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Original Article

Collagenase chemical lysis versus foraminal endoscopic surgery for lumbar disc herniation: superior efficacy and prognostic factors in postoperative recovery

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Abstract: Objective: To compare the efficacy of collagenase chemonucleolysis (CCNL) and percutaneous transforaminal endoscopic discectomy (PTED) in treating lumbar disc herniation and to identify risk factors affecting patient outcomes. Methods: A total of 157 patients with lumbar disc herniation admitted to our hospital between May 2022 and March 2024 were retrospectively analyzed and divided into the PTED group (n = 72) and the CCNL group (n = 85) based on the intervention approach. Clinical data, including age, gender, and BMI, were collected, and procedure-related indicators were recorded. Clinical efficacy was assessed three months postoperatively using the MacNab functional criteria. Pain intensity, lumbar function, and disability were evaluated using the Visual Analog Scale (VAS), Japanese Orthopedic Association assessment (JOA) score, and Oswestry Dysfunction Index (ODI) score, respectively. Results: No significant differences were observed in baseline data between the two groups ($P > 0.05$). The CCNL group demonstrated superior outcomes in operative time, intraoperative fluoroscopy time, blood loss, incision size, and postoperative hospital stay ($P < 0.001$). At 1 week, 1 month, and 3 months after surgery, the CCNL group showed significantly lower VAS scores and better JOA and ODI scores compared to the PTED group ($P < 0.05$). The total response rate was significantly higher in the CCNL group (81.18%) compared to the PTED group (63.89%) ($P = 0.015$). Conclusion: CCNL is associated with better surgical efficiency, faster recovery, and superior pain relief and lumbar function recovery compared to PTED in the treatment of lumbar disc herniation. Age, disease duration, and preoperative VAS and ODI scores are independent prognostic factors for CCNL outcomes. This combined model effectively predicts the risk of poor postoperative outcomes.

Keywords: Collagenase lysis, endoscopic surgery, lumbar disc herniation, postoperative recovery, prognostic factors

Introduction

Lumbar disc herniation (LDH) is a prevalent degenerative spinal condition, primarily characterized by partial or complete rupture of the annulus fibrosus, allowing the nucleus pulposus to protrude and compress or irritate adjacent nerve roots. This often results in symptoms such as low back pain, radiating lower limb pain, numbness, and muscle weakness [1, 2]. With the advent of modern lifestyles, characterized by prolonged sedentary behavior, reduced physical activity, and extensive use of electronic devices, the incidence of LDH has steadily increased. Consequently, LDH has become a major public health concern, profoundly impacting individuals' quality of life and work productivity. Epidemiological data indicate that nearly 80% of the population may experience back and leg pain at some point, with an increasing prevalence among younger demographics, thereby imposing a substantial economic burden on society [3, 4].

Treatment modalities for LDH are generally classified as conservative and surgical. Conservative treatments, including pharmacotherapy, physical therapy, and rehabilitative exercises, can mitigate symptoms in some patients. However, individuals with severe pathology or those who fail to respond to conservative treatment often require surgical intervention to

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decompress nerve roots and restore lumbar function [5].

Recent advances in minimally invasive techniques have led to the increasing use of procedures such as percutaneous transforaminal endoscopic discectomy (PTED) and collagenase chemonucleolysis (CCNL) [6, 7]. PTED involves the endoscopic removal of herniated disc material under direct visualization, offering benefits such as reduced tissue trauma, minimal blood loss, faster postoperative recovery, and preservation of lumbar spine stability [4, 8]. In contrast, CCNL employs collagenase to specifically dissolve collagen fibers within the intervertebral disc, facilitating the gradual absorption of the herniated tissue and alleviating nerve root compression. This technique is particularly beneficial for patients reluctant to undergo surgery or those at higher surgical risk, due to its simplicity, minimal invasiveness, and rapid recovery profile [9-11].

Although both PTED and CCNL have demonstrated clinical efficacy, comparative studies evaluating their outcomes and prognostic determinants in LDH are limited. Therefore, this study aims to compare the effectiveness of CCNL versus PTED in the treatment of LDH and to identify risk factors influencing prognosis in LDH patients, with a particular focus on the prognostic factors following CCNL treatment. The findings are anticipated to offer valuable guidance for clinicians in optimizing treatment strategies, improving therapeutic outcomes and patient prognoses, and reducing both discomfort and financial burdens.

Data and methods

Case selection

A total of 157 patients diagnosed with lumbar disc herniation and admitted to Gansu Province Hospital Rehabilitation Center between May 2022 and March 2024 were retrospectively enrolled in this study. Based on the treatment plan, the patients were divided into two groups: the PTED group (n = 72), which underwent foraminal endoscopic surgery, and the CCNL group (n = 85), which received collagenase chemical lysis. The study protocol was approved by the Medical Ethics Committee of Gansu Province Hospital Rehabilitation Center.

Inclusion criteria: (1) Patients with a confirmed diagnosis of lumbar disc herniation, supported by clinical symptoms (e.g., radiating pain in the waist or lower limbs, positive straight leg raise test) and imaging evidence (MRI or CT) indicating herniation at a single lumbar segment. (2) Patients with a symptom duration of at least 6 weeks but not exceeding 12 months. (3) Patients aged 18 years or older. (4) Patients with lumbar disc herniation localized to a single vertebral segment. (5) Patients with complete clinical data, including preoperative assessments, imaging studies, and relevant medical history.

Exclusion criteria: (1) Patients with spondylolisthesis, significant lumbar instability, or spinal stenosis requiring alternative surgical approaches. (2) Patients with active infections (e.g., discitis, osteomyelitis) or spinal tumors/malignancies. (3) Patients with a history of prior spinal surgery for lumbar disc herniation or other lumbar conditions that could complicate the current surgical procedure. (4) Patients presenting with severe or progressive neurological deficits (e.g., cauda equina syndrome, marked motor weakness, or bowel/bladder dysfunction). (5) Patients with psychiatric disorders impairing their ability to understand or comply with treatment protocols, including postoperative rehabilitation and follow-up. (6) Pregnant patients, due to the potential risks associated with lumbar spine treatments during pregnancy. (7) Patients unlikely to adhere to follow-up evaluations, rehabilitation, or postoperative care.

Surgical methods

PTED group: Patients in the PTED group underwent foraminal endoscopic surgery performed by an experienced orthopedic surgeon. Under local anesthesia, the patient was positioned laterally with the affected side upward and the waist elevated to ensure proper lateral fixation. The skin puncture site was located above the iliac crest, approximately 10-14 cm from the midline. Following standard disinfection and local infiltration anesthesia with 1% lidocaine, an 18G needle was introduced through the foramen toward the middle and posterior edge of the target disc. A mixed contrast solution (methylene blue and iodohyanol in a 1:3 ratio) was injected to delineate the herniated tissue.

Once the protrusion was visualized, the needle direction was adjusted accordingly, and a guide wire was inserted and secured. The needle was then withdrawn, and a small skin incision (approximately 0.8 cm) was made at the guide wire entry point. Soft tissue was sequentially dilated, and an expansion sleeve was introduced to establish the working channel. The endoscopic system, saline irrigation, and negative pressure aspirator were connected. Under bipolar radiofrequency guidance, the blue-stained herniated tissue was carefully removed to decompress the nerve root, ensuring no residue compression on the nerve root or dural sac. Continuous communication with the patient was maintained throughout the procedure to monitor for signs of nerve irritation. Upon completion, symptomatic treatment, including anti-infection measures and analgesia, was administered. The working channel was removed, and the incision was disinfected and dressed.

CCNL group: Patients in the CCNL group underwent collagenase chemonucleolysis, performed by an interventional pain physician with over 20 years of experience in this technique. Patients were positioned laterally, and the surgical site was localized under C-arm guidance. Following routine disinfection and draping, the skin puncture site was marked approximately 8 cm lateral to the midline on the affected side. Local anesthesia was administered using 2% lidocaine. Under DSA monitoring, an 18G needle was advanced into the epidural space adjacent to the target intervertebral disc. Accurate needle placement was confirmed by contrast injection (1 mL of non-ionic contrast iododol), ensuring diffusion into the epidural space and ruling out vascular or dural involvement. Subsequently, 3 mL of 1% lidocaine was injected over 15 minutes. Diluted collagenase (1200 U/2.0 mL saline; H31022658; Shanghai Qiaoyuan Biopharmaceutical Co., Ltd.) was then slowly administered. Hemostasis was achieved by applying pressure at the puncture site, followed by sterile dressing. After a 15-minute observation confirming stable vital signs and absence of lower limb dysfunction, patients were transferred back to the ward, maintaining a prone position on the affected side in for at least 6 hours.

Clinical data collection

Data collected included patients' demographic characteristics, imaging findings, and both preoperative and postoperative evaluations. Preoperative imaging (MRI or CT) confirmed the location and extent of the herniation. Baseline evaluations included the Visual Analog Scale (VAS) for pain (0-10 scale), the Japanese Orthopaedic Association (JOA) score for lumbar function (0-29 scale), and the Oswestry Disability Index (ODI) for disability assessment (0-100 scale). Postoperative evaluations were conducted at 1 week, 1 month, and 3 months, focusing on VAS, JOA, and ODI scores to assess pain control, functional recovery, and disability improvement. Surgical parameters, including operation duration, intraoperative fluoroscopic duration, blood loss, incision size, and postoperative hospital stay, were also recorded.

Michigan State University (MSU) somatotype

The MSU grading system was proposed by Prof. Mysliwiec's team at Michigan State University (USA) in 2010 with the aim of evaluating the indications for surgery for herniated discs (LDH) based on lumbar MRI images. Its core elements include: herniation size grading: using the line connecting the medial margins of the bilateral articular synovial joints as a reference line, the distance from the posterior edge of the disc to the line is measured and categorized into three grades: grade 1 (herniation ≤ 50% of the distance from the reference line), grade 2 (herniation > 50% but not exceeding the reference line) and grade 3 (herniation exceeding the reference line). The herniation position is divided into three zones: Zone A (central zone, right and left central quadrants), Zone B (paracentral zone, right and left lateral quadrants), and Zone C (extreme lateral zone, beyond the border of the lateral quadrants). Zone B and Zone C are restricted in anatomical space, and are susceptible to significant compression of the nerves, even if Grade 2 herniation occurs. The B and C zones have limited anatomical space, and even grade 2 herniations tend to significantly compress the nerve.

Outcome measurements

Primary outcome: Efficacy was assessed using the MacNab functional scoring criteria, which categorize outcomes into four categories: (1) Excellent: No pain or occasional mild pain, no need for analgesics, and full return to normal activities without restrictions. (2) Good: Occasional mild pain not affecting daily life, minimal need for analgesics, and near-normal activity levels with slight discomfort in specific situations. (3) Fair: Moderate pain requiring regular analgesic use and limited mobility, though basic daily activities remain achievable. (4) Poor: Persistent pain that significantly impairs daily life, necessitating long-term analgesic use, with substantial restrictions in mobility.

Secondary outcomes: (1) Pain assessment: VAS scores were recorded preoperatively and at 1 day, 1 week, 1 month, and 3 months postoperatively. (2) Lumbar function: JOA scores were assessed at the same time points to evaluate lumbar function. (3) Disability evaluation: ODI scores were obtained preoperatively, and at 1 week, 1 month, and 3 months postoperatively. (4) Surgical indicators: Operation duration, intraoperative fluoroscopic time, blood loss, incision size, and postoperative hospital stay were documented. (5) Nomogram model construction: A nomogram was developed to predict postoperative outcomes based on preoperative variables (VAS, JOA, ODI) and surgical parameters (operation time, fluoroscopy time, blood loss, incision size, and hospital stay).

Statistical methods

Data were analyzed using SPSS 22.0. The normality of continuous variables was assessed using the Kolmogorov-Smirnov (K-S) test. Normally distributed data were expressed as mean ± standard deviation and compared using independent-samples t-tests; non-normally distributed data were expressed as medians with interquartile ranges (IQR) and compared using the Mann-Whitney U test. Repeated measures analysis of variance (ANOVA) was employed for intragroup comparisons across multiple time points, with Bonferroni post-hoc tests for pairwise comparisons. Categorical data were presented as frequencies and percentages, and compared using the chi-square (χ^2) test. Logistic regression analysis was conducted to identify independent risk factors affecting outcomes, and receiver operating characteristic (ROC) curve analysis was employed to evaluate the predictive performance of the model, with the area under the curve (AUC) serving as the accuracy metric. The nomogram model was constructed using R 4.3.3 with the rms package, and calibration curves were generated. A *p*-value of < 0.05 was considered statistically significant.

Results

Comparison of baseline data between the two groups

No significant differences were observed between the PTED and CCNL groups in terms of age, sex, BMI, disease duration, affected segment, MSU classification, ASA grade, hypertension, or diabetes status (all P > 0.05), indicating comparability between the groups (**Table 1**).

Comparison of surgery-related indicators between the two groups

The PTED group showed significantly longer operation duration, intraoperative fluoroscopic time, greater intraoperative blood loss, and longer incision length compared to the CCNL group (t = -54.64, -10.744, -86.636, -46.311, all P < 0.001). Additionally, the postoperative hospital stay was significantly longer in the PTED group (t = -8.666, P < 0.001) (**Table 2**). These findings suggest that the CCNL group demonstrated superior surgical efficiency and faster postoperative recovery.

Comparison of pain levels between the two groups

VAS scores before surgery and 1 day after surgery showed no significant differences between the groups (t = 0.506, P = 0.613; t = 0.016, P = 0.987). However, at 1 week, 1 month, and 3 months post-surgery, the CCNL group demonstrated significantly lower VAS scores compared to the PTED group (Z = 3.066, P = 0.002; Z = 5.220, P < 0.001; Z = 3.538, P < 0.001) (**Table 3**). These results indicate that CCNL is more effective in postoperative pain management.

Comparison of lumbar spine function between the two groups

JOA scores showed no significant differences between the groups before surgery and at 1 day and 1 month after surgery (t = 0.340, P = 0.734; t = 0.988, P = 0.323; t = 0.790, P = 0.430). However, at 1 month and 3 months post-surgery, the CCNL group showed significantly higher JOA scores (t = 2.101, P = 0.036; t = 2.509, P = 0.012) (**Table 4**), suggesting better lumbar spine function recovery in the CCNL group.

Table 1. Comparison of baseline data between the PTED and CCNL groups

Item	PTED group (n = 72)	CCNL group (n = 85)	t/χ^2	*P*
Age (year)	52.94±7.85	54.53±7.44	1.291	0.199
Gender			0.549	0.459
Male	39	41		
Female	33	44		
BMI (kg/m^2)	23.82±1.65	24.28±2.22	1.501	0.135
Course of disease	6.42±1.73	6.61±2.01	0.460	0.642
Affected disc segment			0.867	0.899
L2-3	6	7		
L3-4	4	8		
L4-5	29	34		
L5-S1	33	36		
MSU somatotype			5.584	0.840
1A	7 (9.72)	9 (10.59)		
1B	3 (4.17)	5 (5.88)		
1C	4 (5.56)	2 (2.35)		
1AB	-	3 (3.53)		
2A	29 (40.28)	28 (32.94)		
2B	6 (8.33)	8 (9.41)		
2C	3 (4.17)	5 (5.88)		
2AB	5 (6.94)	8 (9.41)		
3A	3 (4.17)	5 (5.88)		
3B	4 (5.56)	3 (3.53)		
3C	1 (1.39)	1 (1.18)		
3AB	7 (11.11)	8 (9.41)		
ASA classification			0.103	0.749
I	45	51		
II	27	34		
Hypertension			0.055	0.814
Yes	25	28		
No	47	57		
Diabetes mellitus			0.038	0.846
Yes	21	26		
No	51	59		

Note: PTED: Percutaneous Transforaminal Endoscopic Discectomy, CCNL: Collagenase Chemonucleolysis, BMI: Body Mass Index, MSU: Michigan State University, and ASA: American Society of Anesthesiologists.

Comparison of lumbar spine disorder severity between the two groups

ODI scores showed no significant difference before surgery, 1 day or 1 week after surgery (t = 1.041, P = 0.298; t = 0.569, P = 0.570; t = 1.764, P = 0.078). However, at 1 month and 3 months post-surgery, the CCNL group demonstrated significantly lower ODI scores compared to PTED group (t = 2.216, P = 0.027; t = 2.306, P = 0.021) (**Table 5**), indicating superior recovery of lumbar function in the CCNL group.

Comparison of clinical efficacy between the two groups

At the end of 3-month follow-up, clinical efficacy was assessed using the MacNab functional scoring criteria. The total response rate was significantly higher in the CCNL group (81.18%) compared to the PTED group (63.89%) (χ^2 = 5.945, P = 0.015). Specifically, the CCNL group demonstrated a higher percentage of "Excellent" (54.12% vs. 43.06%) and "Good" (27.06% vs. 20.83%) outcomes, and a lower percentage of "Fair" (8.24% vs. 12.50%) and "Poor" (10.59% vs. 23.61%) outcomes (**Table 6**). These results suggest that CCNL is more effective in improving clinical outcomes.

Comparison of baseline data between effective and ineffective groups

Patients were divided into effective (n = 115) and ineffective (n = 42) groups based on clinical efficacy. No significant differences were found between the groups in terms of gender, BMI, affected disc segment, MSU classification, ASA grade, hypertension, or diabetes status (all P > 0.05). Additionally, no significant differences were observed in surgery-related factors (operation duration, intraoperative fluoroscopic time, blood loss, incision size, and postoperative hospital stay). However, patients in the effective group were significantly younger (52.05±7.00 vs. 58.12±7.69), had shorter disease duration (6.24±1.92 vs. 7.28±1.55), and exhibited lower preoperative VAS (7.00 [6.00, 8.00] vs. 8.00 [7.00, 8.75]) and ODI scores (59.61±8.77 vs. 66.21±7.74) (P < 0.05) (**Table 7**).

Table 2. Comparison of surgical parameters between the PTED and CCNL groups

Item	PTED group (n = 72)	CCNL group (n = 85)	*t*	*P*
Operation duration (min)	84.68±8.24	29.18±2.74	-54.64	< 0.001
Intraoperative fluoroscopic time (s)	11.92±1.69	6.51±0.88	-10.744	< 0.001
Intraoperative bleeding (ml)	26.22±2.43	1.39±0.14	-86.636	< 0.001
Incision size (cm)	0.94±0.08	0.48±0.04	-46.311	< 0.001
Postoperative hospital stay (d)	7.99±1.12	5.99±0.96	-8.666	< 0.001

Note: PTED: Percutaneous Transforaminal Endoscopic Discectomy, CCNL: Collagenase Chemonucleolysis.

Table 3. Comparison of VAS scores between the CCNL and PTED groups

Item	PTED group (n = 72)	CCNL group (n = 85)	*z*	*P*
Preoperative	7.00 [6.00, 8.00]	7.00 [7.00, 8.00]	0.506	0.613
Postoperative 1 day	5.00 [4.75, 6.00]	5.00 [5.00, 6.00]	0.016	0.987
Postoperative 1 week	4.00 [4.00, 4.00]	3.00 [3.00, 3.00]	3.066	0.002
Postoperative 1 month	3.00 [2.00, 3.00]	1.00 [1.00, 2.00]	5.22	< 0.001
Postoperative 3 months	2.00 [2.00, 2.00]	1.00 [1.00, 1.00]	3.538	< 0.001

Note: PTED: Percutaneous Transforaminal Endoscopic Discectomy, CCNL: Collagenase Chemonucleolysis, and VAS: Visual Analog Scale.

Table 4. Comparison of JOA scores between the CCNL and PTED groups

Item	PTED group (n = 72)	CCNL group (n = 85)	*t*	*P*
Preoperative	11±1.86	11.28±1.75	0.34	0.734
Postoperative 1 day	13.96±2.59	14.25±2.48	0.988	0.323
Postoperative 1 week	16.86±2.5	17.94±2.83	0.79	0.43
Postoperative 1 month	18.89±2.69	21.25±2.97	2.101	0.036
Postoperative 3 months	21.88±3.19	24.69±4.55	2.509	0.012

Note: PTED: Percutaneous Transforaminal Endoscopic Discectomy, CCNL: Collagenase Chemonucleolysis, and JOA: Japanese Orthopedic Association.

Table 5. Comparison of ODI scores between the CCNL and PTED groups

Item	PTED group (n = 72)	CCNL group (n = 85)	*t*	*P*
Preoperative	60.14±8.94	62.42±8.92	1.041	0.298
Postoperative 1 day	33.56±5.57	31.91±5.51	0.569	0.57
Postoperative 1 week	19.11±3.96	16.82±3.06	1.764	0.078
Postoperative 1 month	17.74±2.76	15.13±2.51	2.216	0.027
Postoperative 3 months	16.42±2.41	12.73±2.02	2.306	0.021

Note: PTED: Percutaneous Transforaminal Endoscopic Discectomy, CCNL: Collagenase Chemonucleolysis, and ODI: Oswestry Disability Index.

Logistic regression analysis of poor prognosis at three months postoperatively

Univariate analysis identified several factors significantly associated with poor prognosis, including age (OR = 1.132, 95% CI 1.071-1.207, P < 0.001), disease duration (OR = 1.370, 95% CI 1.121-1.704, P = 0.003), operation duration (OR = 1.015, 95% CI 1.002-1.028, P = 0.020), incision size (OR = 1.034, 95% CI 1.130-2.975, P = 0.035), preoperative VAS score (OR = 2.242, 95% CI 1.539-3.401, P < 0.001), and preoperative ODI score (OR = 1.102, 95% CI 1.052-1.16, P < 0.001). Multivariate analysis revealed that age (OR = 1.156, 95% CI 1.079-1.254, P < 0.001), disease duration (OR = 1.436, 95% CI 1.084-1.955, P = 0.015), preoperative VAS score (OR = 2.630, 95% CI 1.646-4.497, P < 0.001), and preoperative ODI score (OR = 1.070, 95% CI 1.007-1.143, P = 0.035) were independent risk factors for poor prognosis (**Tables 8**, **9**).

Predictive efficacy of influencing factors

Age, disease duration, preoperative VAS, and ODI scores each demonstrated good predictive value for poor prognosis, with AUCs of 0.718, 0.657, 0.700, and 0.708, respectively. The combined model yielded an AUC of 0.846, with sensitivity of 85.71%, specificity of 75.65%,

Table 6. Evaluation of clinical efficacy after 3 months of treatment in the PTED and CCNL group

Groups	Effective		Invalid		Total effective
	Excellent	Good	Average	Poor	
PTED group (n = 72)	31 (43.06)	15 (20.83)	9 (12.5)	17 (23.61)	63.89%
CCNL group (n = 85)	46 (54.12)	23 (27.06)	7 (8.24)	9 (10.59)	81.18%
χ^2					5.945
P					0.015

Note: PTED: Percutaneous Transforaminal Endoscopic Discectomy, CCNL: Collagenase Chemonucleolysis.

and Youden index of 61.37% (**Table 10**; **Figure 1**), demonstrating strong predictive performance.

Risk prediction model for postoperative outcomes

The risk prediction model showed strong correlations between preoperative VAS and ODI scores and postoperative outcomes, while age and disease duration showed relatively weaker associations (**Figure 2A**). The model demonstrated excellent discrimination, with a C-index of 0.843 (95% CI: 0.774-0.913), and good calibration (Goodness-of-Fit Test: χ^2 = 2.7387, P = 0.9497). The Likelihood Ratio Test confirmed the model's statistical significance (χ^2 = 52.549, P = 4.2e-13) (**Figure 2B**).

Discussion

The treatment of LDH has long been a focus in spinal surgery research [12]. With advancements in minimally invasive techniques, percutaneous transforaminal endoscopic discectomy (PTED) and collagenase chemonucleolysis (CCNL) have emerged as important approaches for managing LDH [5]. PTED has gained widespread clinical adoption owing to its advantages, such as minimal trauma and rapid recovery. However, as an even less invasive intervention, CCNL offers distinct benefits, including reduced surgical trauma and accelerated postoperative recovery [13, 14]. Despite its promise, research directly comparing the efficacy and prognostic factors of these two treatments is limited, particularly in the context of multivariate analysis and predictive model development. This study aims to address this gap and provide evidence to inform clinical decision-making.

In this study, we compared the efficacy of CCNL and PTED in the treatment of LDH. Our findings showed that the total response rate in the CCNL group was 81.18%, significantly higher than the 63.89% observed in the PTED group. CCNL demonstrated superior outcomes in multiple aspects, including operation duration, intraoperative fluoroscopic time, blood loss, incision size, and postoperative hospital stay. Additionally, at 1 week, 1 month, and 3 months postoperatively, the CCNL group exhibited significantly lower VAS scores and improved JOA and ODI scores compared to the PTED group. These findings suggest that CCNL offers advantages in surgical efficiency, reduced trauma, postoperative pain management, and lumbar functional recovery. The minimally invasive nature of CCNL likely contributes to these superior outcomes. Smaller incisions and reduced tissue disruption minimize surgical trauma, leading to less intraoperative blood loss and shorter hospital stays, which in turn promote faster recovery. The lower postoperative pain levels observed in the CCNL group may result from less damage to surrounding tissues and muscles, allowing patients to resume normal activities and work earlier. This is consistent with the findings of Guo et al. [11], who observed similar benefits in recovery using minimally invasive techniques. Thus, CCNL not only enhances surgical efficiency but also accelerates functional restoration. In contrast, PTED, although effective, is associated with longer operation times and greater postoperative discomfort, which may explain its lower response rate (63.89%) compared to CCNL. These findings suggest that CCNL may represent a more optimal treatment for lumbar disc herniation, particularly for those seeking quicker recovery and less invasive procedures [15, 16].

CCNL exerts its therapeutic effect by gradually dissolving collagen within the intervertebral disc through collagenase, which relieves the pressure exerted by the herniated disc tissue [7]. Although PTED directly removes the herni-

Table 7. Comparison of baseline data of patients with different treatment efficacy

Item	Effective group (n = 115)	Invalid group (n = 42)	t/χ^2	P
Age (year)	52.05±7.00	58.12±7.69	4.481	< 0.001
Gender			0.332	0.564
Male	57	23		
Female	58	19		
BMI (kg/m²)	23.91±1.94	24.51±2.08	1.513	0.131
Course of disease	6.24±1.92	7.28±1.55	3.014	0.002
Affected disc segment				
L2-3	10	3	0.864	0.834
L3-4	9	3		
L4-5	48	15		
L5-S1	48	21		
MSU somatotype			9.352	0.589
1A	13 (18.06)	3 (3.53)		
1B	6 (8.33)	2 (2.35)		
1C	5 (6.94)	1 (1.18)		
1AB	3 (4.17)	-		
2A	43 (59.72)	14 (16.47)		
2B	10 (13.89)	4 (4.71)		
2C	3 (4.17)	5 (5.88)		
2AB	8 (11.11)	5 (5.88)		
3A	6 (8.33)	2 (2.35)		
3B	6 (8.33)	1 (1.18)		
3C	1 (1.39)	1 (1.18)		
3AB	11 (15.28)	4 (4.71)		
ASA classification			0.014	0.906
I	70	26		
II	45	16		
Hypertension			2.538	0.111
Yes	43	10		
No	72	32		
Diabetes mellitus			1.979	0.160
Yes	38	9		
No	77	33		
Operation duration (min)	32.00 [29.00, 82.00]	78.50 [30.00, 87.75]	1.907	0.056
Intraoperative fluoroscopic time (s)	7.00 [6.00, 12.00]	9.50 [7.00, 11.00]	1.031	0.298
Intraoperative bleeding (mL)	1.53 [1.38, 26.80]	22.52 [1.38, 24.81]	-0.147	0.885
Incision size (cm)	0.52 [0.48, 0.92]	0.83 [0.48, 0.98]	1.656	0.098
Postoperative hospital stay (d)	7.00 [6.00, 8.00]	7.00 [6.00, 8.00]	1.126	0.250
Preoperative VAS	7.00 [6.00, 8.00]	8.00 [7.00, 8.75]	3.827	< 0.001
Preoperative JOA	10.95±2.07	11.23±1.69	-0.73	0.459
Preoperative ODI	59.61±8.77	66.21±7.74	4.564	< 0.001

Note: BMI: Body Mass Index, MSU: Michigan State University, ASA: American Society of Anesthesiologists, VAS: Visual Analog Scale, JOA: Japanese Orthopedic Association, and ODI: Oswestry Disability Index.

ated tissue, it can cause mechanical damage to surrounding tissues, leading to postoperative pain and delayed functional recovery [17]. These results align with the study by Guo et al., who reported that combining hypoablation myeloplasty (CN) with CCNL significantly im-

Table 8. Univariate analysis of the poor prognostic outcome

Variable	β	S.E.	P	OR	95% CI
Age	0.124	0.030	0.000	1.132	1.071-1.207
Gender	-0.210	0.362	0.565	0.812	0.396-1.648
BMI	0.150	0.091	0.100	1.162	0.973-1.394
Course of disease	0.315	0.106	0.003	1.370	1.121-1.704
Affected disc segment	0.155	0.209	0.458	1.168	0.786-1.797
MSU somatotype	0.054	0.058	0.353	1.056	0.941-1.184
ASA classification	-0.040	0.371	0.906	0.957	0.456-1.967
Hypertension	0.648	0.410	0.114	1.911	0.878-4.448
Diabetes mellitus	0.593	0.425	0.163	1.810	0.812-4.366
Operation duration	0.015	0.006	0.020	1.015	1.002-1.028
Intraoperative fluoroscopic time	0.041	0.060	0.488	1.042	0.926-1.172
Intraoperative bleeding	0.023	0.014	0.109	1.024	0.995-1.053
Incision size	1.609	0.765	0.035	1.034	1.130-2.975
Postoperative hospital stay	0.095	0.126	0.450	1.100	0.859-1.409
Preoperative VAS	0.807	0.201	0.000	2.242	1.539-3.401
Preoperative JOA	-0.090	0.101	0.399	0.918	0.751-1.119
Preoperative ODI	0.097	0.025	0.000	1.102	1.052-1.16

Note: BMI: Body Mass Index, MSU: Michigan State University, ASA: American Society of Anesthesiologists, VAS: Visual Analog Scale, JOA: Japanese Orthopedic Association, and ODI: Oswestry Disability Index.

Table 9. Multivariate analysis of poor prognosis

Variable	β	S.E.	P	OR	95% CI
Age	0.145	0.038	0.000	1.156	1.079-1.254
Course of disease	0.362	0.149	0.015	1.436	1.084-1.955
Operation duration	-0.010	0.039	0.711	0.986	0.911-1.063
Incision size	-3.440	3.752	0.359	1.032	0.941-3.968
Preoperative VAS	0.967	0.254	0.000	2.630	1.646-4.497
Preoperative ODI	0.067	0.032	0.035	1.070	1.007-1.143

Notes: VAS: Visual Analog Scale, and ODI: Oswestry Disability Index.

proved treatment outcomes for patients with grade I degenerative spondylolisthesis. Specifically, postoperative VAS scores for back and leg pain, as well as ODI and Recovery Quality-15 (QoR-15) scores, improved substantially compared to preoperative levels [11]. This indicates that the CN+CCNL combination effectively relieves lumbar and leg pain, promotes high-quality postoperative recovery, and prevents further progression of spondylolisthesis, thereby demonstrating its safety.

In our study, multivariate logistic regression analysis revealed several factors influencing the prognosis of LDH patients. Univariate and multivariate analyses identified age, disease course, operation duration, incision size, and preoperative VAS and ODI scores as significant predictors of treatment efficacy. Among these, age, disease course, preoperative VAS, and ODI scores were independent risk factors. As patients age, their physiological functions, including bone, muscle, and neural integrity, gradually deteriorate, leading to slower recovery and a higher risk of postoperative complications, ultimately affecting treatment outcomes [18, 19]. Similarly, a study by Kazuyoshi Kobayashi et al. on condoliase injection for LDH identified age, high-intensity MRI signals, and baseline Pfirrmann grade as critical factors influencing early recovery [20]. Additionally, patients with longer disease duration and higher preoperative VAS scores may experience irreversible nerve root damage, resulting in more extensive lesions, increased surgical difficulty, and delayed recovery [21, 22]. Sheng Shi's study found that anxiety negatively affects the prognosis of PTED patients, with pain severity, neurological deficits, disease duration, and quality of life contributing to anxiety development [23]. Augustine Balaara's research further demonstrated that both patient age and pain duration are associated with increased estimated blood loss, with prolonged pain duration correlating with persistent LDH, exacerbated injury, height-

Table 10. ROC curve analysis of factors affecting adverse prognosis

Marker	AUC	Cut off	Specificity	Sensitivity	95% CI	Youden index
Age	0.718	59.5	87.83%	47.62%	0.623-0.814	35.45%
Course of disease	0.657	5.5	34.78%	90.48%	0.569-0.746	25.26%
Preoperative VAS	0.700	7.5	70.43%	57.14%	0.612-0.788	27.58%
Preoperative ODI	0.708	67.5	80.87%	50.00%	0.617-0.799	30.87%
Combined model	0.846	-4.875	75.65%	85.71%	0.777-0.914	61.37%

Notes: ROC: Receiver's Operating Characteristic, VAS: Visual Analog Scale, and ODI: Oswestry Disability Index.

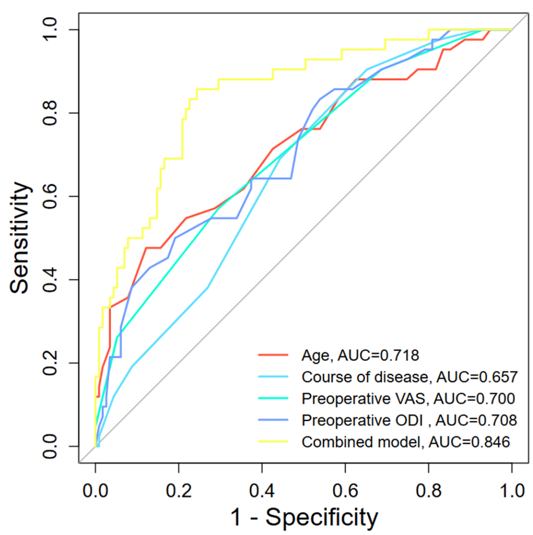

Figure 1. ROC curves of independent risk factors and their combination for predicting poor patient prognosis. Notes: ROC: Receiver's Operating Characteristic, VAS: Visual Analog Scale, and ODI: Oswestry Disability Index.

ened inflammation, and hematoma formation [24]. Furthermore, higher preoperative ODI scores reflect more severe dysfunction, which can prolong postoperative rehabilitation and hinder recovery [25, 26]. Bjørnar Berg's study employed a machine learning model based on ODI and pain improvement scores (NRS) to predict surgical benefits in LDH patients, demonstrating that such models are feasible for predicting long-term disability and pain outcomes [27]. ROC curve analysis in our study showed that age, disease duration, preoperative VAS score and ODI score had good predictive accuracy for postoperative outcomes, suggesting that these indicators may serve as potential predictors of prognosis.

This study examined the efficacy of CCNL and PTED in treating lumbar disc herniation, explored risk factors influencing CCNL prognosis, and developed a combined predictive model for poor postoperative outcomes. However, several limitations should be acknowledged. First, the sample size was relatively small, which may affect the generalizability of the findings. Future studies should expand the sample size to enhance the statistical power of the findings. Second, this study primarily focused on short-term outcomes within three months after surgery, and long-term follow-up data were limited. Future research should extend the follow-up duration to better assess sustained recovery and long-term quality of life. Furthermore, the effect of different MSU classification on treatment efficacy was not extensively analyzed. Future studies should refine patient subgroup analyses to better evaluate differential treatment responses. Lastly, psychological status and quality of life were not assessed, despite their potential influence on patient prognosis. Future investigations are recommended to incorporate these factors to achieve a more comprehensive evaluation of patient outcomes.

In conclusion, the findings of this study suggest that CCNL offers high surgical efficiency, rapid postoperative recovery, effective pain control, and excellent lumbar function restoration in the treatment of lumbar disc herniation. Age, disease duration, preoperative VAS score, and preoperative ODI score are independent prognostic factors for CCNL outcomes. The combined predictive model developed in this study demonstrates strong predictive capability for poor postoperative outcomes, providing valuable insights to guide treatment selection. These findings are expected to contribute to improved treatment outcomes, enhanced patient recovery, and reduced financial burdens associated with lumbar disc herniation management.

Disclosure of conflict of interest

None.

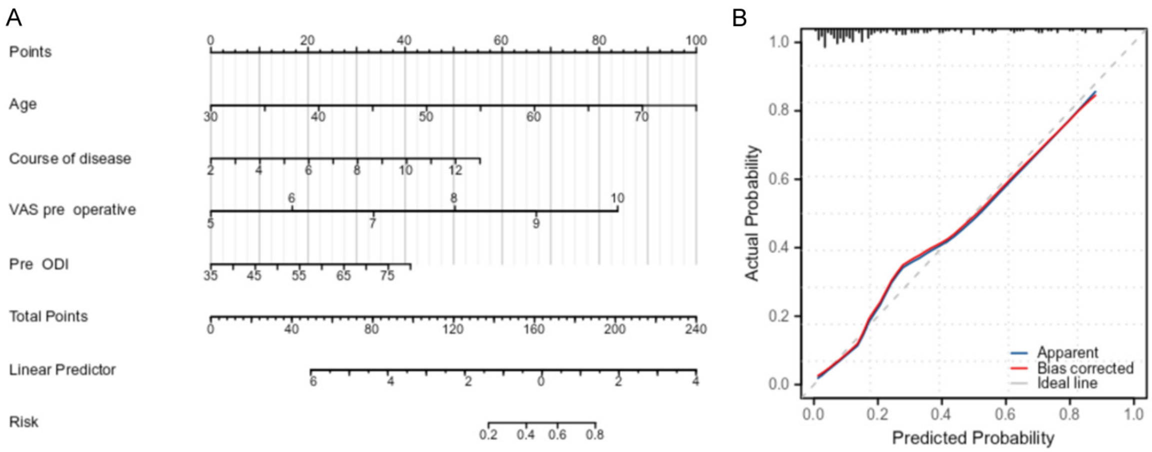

Figure 2. Risk prediction model and its calibration curve. A. The risk prediction model. B. The calibration curve comparing predicted probabilities with actual outcomes. Notes: VAS: Visual Analog Scale, and ODI: Oswestry Disability Index.

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