for its capacity to capture thin slices that can be precisely reconstructed into detailed 3D models, offering excellent visualization of spatial structures. While CT is particularly effective at depicting bone tissue due to its density-dependent nature, it is less adept at identifying softer structures such as ligaments, nerves, and discs. MRI excels in the visualization of soft tissues such as nerves, discs, and ligaments. However, the use of thin-slice scanning in MRI is often limited by factors such as time and cost. Therefore, this study combined the complementary strengths of both CT and MRI: the three-dimensional reconstruction capabilities of CT, which is sensitive to bony structures, and the soft tissue sensitivity of MRI, namely CT and MRI registration (CMR which is less commonly studied but potentially offers enhanced diagnostic and planning capabilities in spinal care.

Percutaneous Endoscopic Lumbar Discectomy (PELD), a minimally invasive procedure, is widely employed for LDH [20, 21]. It allows for the resection of the affected disc under local anesthesia [22], minimizing damage to the lamina, paraspinal muscles, and soft tissues, thereby reducing the risk of post-operative segmental

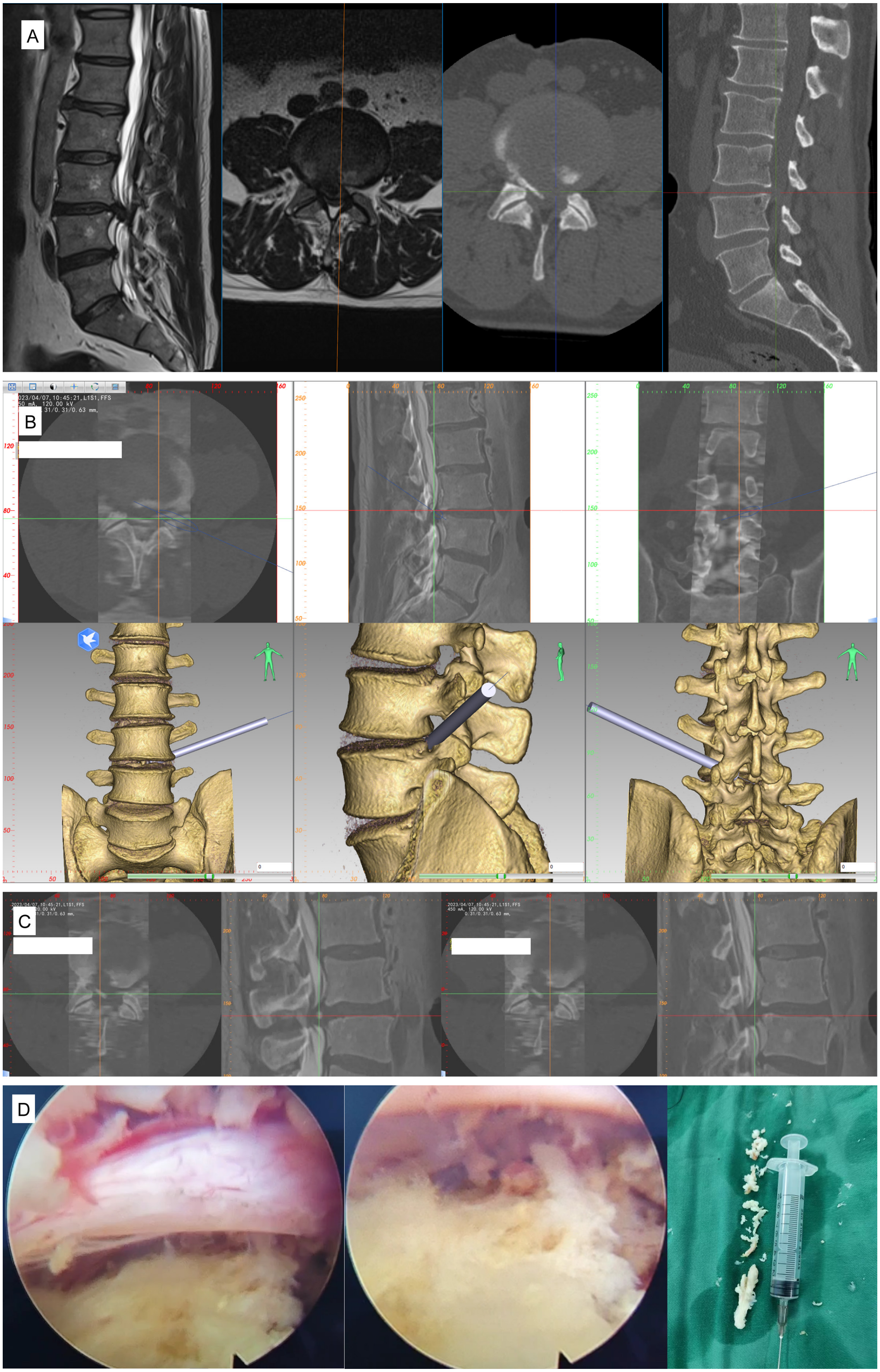
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Figure 2. Case #1. A: MRI: LDH (L3/4); CT: disc calcification OF L3/4. B: CT and MRI registration (CMR) was performed and working cannula was simulated on the CT 3D reconstruction image. C: The extent of soft protrusions and calcifications is precisely shown on the fusion image. D: Endoscopic images show that the nerves and spinal cord have been completely released and the herniated disc has been removed.

instability. PELD is typically performed through either a transforaminal (TF) or interlaminar (IL) approach to remove the herniated disc [23-25]. Compared with conventional open discectomy, PELD can reduce the severity of post-operative pain and improve patient satisfaction [26-28]. In our study, the VAS leg pain and VAS low back pain in both groups were significantly reduced compared to preoperative levels. Additionally, the JOA scores showed a significant increase compared to preoperative levels, indicating the effectiveness of PELD in treating LDH. However, the minimally invasive nature of PELD requires precise positioning and puncture techniques, as well as a clearer understanding of the location and characteristics of the herniated disc. Repeated puncture not only prolongs the operation time, but also increases patient discomfort, and can even hurt other tissues. Therefore, accurate and rapid puncture positioning is crucial to reduce the radiation exposure and shorten the operation time.

The combination of navigation technology with spinal endoscopy has achieved inspiring advancements. Navigation technology enables surgeons to accurately locate target areas and perform delicate operations, achieving better surgical outcomes [29-33]. The commonly used navigation technologies, such as electromagnetic navigation, robot navigation, and virtual reality navigation, are predominantly operated based on CT data [30-34]. By combining CT and MRI data, the strengths of both modalities are harnessed - CT's excellent visualization of bony structures and MRI's detailed imaging of nerves, ligaments, and intervertebral discs. Jiro Hirayama used 3D CT/MR fusion images for interlaminar endoscopic discectomy planning, finding that preoperative simulations of IL window to visualize the 3D regional anatomy effectively predicted the feasibility of a PED-IL [35]. In Kambin's triangular region, Jiro Hirayama's use of 3D CT/MR fusion images for preoperative planning enhanced patient safety [36]. Cao, J employed magnetic resonance-magnetic resonance-ultrasound (MR-MR-US) fusion imaging navigation (FIN) with needle tail intelligent positioning (NTIP) to guide puncture in percutaneous transforaminal endoscopic discectomy (PTED) [37]. Tabarestani, T. Q demonstrated successful and safe nerve segmentation using MRI/CT fusion to perform percLIF, leading to positive patient outcomes [38]. Yamada, K used 3D MRI/CT fusion images to evaluate operability in simulated FED-TF surgery without foraminoplasty, noting that 13 out of the 52 cases were operable. All the 13 cases underwent FED-TF surgery without neurological complications and achieved significant improvement in clinical symptoms [39]. Despite these promising results, the existing literature often involves a small number of cases or relies on animal studies. Nonetheless, with CT and MRI scans being routine in most hospitals, CMR is a viable option. Various imaging software platforms now offer CMR capabilities, and with proper training, spinal surgeons can proficiently use this technology. Preoperative CMR analysis allows for the precise identification of nerve impingement-whether by osteophytes, calcified or non-calcified intervertebral discs, or compression by the ligamentum flavum. Identifying the compressed nerve root through physical examination and locating the compression site in CMR images preoperatively enhances the precision and efficiency of surgical interventions.

Utilizing the E3D software, the B-spline transformation method serves as a coarse registration to achieve better results. After successful registration, the dural sac can be reconstructed on CT image, as it appears hyperintense on MRI T2 images. This capability allows CMR to generate CT myelography-like images [40], which directly reveal whether nerve compression is due to bone, disc, or ligament. This is combined with preoperative 3D planning for more precise surgical preparation. In this study, a 3D reconstruction of the disc and lumbar spine was performed after image fusion, and the working cannula was placed virtually to determine the optimal path. This ensures minimal resection of the superior articular process and reduces the occurrence of long-term lumbar instability. In this study, the surgery time, VAS score at 2 months after surgery in the CMR group were significantly lower than the control group. JOA score at 2 months after sur-

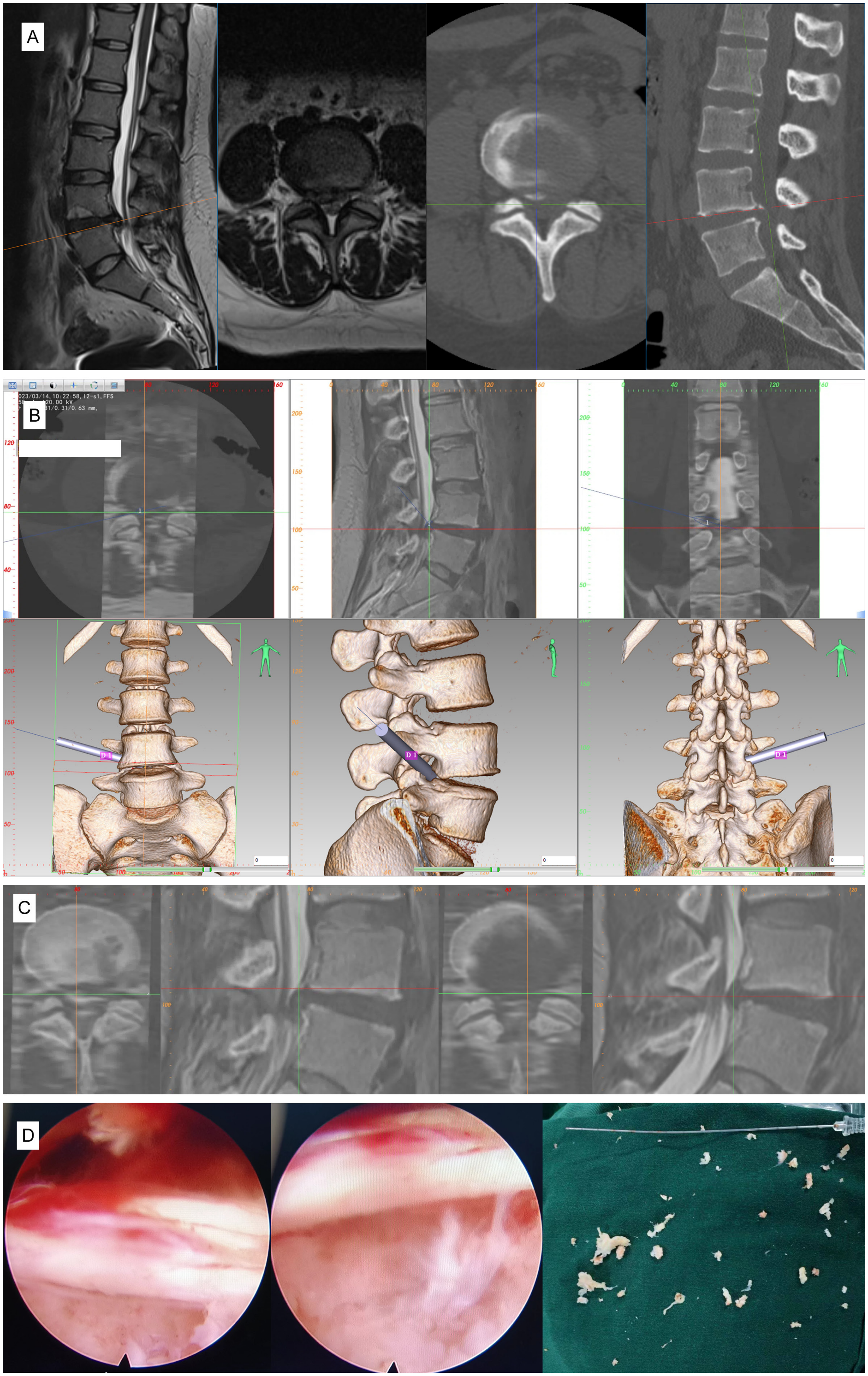
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Figure 3. Case #2. A: MRI: LDH (L4/5); CT: A small fraction of the calcified discs at L4/5. B: CT and MRI registration (CMR) was performed and working cannula was simulated on the CT 3D reconstruction image. C: The extent of soft protrusions and calcifications is precisely shown on the fusion image. D: Endoscopic images show that the nerves and spinal cord have been completely released and the herniated disc has been removed.

gery in the CMR group were significantly higher than the control group. These findings suggest that CMR could improve the prognosis compared with conventional spine endoscopic surgery.

The limitations in MRI examinations, stemming from cost and scanning time constraints, lead to fewer and narrower scanning layers compared to CT. As a result, automatic registration often suffers from low accuracy, necessitating manual adjustment. To address this, the future development of automated CMR software is promising, as it could effectively alleviate technological challenges and reduce labor costs. Furthermore, our study is a retrospective single-center analysis. To provide more comprehensive references for the application of CMR technology, future endeavors should encompass prospective, multicenter studies with expanded sample sizes. In the future, CMR holds potential for 3D reconstruction of nerves, cerebrospinal fluid, intervertebral discs, and bone. Additionally, its integration with virtual reality (VR) technology for intraoperative navigation could significantly enhance surgical precision and improve postoperative recovery.

Conclusion

Compared with the traditional PELD, the preoperative use of CMR has been shown to reduce surgery time, alleviate leg and low back pain, and increase the lumbar JOA score at 2 months after surgery, underscoring its efficacy in enhancing surgical outcomes.

Acknowledgements

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Disclosure of conflict of interest

None.

Address correspondence to: Xiaobo Guo, Department of Orthopedics, Jincheng General Hospital, Changan Road, Jincheng 048006, Shanxi, China. Tel: +86-0356-3883072; E-mail: bobo4310@163.com

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