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Improving patient outcomes and education in minimally invasive spine surgery

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Published in
Frontiers in Surgery

ISSN 1664-8714
ISBN 978-2-8325-2872-3
DOI 10.3389/978-2-8325-2872-3

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Improving patient outcomes and education in minimally invasive spine surgery

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Citation

Tu, J., Cheung, J. P. Y., eds. (2023). *Improving patient outcomes and education in minimally invasive spine surgery*. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-8325-2872-3

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frontiers | Frontiers in Surgery

TYPE Original Research
PUBLISHED 06 October 2022
DOI 10.3389/fsurg.2022.999406

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

RECEIVED 21 July 2022
ACCEPTED 20 September 2022
PUBLISHED 06 October 2022

CITATION
Zhao Z, Deng L, Hua X, Liu H, Zhang H, Jia X, Wei R, Liu M and Lv N (2022) A retrospective study on the efficacy and safety of bone cement in the treatment of endplate fractures. Front. Surg. 9:999406. doi: 10.3389/fsurg.2022.999406

A retrospective study on the efficacy and safety of bone cement in the treatment of endplate fractures

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Background: Endplate fractures is an important factor affecting the curative effect of percutaneous kyphoplasty for spinal fracture. The purpose of this study is to investigate the effect of sealing endplate fracture with bone cement on minimally invasive treatment of spinal fracture.
Methods: A total of 98 patients with osteoporotic vertebral fractures combined with endplate fractures treated with bone cement surgery in our hospital were retrospectively analyzed. They were grouped according to whether bone cement was involved in the endplate fractures. Group A: bone cement was not only distributed in the fractured vertebral body, but also dispersed into the endplate fractures. Group B: bone cement was confined to the fractured vertebra but did not diffuse into the cracks of the endplate. The basic information, imaging changes of the fractured vertebral body, VAS score, ODI score, bone cement distribution and postoperative complications of the two groups were analyzed and compared.
Results: The height of the injured vertebra and the kyphotic Cobb angle in the two groups were significantly improved after surgery, but the anterior height of the vertebra in group B was lower than that in group A and the kyphotic Cobb angle was higher than that in group A at the last follow-up ($P < 0.05$). VAS score and ODI score in 2 groups were significantly improved after operation ($P < 0.05$), but the VAS score and ODI score in group A were lower than those in group B at the last follow-up ($P < 0.05$). The incidence of bone cement leakage and adjacent vertebral fracture in group A was higher than that in group B ($P < 0.05$).
Conclusion: Diffusion of bone cement into the cracks of the endplate may also restore and maintain the height of the injured vertebra, relieve pain and restore lumbar function. However, diffusion of bone cement into the cracks of the endplate can increase the incidence of cement leakage and adjacent vertebral fractures.

KEYWORDS
percutaneous kyphoplasty, endplate, bone cement, osteoporosis, fracture

Introduction

Osteoporosis is a common orthopedic disease in the elderly, and osteoporotic vertebral compression fracture is one of the most common complications of osteoporosis (1, 2). With the acceleration of the aging process of China's population, the incidence of osteoporotic vertebral compression fractures has increased yearly, one of the incidences of women is higher than that of men (3). Osteoporotic vertebral fractures cause severe low back pain, decreased vertebral height and kyphosis, which seriously affect the life quality of patients (4). Bone cement-reinforced vertebral fractures are currently an important method for the clinical treatment of osteoporotic vertebral compression fractures, including percutaneous vertebroplasty (PVP) and percutaneous kyphoplasty (PKP), which can effectively relieve pain and stabilize fractured vertebral bodies in patients (5, 6). For patients with vertebral fractures, the formation of microscopic nooses between bone cement and trabecular bone and the elimination of fracture fretting are important factors to relieve pain and restore spinal biomechanics (7).

In the treatment of osteoporotic vertebral compression fractures, we often pay too much attention to the mechanical recovery of the fractured vertebral body, while the treatment of endplate fractures and adjacent disc injuries is often neglected. The endplate is the intermediary that connecting the vertebral body and intervertebral disc. The endplate transmits the load of the human body and plays an important role in undertaking the nutrient exchange and stress buffering of the intervertebral disc (8). For patients with endplate fractures, it is often difficult to disperse bone cement into the endplate cracks owing to the risk of bone cement leakage into the intervertebral space causing intervertebral disc damage. Is it better to pack endplate cracks with bone cement to stabilize the fracture fragment? Or is it better to limit the cement to the inside of the vertebral body to avoid cement leakage? At present, the clinical application of bone cement in endplate cracks is still unclear. This study retrospectively analyzed the patients with osteoporotic vertebral compression fractures with endplate cracks treated by percutaneous kyphoplasty. The influence of cement leakage and clinical efficacy was aimed to provide certain theoretical guidance for the targeted application of bone cement in the treatment of osteoporotic fractures.

Methods

Study design and participants

A total of 98 patients with osteoporotic vertebral fractures combined with endplate fractures who received bone cement surgery in our hospital from January 2017 to December 2020 were retrospectively analyzed. The relevant information of patients before and after surgery was collected. The work has been reported in line with the STROCSS criteria.

Inclusion criteria: fresh vertebral fractures diagnosed by preoperative x-ray, CT, and MRI (MRI was performed to observe intravertebral hemorrhage and bone marrow edema. Extensive hyperintensity and/or definite hyperintensity fracture line changes were observed on T2 lipid-suppression sequence.); combined with endplate fractures; fractured

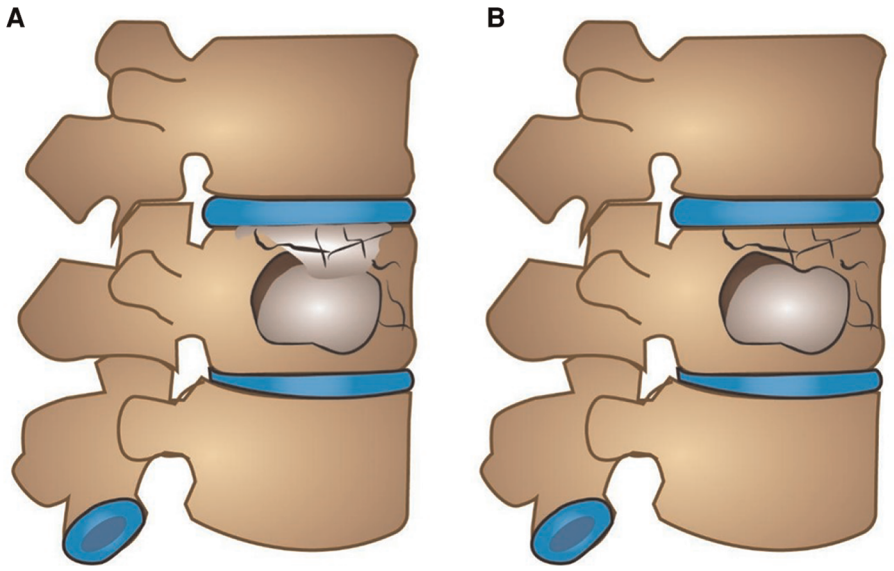

FIGURE 1
Schematic diagram of both groups. (A) The bone cement was not only distributed in the fractured vertebral body, but also diffused into the cracks of the endplate. (B) The bone cement was only confined in the fractured vertebral body but did not diffuse into the endplate cracks.

vertebral body with intact posterior wall of vertebral body without symptoms of spinal canal and nerve compression; single vertebral disease patients. Exclusion criteria: old fracture; primary or metastatic spinal tumor; spinal infection; abnormal coagulation function and mental abnormality; posterior vertebral body collapse defect accompanied by symptoms of dural sac or nerve tissue compression. Grouping was based on whether bone cement filled into endplate fractures (as shown in Figure 1). Group A: The bone cement was not only distributed in the fractured vertebral body, but also diffused into the cracks of the endplate, a total of 46 cases (Figure 2 shows the imaging data of a typical case). Group B: The bone cement was only confined in the fractured vertebral body but did not diffuse into the endplate cracks, a total of 52 cases (Figure 3 shows the imaging data of a typical case). All patients were followed up for at least 1 year.

Surgical methods

The patient was treated with percutaneous kyphoplasty. The patient was placed in the prone position under local anesthesia. Accurately locate the fractured vertebral body under C-arm x-ray fluoroscopy. Confirm the lateral compression position of the vertebral body, and routinely disinfect the towel. Under fluoroscopy, a puncture needle was used to enter the pedicle through the skin puncture point on one or both sides of the injured vertebra. After adjusting the angle of the puncture needle, the needle was punctured to the anterior 1/3 of the vertebral body, and a working sleeve was placed. Insert a balloon dilator along the working channel, slowly pressurize the expansion balloon to restore the height of the vertebral body and release the pressure to withdraw the balloon. The bone cement was prepared and slowly injected into the vertebral body under the monitoring of the C-arm machine after waiting for it to become filamentous. The injection was stopped when the bone cement dispersed satisfactorily or the bone cement leaked. Intermittently rotate the cannula, pull out the cannula after the bone cement solidifies, and cover it with a sterile dressing.

Assessed parameters

The imaging data, clinical efficacy and postoperative complications of all patients were analyzed 1 day before operation, 2 days after operation and 1 year after operation.

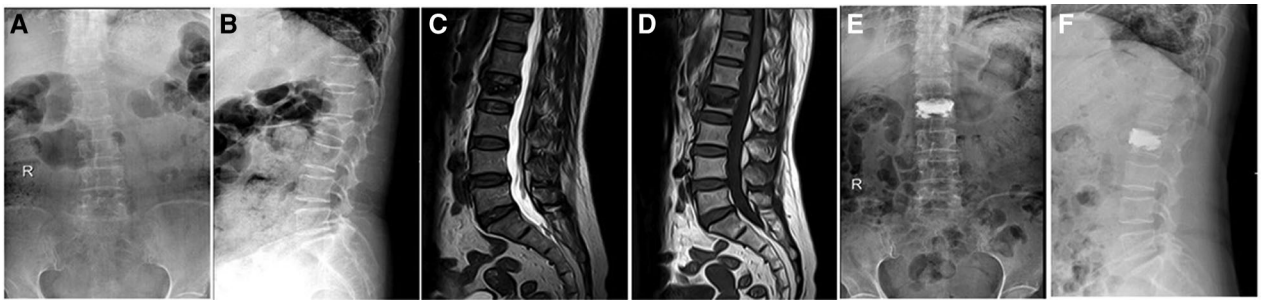

FIGURE 2
In group A, a patient with L2 vertebral fracture with upper endplate fracture was treated with bone cement, and the bone cement was completely filled in the fracture fissure of upper endplate. (A–B) Preoperative x-ray. (C–D) Preoperative MRI. (E–F) x-ray after surgery.

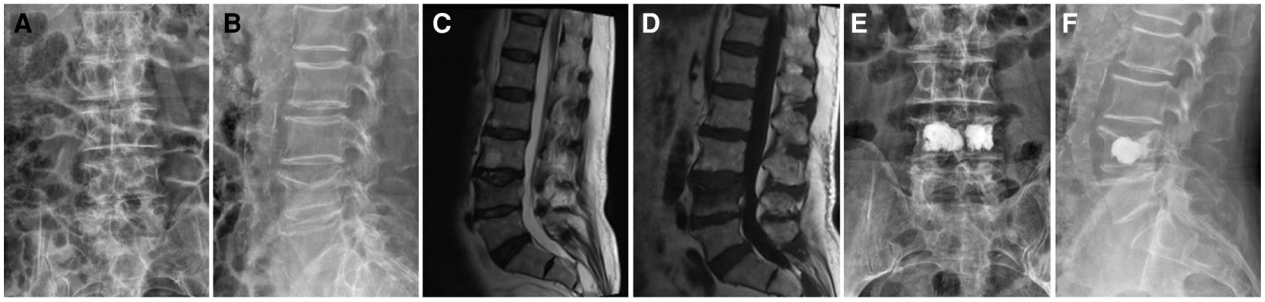

FIGURE 3
In group B, a patient with L4 vertebral fracture with upper endplate fracture was treated with bone cement, and no or a small amount of bone cement diffused into the fracture crack of the upper endplate. (A–B) Preoperative x-ray. (C–D) Preoperative MRI. (E–F) x-ray after surgery.

Imaging data: The frontal and lateral x-ray images of the injured vertebra were collected, respectively before and after the operation from all patients. The height of the anterior edge of the vertebral body and the kyphotic Cobb angle (The angle between the parallel lines between the superior endplate of the injured vertebra and the inferior endplate of the inferior vertebral body) were measured before and after the operation.

Clinical efficacy: Visual analogue scale (VAS) and Oswestry disability index (ODI) scores were recorded before and after surgery.

Adverse reactions: Complications such as bone cement leakage, adjacent vertebral fractures and refractures after surgery were recorded.

TABLE 1 Comparison of basic data and intraoperative related information.

	Group A ($n = 46$)	Group B ($n = 52$)	*P*-value (A vs. B)
Age (years)	64.85 ± 9.03	63.12 ± 8.83	0.342
Gender			
Male	12	13	0.279
Female	34	39	
Follow-up time (month)	18.13 ± 3.39	17.98 ± 3.07	0.819
Operation time (min)	22.93 ± 4.24	23.79 ± 4.05	0.311
Bone mineral density	−2.46 ± 0.45	−2.49 ± 0.5	0.708
x-ray time	23.59 ± 3.37	22.62 ± 3.31	0.154
Cement dosage (ml)	5.16 ± 1.04	4.85 ± 0.95	0.118
Pre-op. VAS	7.87 ± 0.98	8.06 ± 1.04	0.360
Pre-op. ODI	78.07 ± 6.74	79.42 ± 6.89	0.333
Pre-op. AHD (mm)	17.14 ± 2.25	17.55 ± 2.30	0.368
Pre-op. Cobb angles	21.07 ± 4.57	22.62 ± 4.31	0.087

AHD, Anterior height of diseased vertebrae.

Statistical analysis

SPSS 13.0 statistical software was used for data analysis, and the data were expressed in the form of mean ± standard error. The independent sample t-test was used for analysis for two groups comparison. Analysis of variance was used for multi-sample comparison. Differences were considered statistically significant at $P < 0.05$.

Results

General data

The demographic data of both groups was shown in Table 1. A total of 98 patients were included in this study, including 46 patients in group A and 52 patients in group B. All patients were followed up for at least 1 year. There was no significant difference in age, sex, bone mineral density, preoperative VAS, and preoperative ODI between the two groups ($P > 0.05$), so these patients were comparable. There were no significant differences in bone cement injection volume and times of fluoroscopy between the two groups ($P > 0.05$). The fractured vertebral bodies of the two groups of patients are shown in Figure 4.

Imaging data

The height of the anterior edge of the vertebral body of both groups was shown in Table 2. There was no significant difference in the height of the anterior edge of the vertebral body between the two groups before surgery ($P > 0.05$).

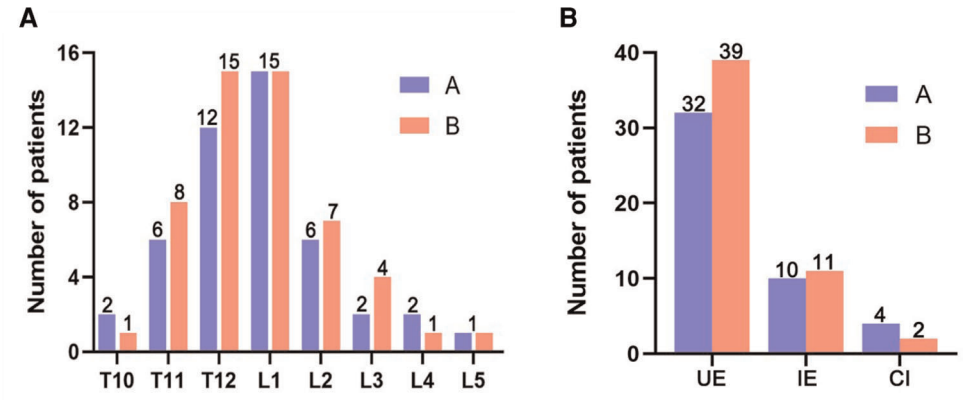

FIGURE 4
Injured vertebral segment and endplate injury site. (A) Comparison of vertebral injury segments between two groups. (B) Comparison of endplate injury site between two groups. UE: Only the upper endplate was damaged. IE: Only the Inferior endplate was damaged. CI: Both the upper endplate and the lower endplate were damaged.

There was no significant difference in the height of the anterior edge of the vertebral body between the two groups after surgery ($P > 0.05$), but the height of the anterior edge of the vertebral body in the group B was lower than that in the group A at the last follow-up, and the difference between the two groups was statistically significant ($P < 0.05$). (As shown in Figure 5).

The Cobb angle of kyphosis of both groups was shown in Table 3. There was no significant difference in the Cobb angle of kyphosis between two groups before surgery ($P > 0.05$), and the Cobb angle of kyphosis between the two groups was significantly improved after surgery and at the last follow-up ($P < 0.05$). There was no significant difference in the Cobb angle of kyphosis between the two groups after operation ($P > 0.05$), but the Cobb angle of kyphosis in group B was greater than that in group A at the last follow-up, and the difference between the two groups was statistically significant ($P < 0.05$). (As shown in Figure 5).

Clinical efficacy

The VAS and ODI of both groups were shown in Tables 4, 5. There was no significant difference in the preoperative VAS score and ODI score between two groups ($P > 0.05$). After operation, the VAS score and ODI score of the two groups were significantly improved ($P < 0.05$), but there was no significant difference ($P > 0.05$) between the two groups. The last follow-up found that the VAS score and ODI score of group A were lower than those of group B, and the difference was statistically significant ($P < 0.05$). (As shown in Figure 6).

Postoperative complications

There were 16 cases of bone cement leakage in group A, among which 12 cases were intervertebral disc leakage and 4 cases were paravertebral. There were 5 cases of bone cement leakage in group B, including 2 cases of anterior vertebral

TABLE 2 Anterior height of diseased vertebrae (mean ± SD; mm).

Classify	Group A ($n = 46$)	Group B ($n = 52$)	*P*-value (A vs. B)
Pre-op.	17.14 ± 2.25	17.55 ± 2.30	0.368
Post-op. 2 days	25.05 ± 2.34	24.69 ± 2.18	0.431
Post-op. 1 year	24.50 ± 2.34	22.82 ± 2.26	<0.001
P. (pre. vs. 2 d.)	<0.0001	<0.0001	–
P. (2 d. vs. 1 y.)	0.264	<0.001	–

Pre-op., pre-operation; Post-op., Post-operation; 2 d., 2 days; 1 y., 1 year; *P.*, *P*-value.

TABLE 3 Cobb angles (mean ± SD; °).

Classify	Group A ($n = 46$)	Group B ($n = 52$)	*P*-value (A vs. B)
Pre-op.	21.07 ± 4.57	22.62 ± 4.31	0.087
Post-op. 2 days	13.05 ± 2.26	13.89 ± 2.07	0.057
Post-op. 1 year	13.82 ± 2.50	15.81 ± 2.30	0.014
P. (pre. vs. 2 d.)	<0.0001	<0.0001	–
P. (2 d. vs. 1 y.)	0.500	0.005	–

Pre-op., pre-operation; Post-op., Post-operation; 2 d., 2 days; 1 y., 1 year; *P.*, *P*-value.

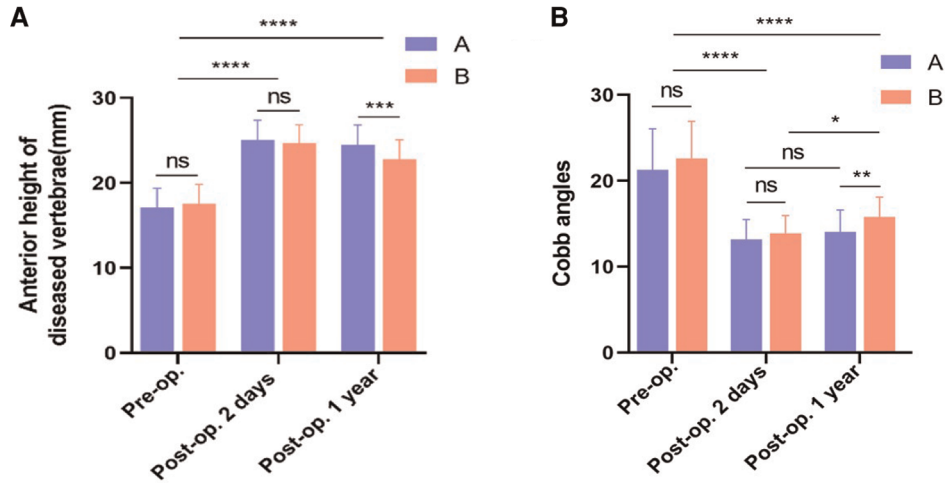

FIGURE 5
Vertebral imaging data. (A) Comparison of anterior height of diseased between two groups. (B) Comparison of Cobb angles between two groups. *, $P < 0.05$ vs. control; **, $P < 0.001$ vs. control; ***, $P < 0.0001$ vs. control.

leakage, 1 case of intervertebral disc, and 2 cases of paravertebral body leakage. The bone cement leakage rate in group A was higher than group B ($P < 0.05$) as shown in Figure 7. During the postoperative follow-up, 7 patients in group A had adjacent vertebral fractures, and 1 in group B. There was statistically significant difference in the incidence of adjacent vertebral fractures between the two groups ($P < 0.05$) (as shown in Figure 7). Further, we calculate the number needed to harm (NNH) on 7.52 vertebral bodies are treated with bone cement at the endplate fractures to "produce" one postoperative complication.

TABLE 4 Visual analogue scale (VAS; mean ± SD).

Classify	Group A ($n = 46$)	Group B ($n = 52$)	*P*-value (A vs. B)
Pre-op.	7.87 ± 0.98	8.06 ± 1.04	0.360
Post-op. 2 days	2.24 ± 0.95	2.52 ± 0.80	0.117
Post-op. 1 year	1.39 ± 0.93	2.42 ± 0.82	<0.0001
P. (pre. vs. 2 d.)	<0.0001	<0.0001	–
P. (2 d. vs. 1 y.)	<0.001	0.848	–

Pre-op., pre-operation; Post-op., Post-operation; 2 d., 2 days; 1 y., 1 year; *P.*, *P*-value.

TABLE 5 Oswestry disability index (ODI; mean ± SD).

Classify	Group A ($n = 46$)	Group B ($n = 52$)	*P*-value (A vs. B)
Pre-op.	78.07 ± 6.74	79.42 ± 6.89	0.333
Post-op. 2 days	31.37 ± 5.66	32.12 ± 5.25	0.213
Post-op. 1 year	24.35 ± 4.11	30.77 ± 5.37	<0.0001
P. (pre. vs. 2 d.)	<0.0001	<0.0001	–
P. (2 d. vs. 1 y.)	<0.0001	0.482	–

Pre-op., pre-operation; Post-op., Post-operation; 2 d., 2 days; 1 y., 1 year; *P.*, *P*-value.

Discussion

The endplate is the intermediary that connects the vertebral body and the intervertebral disc and transmits the load of the human body. Each endplate includes two parts: the bone endplate and the cartilage endplate. The former is the structure covered by cartilage in the vertebral body, and the latter is responsible for the nutrient exchange and stress of the intervertebral disc (9). Endplate rupture injury mostly occurs in the center or anterior part of the endplate. When it is severely ruptured, the nucleus pulposus will lose function and enter the vertebral body (10). Endplate and annulus fibrosus are rich in innervation of nerve endings, and their damage is an important cause of low back pain with a high incidence in OVCF (11). The complex of endplate and intervertebral disc is unstable. During spinal extension and flexion activities and weight-bearing walking, nerve endings in the injured area are stimulated to cause pain, and this injury will not heal for a long time due to continuous breathing movement of the thorax and spinal movement. A common cause of chronic back pain that persists over time (12).

Since the application of bone cement filling technology in spine surgery, minimally invasive surgery represented by PVP and PKP has been widely used in diseases such as osteoporotic vertebral compression fractures and achieved good results (13, 14). However, it cannot be ignored that the incidence of postoperative complications is relatively

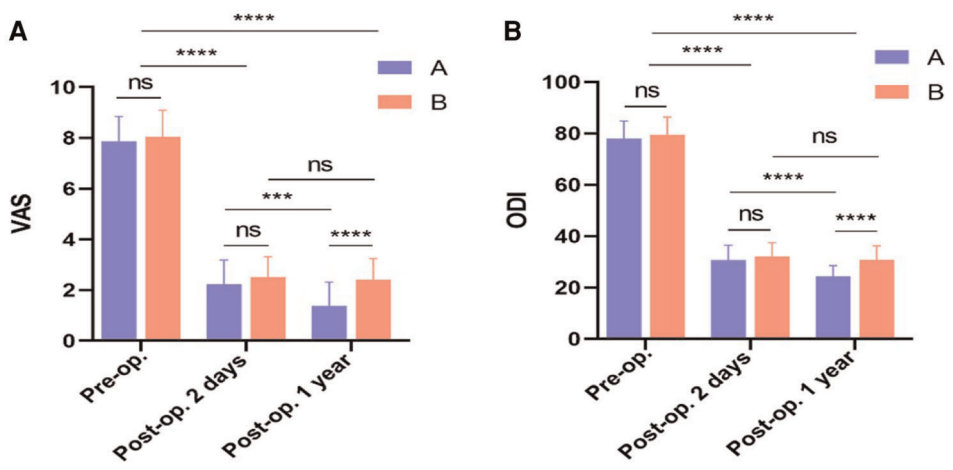

FIGURE 6
Clinical efficacy. (A) Comparison of VAS between two groups. (B) Comparison of ODI between two groups. ***, $P < 0.001$ vs. control; ****, $P < 0.0001$ vs. control.

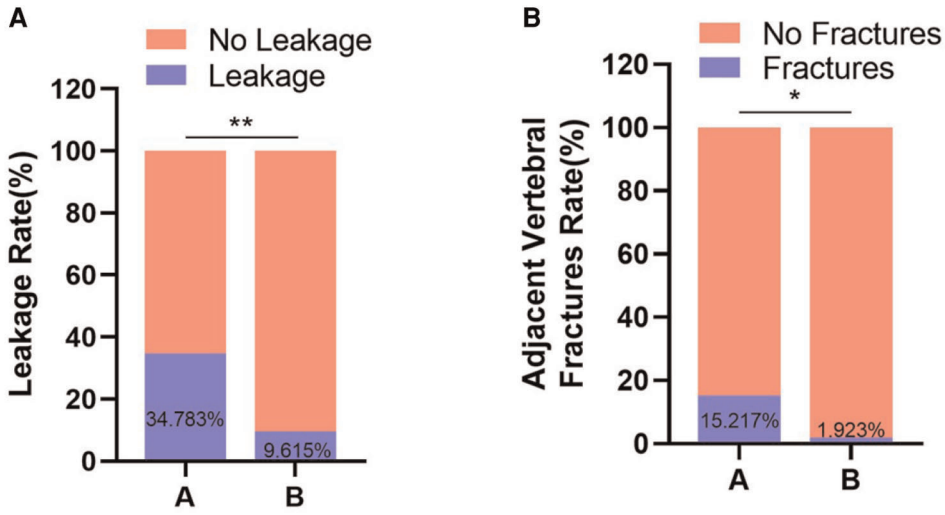

FIGURE 7
Postoperative complications. (A) Comparison of bone cement leakage rate between two groups. (B) Comparison of adjacent vertebral fractures between two groups. *, $P < 0.05$ vs. control; **, $P < 0.01$ vs. control.

high. The long-term loss of vertebral height and the aggravation of kyphosis after surgery lead to chronic pain and limited mobility in patients. The treatment of such complications is quite difficult (15). Previous studies have shown that osteoporotic vertebral compression fractures are often accompanied by vertebral endplate fractures, and endplate fractures are one of the main risk factors for vertebral height loss after thoracolumbar fractures (16). From the perspective of biomechanical research, the vertebral body endplates bear 40%–75% of the vertebral body pressure are directly involved in the transfer of pressure from the intervertebral disc to the vertebral body. Even a slight change in the shape of the endplate will lead to significant vertebral body motor function (17). However, it is often difficult to completely correct the deformity of the endplate during surgery, which leads to increased stress in the perivertebral portion of patients with endplate fractures. In addition, the aggravation of kyphosis is related to the insertion of the intervertebral disc into the vertebral body or endplate from the fracture of the endplate, and the intervertebral disc embedded in the vertebral body or endplate is more likely to lose the height of the injured vertebral body due to necrosis after surgery (18). Therefore, the loss of postoperative vertebral height and the occurrence of kyphosis are closely related to the biomechanical changes of the vertebral body caused by changes in the stress distribution of the endplates (19). This study also confirmed that patients who did not fill endplate fractures with bone cement had postoperative vertebral height reduction and increased kyphosis. However, in patients with bone cement diffused to the endplate fractures, there was no significant change in vertebral body height and kyphosis after surgery. This indicated that the re-collapse of the fractured vertebral body could be prevented to a certain extent by sealing the fracture of the endplate with bone cement. On the other hand, the study also found that the VAS score and ODI score at last follow-up of patients with unsealed endplate fractures were also higher than those of patients with endplate fractures sealed with bone cement, which may be due to the endplate fracture line insufficient diffusion of the bone cement at the site and difficulty in maintaining the stability of the bone around the fracture line led to fretting of the endplate fracture. In addition, the long-term pain exacerbation in patients with unsealed endplate fractures with bone cement was also closely related to the decrease in the height of the injured vertebra and the exacerbation of kyphosis.

Studies have shown that endplate fractures increase the risk of bone cement leakage into the intervertebral disc, which is also an important cause of low back pain after fracture surgery and a high-risk factor for refracture of adjacent vertebral bodies later (20). Biomechanical studies have shown that bone cement-reinforced vertebrae conduct excessive stress through the intervertebral disc to adjacent vertebral bodies, which may lead to refractures of adjacent vertebral bodies (21). After the bone cement leaks into the intervertebral disc, the distance between the cement and the endplate of the adjacent vertebra is closer, and the bone cement leaking into the intervertebral disc produces a

concentrated stress effect on the adjacent vertebra. The effect of small shock absorption, thereby increasing the stress transmission of the strengthened vertebra to the adjacent vertebral body, has become an important risk factor for refracture of the adjacent vertebral body (22). This study also found that the bone cement sealing of endplate fractures increased the risk of bone cement intervertebral disc leakage, and the incidence of postoperative refracture was also higher than that of the non-cemented endplate fracture group.

In conclusion, for OVCF patients with endplate fractures, the closure of endplate cracks with bone cement can effectively strengthen the fractured vertebral body, maintain the postoperative vertebral height, relieve pain, and restore lumbar vertebral function well. However, the incidence of postoperative bone cement leakage and refracture of adjacent vertebral bodies is high. Therefore, when using bone cement to strengthen the fractured vertebral body in the treatment of OVCF patients with endplate fractures, the purpose of surgery should include sealing and repairing endplate fissures, preventing leakage of bone cement into the intervertebral space, and preventing intervertebral disc herniation in addition to supporting the fractured vertebral body and endplate gap. The surgical strategy is to choose PKP as much as possible, reducing the collapsed endplate through balloon dilation, creating a cavity in the vertebral body, forming a dense bone to seal the fracture fissure, and adjusting the bone cement to be more viscous and reduce the bolus pressure to reduce the cement to the wall. External (disc) leaks are possible, and injections should be discontinued as soon as leakage occurs. In addition, more attention should be paid to comprehensive measures such as long-term anti-osteoporosis treatment, functional exercise of lumbar back muscles, analgesia, physiotherapy, and psychological treatment after operation. However, there are still shortcomings in this study. Because it is a retrospective study, it cannot fully demonstrate the impact of endplate fractures, intervertebral disc injuries and other factors on the surgical effect. The realization of the diffuse distribution pattern of bone cement in the diseased vertebra are also needed to be further explored.

Conclusion

Diffusion of bone cement into the cracks of the endplate may also restore and maintain the height of the injured vertebra, relieve pain and restore lumbar function. However, diffusion of bone cement into the cracks of the endplate can increase the incidence of cement leakage and adjacent vertebral fractures.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author/s.

Ethics statement

The studies involving human participants were reviewed and approved by The Ethics Committee of the Second People's Hospital of Lianyungang. The patients/participants provided their written informed consent to participate in this study.

Author contributions

ZZ and NL completed the study design. LD, XH, HL and HZ performed the study and collected and analyzed the data. ZZ and LD drafted the manuscript. XJ, RW and ML provided the expert consultations and suggestions. ZZ, NL and ML conceived the study, participated in its design and coordination, and helped to embellish language. All authors contributed to the article and approved the submitted version.

Funding

This work was supported by The Lianyungang Health Science and Technology Project (No. 201917), and the Growth Foundation for middle-aged and young medical talents of The Second People's Hospital of Lianyungang (No. TQ202002), and the major scientific and technological projects of Bengbu Medical College (No. 2020byzd339), and the Lianyungang aging health research project (No. L202116).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Parreira P, Maher CG, Megale RZ, March L, Ferreira ML. An overview of clinical guidelines for the management of vertebral compression fracture: a systematic review. *Spine J*. (2017) 17:1932–8. doi: 10.1016/j.spinee.2017.07.174

2. Schnake KJ, Bouzakri N, Hahn P, Franck A, Blattert TR, Zimmermann V, et al. Multicenter evaluation of therapeutic strategies of inpatients with osteoporotic vertebral fractures in Germany. *Eur J Trauma Emerg Surg*. (2022) 48:1401–8. doi: 10.1007/s00068-021-01708-x

3. Anam AK, Insogna K. Update on osteoporosis screening and management. *Med Clin North Am*. (2021) 105:1117–34. doi: 10.1016/j.mcna.2021.05.016

4. Alsoof D, Anderson G, McDonald CL, Basques B, Kuris E, Daniels AH. Diagnosis and management of vertebral compression fracture. *Am J Med*. (2022) 135:815–21. doi: 10.1016/j.amjmed.2022.02.035

5. Buchbinder R, Johnston RV, Rischin KJ, Homik J, Jones CA, Golmohammadi K, et al. Percutaneous vertebroplasty for osteoporotic vertebral compression fracture. *Cochrane Database Syst Rev*. (2018) 4:D6349. doi: 10.1002/14651858.CD006349.pub3

6. Lin S, Cheng M, Liang W, Yuan X. Efficacy of vertebral augmentation in the treatment of osteoporotic vertebral compression fractures: a systematic review and meta-analysis. *Ann Palliat Med*. (2021) 10:11767–75. doi: 10.21037/apm-21-2834

7. Ma JH, Li M, Zhang XQ, Yao X. Modified percutaneous kyphoplasty with better cement diffusion and improved biomechanics. *Asian J Surg*. (2021) 44:1546–8. doi: 10.1016/j.asjsur.2021.08.052

8. McKay M, Jackman TM, Hussein AI, Guermazi A, Liu J, Morgan EF. Association of vertebral endplate microstructure with bone strength in men and women. *Bone*. (2020) 131:115147. doi: 10.1016/j.bone.2019.115147

9. Moore RJ. The vertebral endplate: disc degeneration, disc regeneration. *Eur Spine J*. (2006) 15(Suppl 3):S333–7. doi: 10.1007/s00586-006-0170-4

10. Xiaorong W, Feirong X, Yuan F, Huanhuan C, Xiang G, Qiuli H. Traumatic vertebral fractures involve the anterior end plate more than the posterior end plate: a retrospective study. *Med (Baltimore)*. (2020) 99(34):e21572. doi: 10.1097/MD.0000000000021572

11. Zhang S, Wang S, Wang Q, Yang J, Xu S. Image classification of osteoporotic vertebral fracture with endplate-disc complex injury. *Bmc Musculoskel Dis*. (2021) 22(1):197. doi: 10.1186/s12891-021-04070-6

12. Lawan A, Crites VJ, Battié MC. The association between vertebral endplate structural defects and back pain: a systematic review and meta-analysis. *Eur Spine J*. (2021) 30:2531–48. doi: 10.1007/s00586-021-06865-6

13. Kopparapu S, Lubelski D, Pennington Z, Khan M, Theodore N, Sciubba D. Comparison of operator and patient radiation exposure during fluoroscopy-guided vertebroplasty and kyphoplasty: a systematic review and meta-analysis. *J Neurosurg Spine*. (2021) 35:1–10. doi: 10.3171/2020.9.SPINE201525

14. Long Y, Yi W, Yang D. Advances in vertebral augmentation systems for osteoporotic vertebral compression fractures. *Pain Res Manag*. (2020) 2020:3947368. doi: 10.1155/2020/3947368

15. Yu WB, Jiang XB, Liang D, Xu WX, Ye LQ, Wang J. Risk factors and score for recollapse of the augmented vertebrae after percutaneous vertebroplasty in osteoporotic vertebral compression fractures. *Osteoporos Int*. (2019) 30:423–30. doi: 10.1007/s00198-018-4754-8

16. Chongyan W, Xuyang Z, Junhui L, Zhi S, Shengyun L, Fengdong Z. Percutaneous kyphoplasty: risk factors for recollapse of cemented vertebrae. *World Neurosurg*. (2019) 130:e307–e15. doi: 10.1016/j.wneu.2019.06.071

17. Moura DL, Gabriel JP. Expandable intravertebral implants: a narrative review on the concept, biomechanics, and outcomes in traumatology. *Cureus*. (2021) 13(9): e17795–00. doi: 10.7759/cureus.17795

18. Xiong Y, Guo W, Xu F, Zhang C, Liang Z, Wu L, et al. Refracture of the cemented vertebrae after percutaneous vertebroplasty: risk factors and imaging findings. *Bmc Musculoskel Dis*. (2021) 22(1):459. doi: 10.1186/s12891-021-04355-w

19. Lei T, Bingtao W, Zhaoqing G, Zhongqiang C. The effect of bone cement distribution on the outcome of percutaneous vertebroplasty: a case cohort study. *Bmc Musculoskel Dis*. (2020) 21(1):541. doi: 10.1186/s12891-020-03568-9

20. Zhang TY, Zhang PX, Xue F, Zhang DY, Jiang BG. Risk factors for cement leakage and nomogram for predicting the intradiscal cement leakage after the vertebra augmented surgery. *Bmc Musculoskel Dis*. (2020) 21(1):792. doi: 10.1186/s12891-020-03810-4

21. Baroud G, Vant C, Wilcox R. Long-term effects of vertebroplasty: adjacent vertebral fractures. *J Long Term Eff Med Implants*. (2006) 16(4):265–80. doi: 10.1615/jlongtermeffmedimplants.v16.i4.10

22. Dai C, Liang G, Zhang Y, Dong Y, Zhou X. Risk factors of vertebral re-fracture after PVP or PKP for osteoporotic vertebral compression fractures, especially in Eastern Asia: a systematic review and meta-analysis. *J Orthop Surg Res*. (2022) 17(1):161. doi: 10.1186/s13018-022-03038-z

frontiers | Frontiers in Surgery

TYPE Original Research
PUBLISHED 12 October 2022
DOI 10.3389/fsurg.2022.1031919

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

RECEIVED 30 August 2022
ACCEPTED 27 September 2022
PUBLISHED 12 October 2022

CITATION
Khashan M, Ofir D, Grundshtein A, Kuzmenko B, Salame K, Niry D, Hochberg U, Lidar Z and Regev GJ (2022) Minimally invasive discectomy versus open laminectomy and discectomy for the treatment of cauda equina syndrome: A preliminary study and case series.
Front. Surg. 9:1031919.
doi: 10.3389/fsurg.2022.1031919

Minimally invasive discectomy versus open laminectomy and discectomy for the treatment of cauda equina syndrome: A preliminary study and case series

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Background: Cauda Equina syndrome (CES) is a potentially devastating condition and is treated usually with urgent open surgical decompression of the spinal canal. Currently, the role of minimally invasive discectomy (MID) as an alternative surgical technique for CES is unclear.

Objective: The purpose of this study was to compare clinical outcomes following MID and open laminectomy and discectomy for the treatment of CES.

Methods: The study cohort included patients that underwent surgery due to CES at our institute. Patients' outcomes included: surgical complications, length of hospitalization, postoperative lower extremity motor score (LEMS), Numerical Rating Scale (NRS) for leg and back pain, Oswestry disability index (ODI), and the EQ-5D health-related quality of life questionnaire.

Results: Twelve patients underwent MID and 12 underwent open laminectomy and discectomy. Complications and revisions rates were comparable between the groups. Postoperative urine incontinence and saddle dysesthesia improved in 50% of patients in both groups. LEMS improved from 47.08 ± 5.4 to 49.27 ± 0.9 in the MID group and from 44.46 ± 5.9 to 49.0 ± 1.4 in the open group. Although, leg pain improved in both groups from 8.4 ± 2.4 to 3 ± 2.1 in the MID and from 8.44 ± 3.3 to 3.88 ± 3 in the open group, significant improvement in back pain was found only in the MID group. Final functional scores were similar between groups.

Conclusions: Our preliminary results suggest that minimally invasive discectomy is an effective and safe procedure for the treatment of CES when compared to open laminectomy and discectomy. However, MID in these cases should only be considered by surgeons experienced in minimally invasive spine surgery. Further studies with bigger sample sizes and long-term follow-ups are needed.

KEYWORDS

cauda equina syndrome, open laminectomy, case series, minimally invasive, tubular discectomy

Introduction

Cauda Equina syndrome (CES) is a potentially devastating condition that can result in severe and permanent neurological deficits (1, 2). In the absence of trauma or an oncological condition, CES is most often caused by a giant disc herniation that occludes the spinal canal and severely compresses the thecal sac (3, 4). Severe possible consequences of this condition may include bowel and/or bladder dysfunction and motor weakness of the lower limbs. Therefore the recommended treatment option is urgent surgical decompression of the spinal canal, which includes the removal of the herniated disc fragment (5–7). Urgent surgical intervention has been found to be most effective in cases of incomplete neurological damage and when it is done within the first 48 h of presentation (3). Currently, the optimal surgical approach for the decompression of the spinal canal is still unclear. Several authors recommended the use of an open total laminectomy and discectomy in order to minimize chances of iatrogenic damage to the thecal sac and the neural elements while other authors reported that microdiscectomy neither increased the risk of postoperative complications nor resulted in incomplete decompression of the spinal canal (8, 9).

Minimally invasive discectomy (MID) was first described by Foley et al. (10) and has since gained acceptance as an alternative to traditional microdiscectomy. The limited trauma to the paraspinal muscles and posterior spinal ligaments has been shown to decrease post-operative back pain and thus enable faster mobilization and recovery (11–13).

It remains unclear whether outcomes of MID, for the treatment of CES, are comparable to those of open surgery. The aim of the present study was to compare Minimally invasive discectomy to open laminectomy and discectomy for the treatment of CES with regards to postoperative complication, recovery and overall quality of life.

Methods

This is a retrospective analysis of prospectively collected data. The study was approved by our local Institutional Review Board and all patients provided informed consent before conducting the follow-up by phone interview. We collected medical records on all consecutive patients who underwent lumbar spine surgery due to CES between January 2010 and December 2019. Inclusion criteria included the diagnosis of CES due to lumbar disc herniation. The diagnosis of CES was determined by a combination of radiological evidence of a centrally herniated disc occluding the spinal canal and clinical symptoms that included: saddle anesthesia, low back pain, radicular pain, muscle weakness of the lower limbs, and acute bladder/bowel incontinence **Figures 1**, **2**. The choice of surgical technique was made solely on the basis of the treating surgeon's preference and expertise.

Exclusion criteria included: spinal fracture, oncological pathology, or history of previous spinal surgery at the level of the current pathology.

Preoperative data included: demographic data, duration of clinical symptoms before surgery, and presenting symptoms. Radiological data included: spinal level of compression, and the type of disc pathology. Radiological analysis was conducted by a senior neuro-radiologist (D.N). Operative data included: operated spinal levels, and incidence of intraoperative complications. Measured clinical outcomes included: hospital length of stay (LOS), early postsurgical complications and revision surgery rates. Postoperative neurological outcomes included a subjective assessment of the patients improvement following surgery with regards to their urine inconstancy, dysesthesia and motor weakness. Additionally, the American Spinal Injury Association (ASIA) lower extremity motor score (LEMS) was used to evaluate objective lower-extremity motor function (14). This score grades motor function on a scale of 0 (no motor function) to 5 (full motor function) for each of the following 5 lower-extremity muscle groups. The LEMS has a maximum of 50 points (25 points per side). Pain and functional outcomes were assessed using the Numerical Rating Scale (NRS) for back and leg pain, Oswestry disability index (ODI) and health-related quality of life EQ-5D instrument.

Surgical technique

All the surgical procedures were performed in a single tertiary medical center by four senior spinal surgeons, experienced in minimally invasive spinal surgeries. MID procedures were done routinely under general anesthesia using an 18 or 20-millimeter tubular retractor system (METRx; Medtronic Sofamor Danek, Memphis, TN) and a surgical microscope. Surgery was performed through a unilateral approach. Using a diamond head high-speed drill, either an ipsilateral hemilaminotomy and medial facetectomy or a bilateral ("over the top") decompression, was done. Once the lateral edge of the thecal sac was exposed, the smallest angled curettes (1.8 mm) and micro-pituitary rongeurs (2 mm) were used to extract and remove the disc fragment from underneath the thecal sac. Special attention was given to limit any retraction of the dura or nerve root in the initial part of the discectomy. Once a significant part of the disc fragment was removed, and the tension over the thecal sac lessened, a more liberal retraction was allowed in order to verify that all the disc fragments were completely removed and that the spinal canal was sufficiently decompressed (15) **Figure 3**.

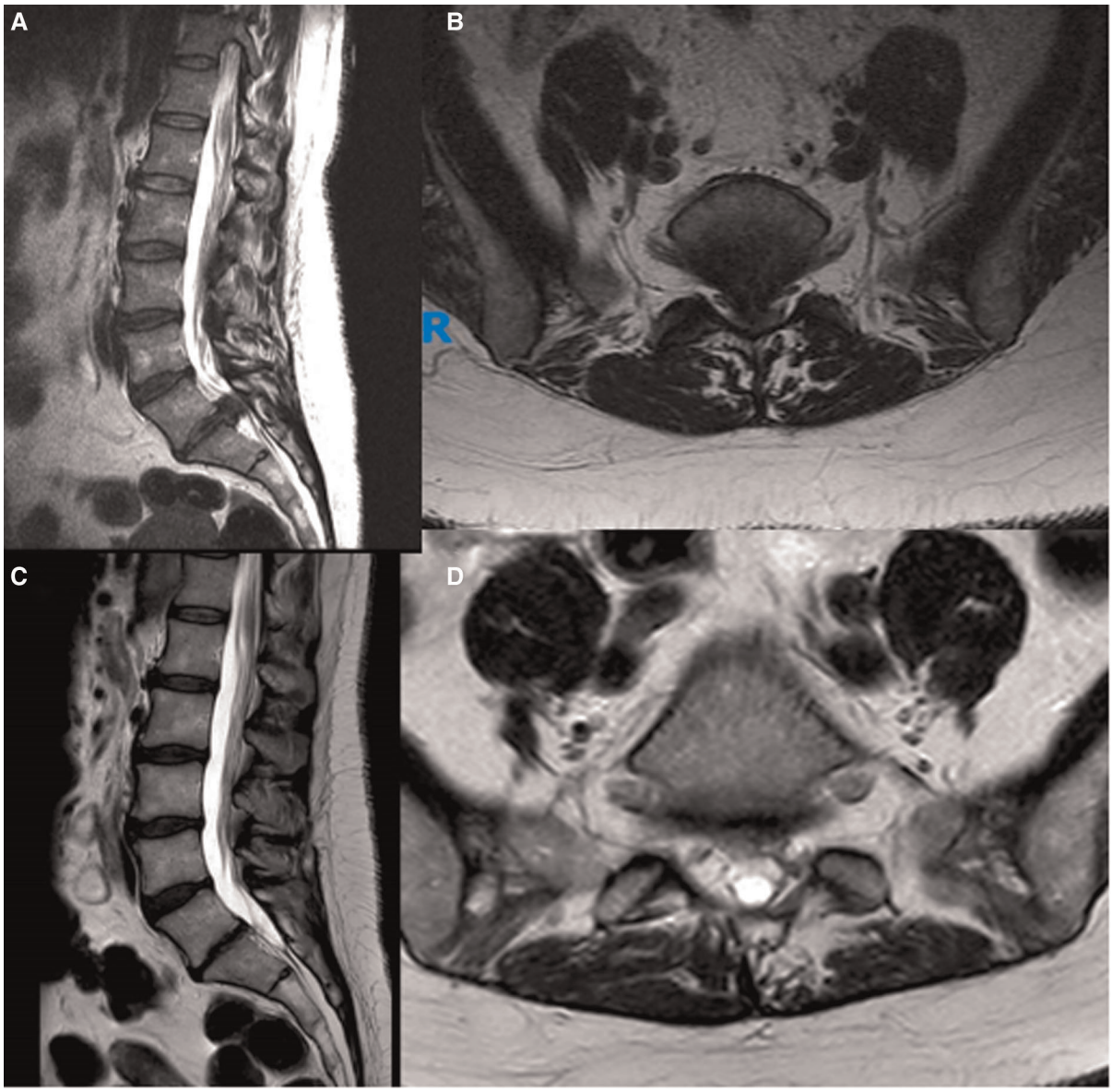

FIGURE 1
Preoperative (**A**,**B**) and postoperative (**C**,**D**) sagittal and axial MRI images of a typical patient diagnosed with an CES due to a giant L5-S1 disc herniation and operated by MID.

Open procedures were routinely done with the use of magnifying loupes. Following exposure of the posterior elements of the spine, a total laminectomy and bilateral medial facetectomy of one or several levels was performed using an ultrasonic bone curette (BoneScalpel; Misonix Farmingdale, NY) and Kerrison rongeurs. In one case, a limited hemilaminectomy was performed in the open group. Following the full exposure of the thecal sac, removal of the herniated disc fragment was available from both sides of the spinal canal. A drain was placed in the surgical wound only in cases where the surgeon was concerned by the possibility of a post-operative hematoma.

Statistical analysis

All data were analyzed using IBM SPSS Statistics for Windows, Version 23.0 (IBM, Armonk, NY, USA). Categorical variables were described as number. Continuous variables were described as mean and standard deviation. Categorical variables were compared between the two groups using Fisher's exact test and continuous variables were compared using Mann-Whitney test. Willcoxon test was used to compare pre- and post-surgical pain scores. All statistical testes were two-sided and $P < 0.05$ was considered as statistically significant.

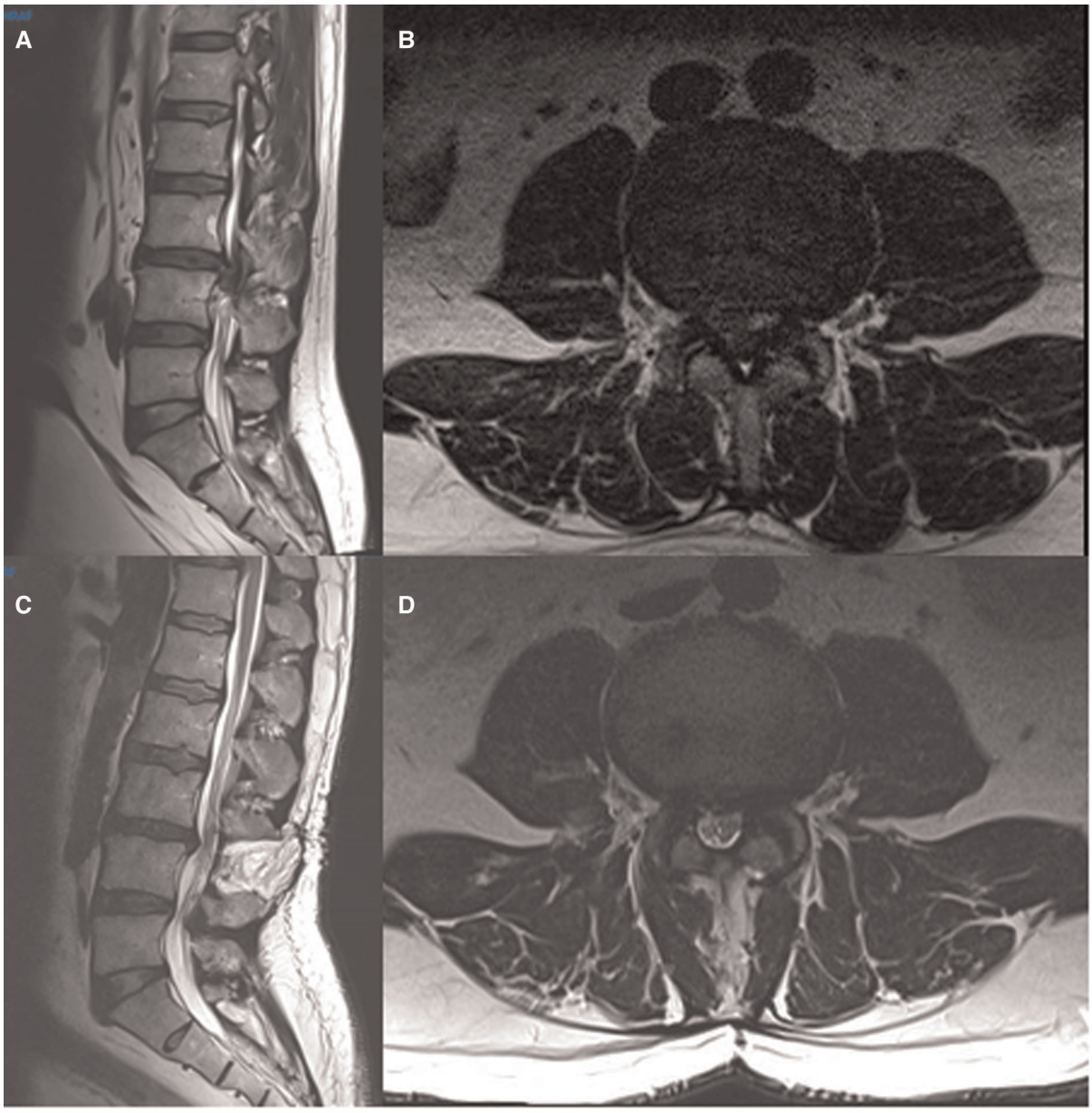

FIGURE 2
Preoperative (A,B) and postoperative (C,D) sagittal and axial MRI images of a typical patient diagnosed with an CES due to a giant L3–4 disc herniation and operated by open laminectomy and discectomy.

Results

Patient characteristics and clinical presentation

The study cohort included a total of 24 patients, of whom 12 patients underwent MID and 12 patients underwent open decompression. Eighteen patients were males and six were females. The mean age was 44.2 ± 15.9 years in the MID group and 43.1 ± 11.2 years in the open surgery group ($P = 0.19$). No significant differences were found between the groups regarding previous spine surgeries, smoking or other systemic co-morbidities. The mean elapsed time from the initial presentation of symptoms until CES was diagnosed was not statistically different between the groups. 2.5 ± 3.1days in the MID group and 3.9 ± 3.9 days in the open surgery group ($P = 0.45$). No statistically differences were found when comparing the neurological presentation of patients in both groups. In the MID group 58% of patients presented with urinary incontinence, 66.7% with motor weakness and 66.7%

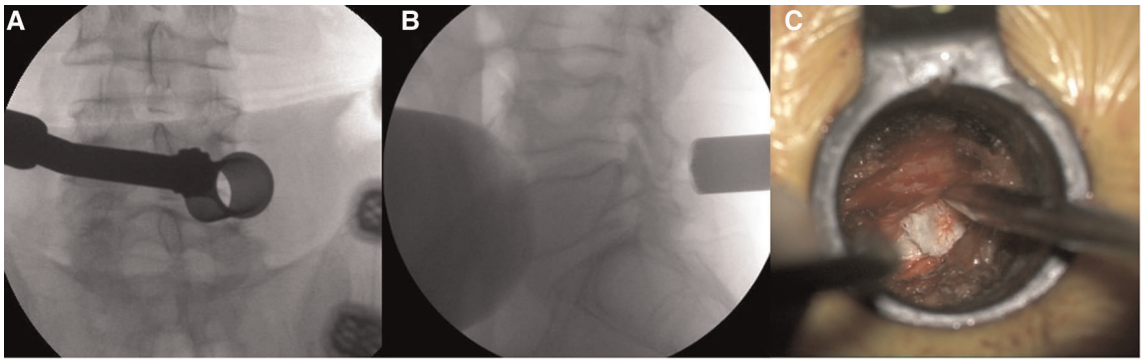

FIGURE 3
(A, B) Intraoperative fluoroscopy images showing the tubular retractor positioned at the L4–5 disc level. (C) Intraoperative view of the herniated disc underneath the retracted thecal sac and nerve root.

TABLE 1 Demographic and clinical presentation.

	MID (N= 12)	Open (N = 12)	P-value
Gender (Male)	7 (53%)	11 (91%)	0.05
Age- mean (years)	44.2 (34.0–54.3)	43.1 (35.9–50.2)	0.19
Previous spine surgey	1 (8.3)%	3 (25%)	0.30
Smoking	1 (8.3)%	2 (17%)	0.50
Cerebrovascular	0 (0%)	1 (8.3)%	0.50
CRF	0 (0%)	0 (0%)	–
Neoplasia	1 (8.3)%	0 (0%)	0.50
Hypertension	3 (25%)	2 (17%)	0.50
Diabetes	1 (12.5%)	2 (17%)	0.50
Cardiovascular	0 (0%)	2	0.48
Pulmonary	0 (0%)	1 (10%)	0.50
Endocrine	0 (0%)	1 (10%)	0.50
Hematology	1 (8.3)%	0 (0%)	0.50
Depression/anxiety	1 (8.3)%	0 (0%)	0.50
Clinical presentation			
Length of complaints before CES diagnosis (days)	2.5 (0.5–4.5)	3.9 (1.4–6.4)	0.45
Back pain	10 (83.3%)	9 (75%)	0.5
Leg pain	10 (83.3%)	8 (67%)	0.37
Urinary incontinence	7 (58%)	9 (75%)	0.67
Bowel incontinence	1 (12.5%)	2 (17%)	0.5
Limb hypoesthesia	10 (83.3%)	10 (83.3%)	–
Saddle anesthesia	8 (66.7%)	8 (66.7%)	–
Motor weakness	8 (66.7%)	10 (90.9%)	0.32
Follow up time (months)	36.17 (14.9–57.5)	38.17 (17.9–58.4)	0.90

with saddle anesthesia. In comparison, in the open surgery group 75% of patients presented with urinary incontinence ($P = 0.67$), 90.9% with motor weakness ($P = 0.31$) and 66.7% with saddle anesthesia ($P > 0.99$) Table 1.

TABLE 2 Preoperative radiological data.

	MID ($N = 12$)	Open ($N = 12$)	P-value
Level of disc			0.19
T12–L1	0 (0%)	1 (8.3%)	0.5
L1–2	0 (0%)	1 (8.3%)	0.5
L2–3	1 (8.3%)	1 (8.3%)	–
L3–4	3 (25%)	5 (42%)	0.67
L4–5	1 (8.3%)	6 (50%)	0.07
L5-S1	7 (58%)	2 (17%)	0.09
Disc pathology			
Bulge	0	0	–
Protrusion	1 (9.1%)	2 (18.2%)	5
Extrusion	8 (63.6%)	7 (63.6%)	0.5
Sequestration	3 (25%)	3 (25%)	–

Radiological analysis

Fifteen patients underwent an MRI study of the lumbar spine, the other 9 patients had a CT scan to confirm their diagnosis. For patients that presented with a clear clinical picture of CES an urgent lumbar spine CT scan was routinely done upon arrival to the Emergency Room (ER). If the CT findings were sufficient for the diagnosis the attending surgeon could elect to proceed immediately to surgery and avoid the delay until an additional MRI study will be done. Herniated discs were most commonly located at L5–S1 level (9 cases) followed by L4–5 and L3–4 (8 cases each). Disc herniations at the T12–L1, L1–2 and L3–4 were found in one patients each. Radiographic details of the intervertebral disc pathology are shown in Table 2. No statistically significant differences were found in type of disc pathology, the spinal levels of the herniation or the incidence of accompanied spondylolysis or spondylolisthesis.

Surgery

Surgery was performed within 19.7 ± 16.6 h of the diagnosis in the MID group compared to 30 ± 13.9 h in the open group ($P = 0.35$). In two cases, a bilateral ("over the top") decompression was done in the MID group through a unilateral approach due to concomitant lumbar stenosis at the same spinal level. In one patient in the MID group the minimally invasive approach was converted to an open laminectomy due to a large dural tear. However, the number of accidental dural tears was not significantly different between the groups Table 3. Mean LOS was 3.75 ± 2.8 days in the MID group compared to 6.1 ± 3.5 days in the open group, showing a strong trend towards shorter admissions for the MID group ($P = 0.059$). Two patients in the open group presented with recurring radicular symptoms following surgery due to recurrent and adjacent disc herniations. Both underwent revision surgeries with satisfactory results Table 3.

Post-operative outcome

Mean follow up time was 36.17 ± 33.53 months for the open group and 38.17 ± 31.9 months for the MIS group ($P = 0.9$). Both groups reported similar improvement in their urinary incontinence, saddle dysesthesia, leg dysesthesia and motor deficits following surgery. At the final follow-up, five patients in the MID group reported no bladder dysfunction compared to six in the open group ($P = 0.68$) Table 4.

Similarly, LEMS scores improved in both groups following surgery. however, no significant difference between was found when the scores at presentation and at all the follow-up visits post-operatively were compared between the groups Figure 4. Postoperative leg pain showed significant improvement in both group. In contrast, significant improvement in back pain was found only in the MID group but not in the open group Figure 5. Functional outcome scores collected at the final

TABLE 3 Surgical data and complications.

	MID ($N = 12$)	Open ($N = 12$)	*P*-value
Time from presentation to surgery (hours)	19.7 (9.1–30.2)	30 (21.1–38.9)	0.75
Drains	1 (8.3%)	6 (54.5%)	0.07
Durotomy	1 (8.3%)	2 (17%)	0.50
Recurrent disc herniation	2 (17%)	1 (8.3%)	0.50
Revision surgeries	1 (8.3%)	1 (8.3%)	–
Conversion to open surgery	1 (8.3%)	–	
Medical complications	2 (17%) Pneumonia	1 (8.3%) Deep vein thrombosis	>0.99
Post-operative length of stay (days)	3.75 ± 3	6.1 ± 2	0.06

TABLE 4 Patient self-reported neurological outcomes.

	MID ($N = 12$)	Open ($N = 12$)	*P*-value
Urine inconstancy			
Pre-operative	7 (58%)	9 (75%)	
Immediate post operatively			
No change	8 (67%)	6 (50%)	0.29
Partial improvement	0 (0%)	1 (8.3%)	
Complete improvement	4 (33%)	5 (41.7%)	
3 months post operatively			
No change	6 (50%)	6 (50%)	0.44
Partial improvement	2 (18.2%)	0 (0%)	
Complete Improvement	4 (33%)	6 (50%)	
6 months post operatively			
No change	6 (50%)	6 (50%)	0.44
Partial improvement	2 (18.2%)	0 (0%)	
Complete improvement	4 (33%)	6 (50%)	
12 months post operatively			
No change	6 (50%)	6 (50%)	0.57
Partial improvement	1 (8.3%)	0 (0%)	
Complete improvement	5 (41.7%)	6 (50%)	
Saddle dysesthsia			
Pre-operative	8 (67%)	8 (67%)	
Immediate post operatively			
No change	8 (67%)	5 (41.7%)	0.29
Partial improvement	4 (33%)	7 (58%)	
Complete improvement	0 (0%)	0 (0%)	
3 months post operatively			
No change	6 (50%)	6 (50%)	0.81
Partial improvement	4 (33%)	3 (25%)	
Complete improvement	2 (18.2%)	3 (25%)	
6 months post operatively			
No change	5 (41.7%)	6 (50%)	0.19
Partial improvement	5 (41.7%)	1 (8.3%)	
Complete improvement	2 (18.2%)	5 (41.7%)	
12 months post operatively			
No change	6 (50%)	6 (50%)	0.68
Partial improvement	4 (33%)	2 (18.2%)	
Complete improvement	3 (25%)	5 (41.7%)	
Limb dysesthesia			
Pre-operative	10 (83%)	10 (83%)	
Immediate post operatively			
No change	7 (58%)	5 (41.7%)	0.90
Partial improvement	4 (33%)	6 (50%)	
Complete improvement	1 (8.3%)	1 (8.3%)	
3 months post operatively			
No change	5 (41.7%)	5 (41.7%)	0.59
Partial improvement	0 (0%)	3 (25%)	
Complete improvement	7 (58%)	4 (33%)	

(*continued*)

TABLE 4 Continued

	MID ($N = 12$)	Open ($N = 12$)	*P*-value
6 months post operatively			
No change	4 (33%)	6 (50%)	0.34
Partial improvement	0 (0%)	1 (8.3%)	
Complete improvement	8 (67%)	5 (41.7%)	
12 months post operatively			
No change	4 (33%)	6 (50%)	0.66
Partial improvement	0 (0%)	0 (0%)	
Complete improvement	8 (67%)	6 (50%)	
Motor weakness			
Pre-operative	8 (58%)	10 (83%)	0.37
Immediate post operatively			
No change	7 (58%)	7 (58%)	–
Partial improvement	3 (25%)	3 (25%)	
Complete improvement	2 (18.2%)	2 (18.2%)	
3 months post operatively			
No change	7 (58%)	5 (41.7%)	0.68
Partial improvement	3 (25%)	5 (41.7%)	
Complete improvement	2 (18.2%)	2 (18.2%)	
6 months post operatively			
No change	5 (41.7%)	5 (41.7%)	0.34
Partial improvement	4 (33%)	4 (33%)	
Complete improvement	3 (25%)	3 (18.2%)	
12 months post operatively			
No change	5 (41.7%)	3 (25%)	0.87
Partial improvement	3 (25%)	5 (41.7%)	
Complete improvement	4 (33%)	4 (33%)	

follow-up did not show a statistically significant difference between the groups Table 5.

Discussion

CES is a relatively rare condition. Approximately 1%–2% of patients with lumbar disc herniation will develop a clinical presentation of acute cauda equina syndrome (16). As a result, the current scientific literature regarding the optimal medical treatment of this condition relies mainly on retrospective case series similar to the one presented herein.

Several studies focused on the clinical presentation of CES and on patients' outcomes following surgical intervention (17, 18). Special interest was given to the correlation between the timing of surgery and patients' post-operative neurological outcomes. Although most authors recommended urgent surgical decompression in this setting, critical analysis of the literature leading to this conclusion is not conclusive (5, 8).

Similarly, several authors claimed that optimal decompression should be achieved by a wide-open laminectomy followed by a discectomy (8). They argued this approach will decrease the risk of intra-operative complications including incidental dural tears and nerve root injury. Some authors also routinely supplement the laminectomy with an instrumented fusion in order to address post-operative iatrogenic instability or recurrent disc herniation (19). However, several studies reported CES could be successfully treated using a less invasive approach. Olivero et al. suggested that a unilateral hemilaminectomy and

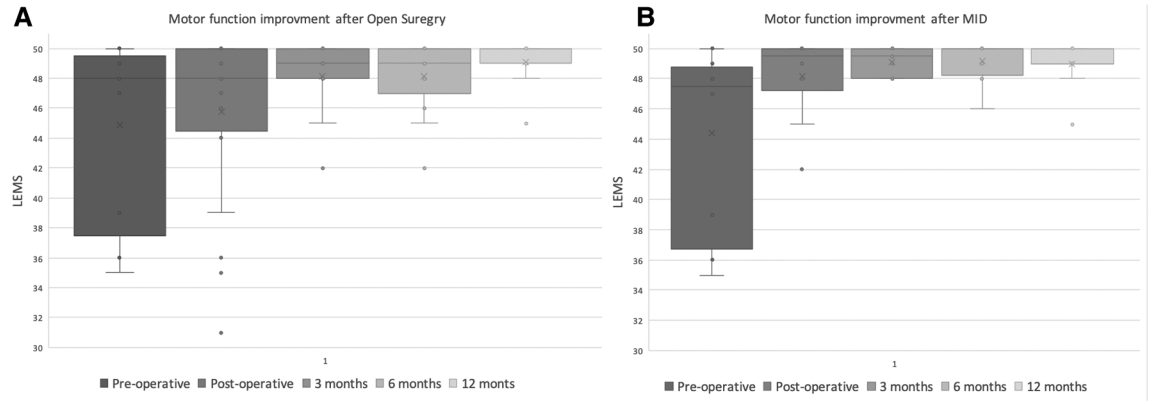

FIGURE 4
Distribution of reported lower extremity motor score (LEMS) of the MID (A) and open decompression (B) groups at preoperative, immediate postoperative, 3,6,12 months.

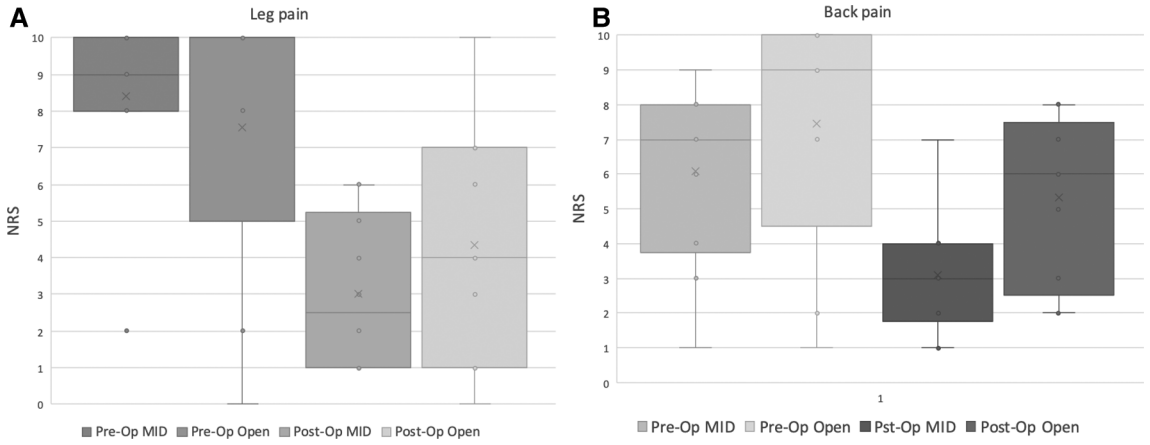

FIGURE 5
Distribution of reported rating scale (NRS) for preoperative and postoperative leg (A) and back (B) pain, in the MID and open decompression groups.

TABLE 5 Postoperative neurological and functional outcomes.

	MID ($N = 12$)	Open ($N = 12$)	*P*-value
Follow up time (months)	36.2 (14.9–57.5)	38.2 (17.9–58.4)	0.90
Baseline LEMS	47.1 (43.7–50.5)	44.5 (40.6–48.2)	0.11
Post op LEMS	48.2 (46.3–50.1)	45.7 (42.3–49.1)	0.10
3 m LEMS	44.7 (48.5–49.8)	49.8 (46.5–49.8)	0.96
6 m LEMS	49.2 (48.4–49.9)	47.9 (46.5–49.9)	0.06
12 m LEMS	49.3 (49.3–48.7)	49.0 (48.0–49.9)	0.75
Pre-operative leg pain NRS	8.4 (6.7–10.1)	8.4 (4.6–10.5)	0.58
post operative leg pain NRS	3.0 (1.5–4.5)	3.9 (1.7–6.9)	0.27
Pre-operative back pain NRS	6.1 (4.2–7.9)	7.4 (4.8–10.1)	0.40
Post operative back pain NRS	3.1 (1.8–4.4)	5.3 (3.4–7.2)	0.16
Final follow up functional outcome			
ODI	10.6 (1.0–20.1)	20.3 (8.9–40.8)	0.24
EQ-5D	6.0 (4.7–7.2)	8.2 (6.2–10.2)	0.15

discectomy could produce similar results as total laminectomy (9). Successful decompression of large disc herniation causing CES was also reported using percutaneous endoscopic techniques (20, 21) and by using a minimally invasive tubular retractor system (22). However, all of these studies consisted of case reports or small retrospective case series without a control group.

Choosing an open laminectomy to treat CES has several inherent advantages over alternative surgical approaches that use a more limited approach. First, open decompression can usually be completed in a relatively short time which is especially important in these cases due to the emergent need to achieve adequate decompression of the thecal sac and in order to maximize the chances to reverse the neurological damage. Moreover, open laminectomy provides a superior exposure of the thecal sac with the option to remove extruded disc fragments from both sides of the spinal canal. Lastly, an initial wide decompression of the thecal sac could decrease the risk of nerve root injury and incidental durotomy during their retraction due to the initial decompression of the thecal sac achieved by the laminectomy. However, the potential disadvantages of open surgery include the relatively larger trauma to the paraspinal soft tissue, posterior ligamentous complex and facet joints. These injuries could be linked to an increased risk of post-operative complications including: surgical wound infection, epidural scarring and post-operative back pain (23, 24).

MID has have the potential of reducing these complication by minimizing damage to the paraspinal muscles and posterior bony spinal elements. In our experience, the risk of postoperative epidural hematoma formation even without the use of a drain is extremely low. It is however imperative to assure that the surgical wound is closed only after meticulous hemostasis has been achieved. MID is more technically challenging and usually requires a lengthy learning curve (25). In this study, Post-operative MRI studies in order to evaluate the efficiency of the decompression were not routinely order during the early post-operative period and thus were not available for this study. However, when comparing between MID and open laminectomy and discectomy we found that MID did not increase the risk of complications or of revision surgeries. Moreover, in one case the minimally invasive approach was aborted in favor of an open approach due to a large dural tear that could not be adequately addressed through the tubular retractor. The overall complication rates in both groups were similar to those previously published in the literature for open laminectomy and discectomy (23, 25). This low complication rate, especially in the MID group, may suggest that minimally invasive spinal decompression is an adequate technique to address CES. Moreover, back pain outcomes in the MID group were more favorable compared to

the open surgery group as leg pain and functional outcomes showed a trend toward a greater improvement in the MID group that did not reach statistical significance. While the minimal surgical exposure could explain these more favorable pain and function outcomes, it should be recognized that these differences might be affected by confounding factors such as the small cohort size and selection bias of the two groups. It however demonstrates, at the very least, the non-inferiority of the MID group's neurological outcome.

Due to the relative rarity of CES this current study has inherent limitations. The number of cases in our cohort albeit small is comparable to others in the literature (9, 22, 26). This factor in association with the usage of appropriate, but less sensitive, non-parametric statistical tests may lean towards a type 1 error. Moreover, our cohort was too small to identify specific risk factors for postoperative improvement. Additionally, evaluating sphincter dysfunction in this study was based on patients self-report without the use of a validated objective assessment tool. Despite these limitations, to date this is the first study that compares outcome of MID and open decompression for the treatment of CES. Additional prospective studies with larger cohorts are needed in order to validate these results.

In conclusion, while laminectomy may still be regarded as the safest surgical option for the treatment of CES, our findings show that MID is just as effective and might also provide superior results compared to open laminectomy and discectomy regarding back pain improvement.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

DO: Preparation, creation of the published work, oversight and leadership responsibility for the research activity planning and execution. MK: Preparation, creation of the published work, writing the initial draft, oversight and leadership responsibility for the research activity planning and execution. GJR: Preparation, creation of the published work, oversight and leadership responsibility for the research activity planning and execution. BK: Conducting the research and investigation process. AG: Conducting the research and investigation process. KS: Conducting the research and investigation process. DN: Conducting the radiological analysis, commentary and revision. ZL: Preparation, critical review, commentary and revision. All authors contributed to the article and approved the submitted version.

Funding

Funding acquisition: The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Dias ALN, Araujo FF, Cristante AF, Marcon RM, Barros Filho TEP, Letaif OB. Epidemiology of cauda equina syndrome. What changed until 2015. *Rev Bras Ortop*. (2018) 53:107–12. doi: 10.1016/j.rboe.2017.11.006

2. Kostuik JP, Harrington I, Alexander D, Rand W, Evans D. Cauda equina syndrome and lumbar disc herniation. *J Bone Joint Surg Am*. (1986) 68:386–91. doi: 10.2106/00004623-198668030-00011

3. Ahn UM, Ahn NU, Buchowski JM, Garrett ES, Sieber AN, Kostuik JP. Cauda equina syndrome secondary to lumbar disc herniation: a meta-analysis of surgical outcomes. *Spine*. (2000) 25:1515–22. doi: 10.1097/00007632-200006150-00010

4. Srikandarajah N, Wilby M, Clark S, Noble A, Williamson P, Marson T. Outcomes reported after surgery for cauda equina syndrome: a systematic literature review. *Spine*. (2018) 43:E1005–13. doi: 10.1097/BRS.0000000000002605

5. Jain A, Menga E, Mesfin A. Outcomes following surgical management of cauda equina syndrome: does race matter? *J Racial Ethn Health Disparities*. (2018) 5:287–92. doi: 10.1007/s40615-017-0369-6

6. Thakur JD, Storey C, Kalakoti P, Ahmed O, Dossani RH, Menger RP, et al. Early intervention in cauda equina syndrome associated with better outcomes: a myth or reality? Insights from the nationwide inpatient sample

database (2005–2011). *Spine J*. (2017) 17:1435–48. doi: 10.1016/j.spinee.2017.04.023

7. Uckun OM, Alagoz F, Polat O, Divanlioglu D, Daglioglu E, Belen AD, et al. Urgent operation improves weakness in cauda equina syndrome due to lumbar disc herniation. *Turk J Phys Med Rehabil*. (2019) 65:222–7. doi: 10.5606/tftrd.2019.3169

8. Gleave JR, Macfarlane R. Cauda equina syndrome: what is the relationship between timing of surgery and outcome? *Br J Neurosurg*. (2002) 16:325–8. doi: 10.1080/0268869021000032887

9. Olivero WC, Wang H, Hanigan WC, Henderson JP, Tracy PT, Elwood PW, et al. Cauda equina syndrome (CES) from lumbar disc herniations. *J Spinal Disord Tech*. (2009) 22:202–6. doi: 10.1097/BSD.0b013e31817baad8

10. Foley KT, Smith MM, Rampersaud YR. Microendoscopic approach to far-lateral lumbar disc herniation. *Neurosurg Focus*. (1999) 7:e5. doi: 10.3171/foc.1999.7.6.6

11. Clark AJ, Safaee MM, Khan NR, Brown MT, Foley KT. Tubular microdiscectomy: techniques, complication avoidance, and review of the literature. *Neurosurg Focus*. (2017) 43:E7. doi: 10.3171/2017.5.FOCUS17202

12. Mobbs RJ, Li J, Sivabalan P, Raley D, Rao PJ. Outcomes after decompressive laminectomy for lumbar spinal stenosis: comparison between minimally invasive unilateral laminectomy for bilateral decompression and open laminectomy: clinical article. *J Neurosurg Spine*. (2014) 21:179–86. doi: 10.3171/2014.4.SPINE13420

13. Rahman M, Summers LE, Richter B, Mimran RI, Jacob RP. Comparison of techniques for decompressive lumbar laminectomy: the minimally invasive versus the "classic" open approach. *Minim Invasive Neurosurg*. (2008) 51:100–5. doi: 10.1055/s-2007-1022542

14. Waters RL, Adkins R, Yakura J, Vigil D. Prediction of ambulatory performance based on motor scores derived from standards of the American spinal injury association. *Arch Phys Med Rehabil*. (1994) 75:756–60. doi: 10.1016/0003-9993(94)90131-7

15. Khoo LT,, Fessler RG. Microendoscopic decompressive laminotomy for the treatment of lumbar stenosis. *Neurosurgery*. (2002) 51:S146–154. doi: 10.1097/00006123-200211002-00020

16. Hoeritzauer I, Wood M, Copley PC, Demetriades AK, Woodfield J. What is the incidence of cauda equina syndrome? A systematic review. *J Neurosurg Spine*. (2020) 32(6):1–10. doi: 10.3171/2019.12.SPINE19839

17. Hazelwood JE, Hoeritzauer I, Pronin S, Demetriades AK. An assessment of patient-reported long-term outcomes following surgery for cauda equina syndrome. *Acta Neurochir*. (2019) 161:1887–94. doi: 10.1007/s00701-019-03973-7

18. Korse NS, Pijpers JA, van Zwet E, Elzevier HW, Vleggeert-Lankamp CLA. Cauda Equina syndrome: presentation, outcome, and predictors with focus on micturition, defecation, and sexual dysfunction. *Eur Spine J*. (2017) 26:894–904. doi: 10.1007/s00586-017-4943-8

19. Shi J, Jia L, Yuan W, Shi G, Ma B, Wang B, et al. Clinical classification of cauda equina syndrome for proper treatment. *Acta Orthop*. (2010) 81:391–5. doi: 10.3109/17453674.2010.483985

20. Jha SC, Tonogai I, Takata Y, Sakai T, Higashino K, Matsuura T, et al. Percutaneous endoscopic lumbar discectomy for a huge herniated disc causing acute cauda equina syndrome: a case report. *J Med Invest*. (2015) 62:100–2. doi: 10.2152/jmi.62.100

21. Li X, Dou Q, Hu S, Liu J, Kong Q, Zeng J, et al. Treatment of cauda equina syndrome caused by lumbar disc herniation with percutaneous endoscopic lumbar discectomy. *Acta Neurol Belg*. (2016) 116:185–90. doi: 10.1007/s13760-015-0530-0

22. Shih P, Smith TR, Fessler RG, Song JK. Minimally invasive discectomy for the treatment of disc herniation causing cauda equina syndrome. *J Clin Neurosci*. (2011) 18:1219–23. doi: 10.1016/j.jocn.2011.01.018

23. O'Toole JE, Eichholz KM, Fessler RG. Surgical site infection rates after minimally invasive spinal surgery. *J Neurosurg Spine*. (2009) 11:471–6. doi: 10.3171/2009.5.SPINE08633

24. McGirt MJ, Parker SL, Lerner J, Engelhart L, Knight T, Wang MY. Comparative analysis of perioperative surgical site infection after minimally invasive versus open posterior/transforaminal lumbar interbody fusion: analysis of hospital billing and discharge data from 5170 patients. *J Neurosurg Spine*. (2011) 14:771–8. doi: 10.3171/2011.1.SPINE10571

25. Sclafani JA, Kim CW. Complications associated with the initial learning curve of minimally invasive spine surgery: a systematic review. *Clin Orthop Relat Res*. (2014) 472:1711–7. doi: 10.1007/s11999-014-3495-z

26. McCarthy MJ, Aylott CE, Grevitt MP, Hegarty J. Cauda equina syndrome: factors affecting long-term functional and sphincteric outcome. *Spine*. (2007) 32:207–16. doi: 10.1097/01.brs.0000251750.20508.84

frontiers | Frontiers in Surgery

TYPE Review
PUBLISHED 01 November 2022
DOI 10.3389/fsurg.2022.1040166

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

RECEIVED 09 September 2022
ACCEPTED 03 October 2022
PUBLISHED 01 November 2022

CITATION
Zhang X, Yang Y, Shen Y-W, Zhang K-R, Ma L-T and Liu H (2022) Effect of perioperative steroids application on dysphagia, fusion rate, and visual analogue scale (VAS) following anterior cervical spine surgery: A meta-analysis of 14 randomized controlled trials (RCTs). Front. Surg. 9:1040166. doi: 10.3389/fsurg.2022.1040166

Effect of perioperative steroids application on dysphagia, fusion rate, and visual analogue scale (VAS) following anterior cervical spine surgery: A meta-analysis of 14 randomized controlled trials (RCTs)

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Objective: To conduct a high-level meta-analysis of the RCTs to evaluate perioperative steroids use in the management of fusion rate, dysphagia, and VAS following anterior cervical spine surgery for up to 1 year.

Methods: We searched the database PubMed, EMBASE, Web of Science, Cochrane Library, Google Scholar, Ovid, and ClinicalTrials.gov without time restriction to identify RCTs that evaluate the effectiveness of perioperative steroids after anterior cervical spine surgery. A subgroup analysis was undertaken to investigate the effects of intravenous and local steroids. This study was registered in the PROSPERO database prior to initiation (CRD42022313444).

Results: A total of 14 RCTs were eligible for final inclusion. This meta-analysis showed that steroids could achieve lower dysphagia rate ($p < 0.001$), severe dysphagia rate within 1 year ($p < 0.001$), lower VAS scores at both 1 day ($p = 0.005$), 2 weeks ($p < 0.001$) and shorter hospital stay ($p = 0.014$). However, there was no significant difference between the two groups regarding operation time ($p = 0.670$), fusion rates ($p = 0.678$), VAS scores at 6 months ($p = 0.104$) and 1 year ($p = 0.062$). There was no significant difference between intravenous and local steroid administration regarding dysphagia rates ($p = 0.82$), fusion rate ($p = 1.00$), and operative time ($p = 0.10$).

Conclusion: Steroids intravenously or locally following anterior cervical spine surgery can reduce incidence and severity of dysphagia within 1 year, VAS score within 2 weeks, and shorten the length of hospital stay without affecting fusion rates, increasing the operating time, VAS score at 6 months and 1 year.

KEYWORDS

steroid, dysphagia, anterior cervical spine surgery, rct, meta-analysis steroid, meta-analysis introduction

Introduction

Since first introduced in 1958 by Cloward (1), Robinson and Smith (2), anterior approach has become the standard approach in the treatment of spondylotic radiculopathy and myelopathy with demonstrated long-term clinical success. However, it is associated with complications such as dysphagia, presumably due to local tissue swelling, intraoperative excessive retraction, and laryngeal nerve palsy. Rates of postoperative dysphagia ranged in frequency from 1.7% to 67% according to previous reports (3–6). Dysphagia after ACDF has raised concerns about increasing morbidity, duration of hospitalization, and medical costs (7).

Many measures have been investigated to decrease the incidence of dysphagia and decreased cuff pressure and plate prominence are just a few (8–11). One promising therapeutic intervention is the use of perioperative steroids (12–14). In some studies, the steroid has resulted in decreased incidence and severity of dysphagia (13, 15). However, the effect of steroids has been equivocal in other studies (16). In addition to inconsistent results for dysphagia, there is concern about the adverse effects of steroids, such as delayed time to fusion (12). From the surgeon's point of view, solid bony fusion is of critical importance in the achievement of expected outcomes following anterior cervical spine surgery. Delayed bony fusion or even non-union after surgery greatly increases the risk of revision (17). In addition, it has been reported that steroids can reduce postoperative pain by reducing the inflammatory response (18). Nevertheless, the duration of this effect still remains controversial.

Considering these issues, it is important to perform a systematic review and meta-analysis to provide clear advice concerning the accurate effect of steroids on the incidence and severity of dysphagia, fusion rate and VAS score. Moreover, a subgroup analysis was needed to compare the effects of intravenous and local steroids as a consensus on the use of intravenous and local injections has not yet been reached.

Methods

This systematic review was conducted following the Preferred Reported Items for Systematic reviews and Meta-Analysis (PRISMA) guidelines, the Cochrane Collaboration recommendations and AMSTAR (Assessing the methodological quality of systematic reviews) (19, 20), and the study protocol was registered in the international open-access Prospective Register of Systematic Reviews (PROSPERO, number: CRD42022313444) prior to data retrieval.

Search strategy

A comprehensive literature search was conducted on PubMed, EMBASE, Web of Science, Cochrane Library, Google Scholar, Ovid, and ClinicalTrials.gov from inception to February 19, 2022. Search terms included both entry terms and medical descriptors/MeSH terms such as "Glucocorticoids", "Steroids", "Methylprednisolone", "Dexamethasone", "anterior cervical discectomy and fusion", "Anterior cervical surgery", "Anterior cervical fusion", "Anterior Cervical Corpectomy and Fusion". **Supplementary File S1** summarizes the search strategy used in each database.

Assessment of eligibility

Studies satisfying the following criteria were included: (1) population: adults with spondylotic radiculopathy and myelopathy undergoing anterior cervical spine surgery; (2) intervention: perioperative intravenous or local steroids administration; (3) comparison: placebo vs. steroids; (4) main outcomes: the event number of dysphagia, visual analog scale (VAS) at postoperative 1 day, 2 weeks, 6 months and 1 year, fusion rates at 1 year; (5) study design: RCT design.

The following studies were excluded: (1) Letters, editorials, conference abstracts, systematic reviews or meta-analyses, consensus statements, guidelines; (2) Had insufficient data this meta-analysis required; (3) Contained comparisons with other comparison protocols; (4) Full-text was not available.

Data extraction

Data extraction was conducted by two independent reviewers using a piloted and standardized data extraction form. Any disagreements were resolved by mutual consensus. The following data from each included study were retrieved: (1) Study characteristics: authors' information, publication year; (2) Patients' characteristics: size of each group, mean age, male-to-female ratio; (3) Intervention: route of administration and dose; (4) Outcomes: dysphagia events, fusion rate, VAS score, operation time, length of hospital stay.

Risk of bias and quality assessment

The quality and risk of bias were assessed by two independent reviewers using the Cochrane Handbook for Systematic Reviews of Interventions (20). Any disagreements were resolved by mutual consensus. This quality evaluation system includes seven domains: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data,

TABLE 1 The characteristics of the included studies.

Study (year)	Country	Surgery type	Experimental data			Control data			Outcomes recorded	Follow-up
			Patients	Mean age	Male: Female	Patients	Mean age	Male: Female		
Cui et al., 2019	USA	49 ACDF, 8 ACCF, 1 hybrid, and 6 single-level CDA	33	53.2	13:20	31	50.3	15:16	Bazaz dysphagia score, Dysphagia Symptom Questionnaire, fusion rate	12 months
Dahapute et al., 2020	India	1 and 2-level ACDF	25	50.4	19:6	25	50.4	19:6	PSTS, VAS, mJOA, NDI, fusion rate	12 months
Edwards et al., 2016	USA	1, 2, and 3-level ACDF	27	54	11:16	23	54.5	9:14	Bazaz scale, average dysphagia scores, operation time, length of hospital stay	28 days
Grasso et al., 2019	Italy	1 and 2-level ACDF	35	46.1	18:17	35	45.5	17:18	Bazaz scale, VAS, operation time	12 months
Hasani Barzi et al., 2016	Iran	1, 2, and 3-level ACDF	20	50.3	8:12	20	48.3	8:12	PSTS, S/V ratio, VAS	10 days
Haws et al., 2018	USA	1, 2, and 3-level ACDF	55	49.4	31:24	49	50.6	30:19	Mean SWAL-QOL score, mean swelling index, mean air index, VAS, operation time, length of hospital stay	12 weeks
Jenkins et al., 2018	USA	1, 2, and 4-level ACDF	29 25	55.6 14:24	15:14 14:11	21 21	11:10 11:10	14:24 14:24	Bazaz scale, EAT-10, VHI-10, VAS, fusion rate	12 months
Jeyamohan et al., 2015	USA	2, 3, 4 and 5-level ACDF	56	54	33:23	56	55	27:28	Bazaz scale, mJOA, FOSS score, ODI score, SF-12 PCS score, SF-12 MCS score, fusion rate, VAS	24 months
Kim et al., 2021	USA	2, 3, 4-level ACDF	56	58.1	27:29	53	58.4	29:24	Eat-10, SWAL-QOL, NDI, operative time, length of hospital stay	1 month
Lee et al., 2011	Korea	1 and 2-level ACDF	25	54.3	18:9	25	50.9	14:7	PSTS, fusion rate, VAS, NDI	22 months
Nam et al., 2013	Korea	1-level ACDF	20 20	45.6 46.9	14:6 11:9	22 22	48.8 48.8	16:6 16:6	PSTS, VAS, operation time	5 days
Seddighi et al., 2017	Iran	1, 2, and 3-level ACDF	38	49.3	18:20	38	50.2	16:22	Bazaz scale, PSTS, S/V ratio, VAS, operative time, length of hospital stay	6 months
Song et al., 2014	Korea	≥3-level ACDF	20	59.9	14:06	20	57.3	16:04	Bazaz scale, PSTS, operative time, length of hospital stay	5 days
Pedram et al., 2003	France	1, 2, and 3-level ACDF and ACCF	78	47	Not reported	158	47	Not reported	Throat lesions, operative time	36 h

ACDF, anterior cervical discectomy and fusion; ACCF, anterior cervical corpectomy decompression and fusion; CDA, cervical disc arthroplasty; PSTS, prevertebral soft-tissue swelling; SWAL-QOL, quality of life in swallowing disorders; VAS, visual analog scale; NDI, neck disability index; mJOA, modified Japanese Orthopedic Association Score; S/V, The ratio of prevertebral soft tissue thickness to mid anteroposterior vertebral body; EAT-10, Eating Assessment Tool-10; VHI-10, Voice Handicap Index-10.

selective outcome reporting, and other bias. Each domain was assessed as low, unclear, or high risk. Risk of bias graphs were plotted using the Revman software (version 5.3). The results of outcomes were assessed the quality of evidence by the Grading of Recommendations Assessment, Development and Evaluation (GRADE) under the software GRADE profiler (https://gradeprofler.sofware.informer.com/download/).

Statistical analysis

We used Stata 14.0 for statistical analysis. Mean difference with 95% confidence intervals (CIs) was used to evaluate continuous data, and odds ratio was used for dichotomous data. p value was calculated and documented for each outcome measure. Statistical significance was defined as a p value less than 0.05 ($p < 0.05$).

Statistical heterogeneity was assessed using the I^2 test. The I^2 statistic describes the percentage of variation in each study due to heterogeneity rather than chance, while I^2 values of 0%–25%, 25%–50%, 50%–75%, and >75% represent very low, low, medium, and high heterogeneity, respectively (21). A random-effect model was applied when the I^2 value was over 50%, and a fixed-effect model was applied conversely.

In addition, a subgroup analyses by the route of administration (Local vs. Intravenous) was performed to further evaluate the effects of intravenous and local steroids. A sensitivity analysis that excluding studies one by one was

TABLE 2 The intervention administration methods, steroid dose and frequency in each included study.

Study	Intervention administration method		Dose		Frequency	
	Steroid group	Control group	Steroid group	Control group	Steroid group	Control group
Cui et al., 2019	Intravenous application	Intravenous application	0.3 mg/kg dexamethasone preoperatively, 0.15 mg/kg dexamethasone postoperatively	Equivalent of saline	1 dose of 0.3 mg/kg preoperatively, 0.15 mg/kg every 8 h for 2 doses postoperatively	2 dose of 0.3 mg/kg preoperatively, 0.15 mg/kg every 8 h for 2 doses postoperatively
Dahapute et al., 2020	Local application	Local application	40 mg triamcinolone	Equivalent of saline	Once intraoperatively	Once intraoperatively
Edwards et al., 2016	Local application	Local application	40 mg Depo-medrol	Equivalent of saline	Once intraoperatively	Once intraoperatively
Grasso, 2019	Local application	Local application	40 mg methylprednisolone	200 ml saline	Once intraoperatively	Once intraoperatively
Hasani Barzi et al., 2016	Local application	None	80 mg methylprednisolone	None	Once intraoperatively	None
Haws, 2018	Local application	Local application	40 mg Depo-medrol	Equivalent of saline	Once intraoperatively	Once intraoperatively
Jenkins et al., 2018	Local application	None	40 mg triamcinolone	None	Once intraoperatively	None
	Intravenous application	None	10 mg dexamethasone	None	Once intraoperatively	None
Jeyamohan et al., 2015	Intravenous application	Intravenous application	0.2 mg/kg dexamethasone intraoperatively, 0.06 mg/kg dexamethasone postoperatively	Equivalent of saline	1 dose of 0.2 mg/kg intraoperatively, 0.06 mg/kg every 6 h for the first 24 h	1 dose of 0.2 mg/kg intraoperatively, 0.06 mg/kg every 6 h for the first 24 h
Kim, 2021	Local application	None	40 mg methylprednisolone	None	Once intraoperatively	None
Lee et al., 2011	Local application	None	40 mg triamcinolone	None	Once intraoperatively	None
Nam et al., 2013	Intravenous application	Intravenous application	10 mg dexamethasone intraoperatively, 5 mg dexamethasone postoperatively	Equivalent of saline	1 dose of 10 mg intraoperatively, 5 mg on postoperative day 1 and day 2, respectively	1 dose of 10 mg intraoperatively, 5 mg on postoperative day 1 and day 2, respectively
	Intravenous application	Intravenous application	20 mg dexamethasone intraoperatively, 10 mg dexamethasone postoperatively	Equivalent of saline	1 dose of 20 mg intraoperatively, 10 mg on postoperative day 1 and day 2, respectively	1 dose of 20 mg intraoperatively, 10 mg on postoperative day 1 and day 2, respectively
Seddighi, Afsoun et al., 2017	Local application	Local application	80 mg methylprednisolone	200 ml saline	Once intraoperatively	Once intraoperatively
Song et al., 2014	Intravenous application	None	250 mg methylprednisolone	None	250 mg and every 6 h for the first 24h	None
Pedram et al., 2003	Intravenous application	None	1 mg/kg methylprednisolone	None	1 mg/kg and every 12 h for the first 24h	None

performed to investigate the effect of steroid intervention on evaluation indicators.

Results

Search results

The systematic literature search initially identified 436 potentially eligible articles from PubMed, Embase, Web of Science, Cochrane Library, Google Scholar, and ClinicalTrials.gov (**Figure 1**). After excluding 120 duplicates, screening of the remaining 436 titles and abstracts yielded 49 potentially eligible articles. After full-text reviews of the 49 provisionally eligible articles, 35 articles were excluded due to no access to full-text (5), contained insufficient data (20), contained comparisons with other comparison protocols (10). Finally, 14 articles were included in this present systematic review and meta-analysis.

Characteristics of the included studies

Details of study demographics of steroid-administered patients, details of the administration of the steroids, and steroids effects assessment after anterior cervical fusion are summarized in **Table 1**, **2**. All the 14 articles (16, 18, 22–33) were prospective randomized controlled trials that were graded as the level of evidence 1, and three of them were double-blinded studies (22, 24, 30). A total of

TABLE 3 GRADE assessment of the level of evidence for all included studies.

Quality assessment							No of patients		Effect	Quality	Importance
No of studies	Design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	Steroids	Control	Relative (95% CI) absolute		
Dysphagia events (follow-up 1 year; assessed with, Dysphagia events)											
8	Randomized trials	Serious[a]	No serious inconsistency	No serious indirectness	No serious imprecision	None	231/723 (32%)	375/729 (51.4%)	OR 0.34 (0.26 to 0.46)	⊕⊕⊕O MODERATE	CRITICAL
Dysphagia events (moderate + severe) (follow-up 1 year; assessed with, Bazaz stratification)											
5	Randomized trials	Serious[b]	No serious inconsistency	No serious indirectness	No serious imprecision	None	77/535 (14.4%)	138/469 (29.4%)	OR 0.21 (0.13 to 0.34)	⊕⊕⊕O MODERATE	CRITICAL
Fusion rate (follow-up 1 year; assessed with, Fusion events)											
6	Randomized trials	No serious risk of bias	No serious inconsistency	Serious[c]	No serious imprecision	None	166/191 (86.9%)	154/175 (88%)	OR 0.87 (0.46 to 1.65)	⊕⊕⊕O MODERATE	CRITICAL
VAS score (follow-up 1 year; measured with, VAS)											
7	Randomized trials	Serious[d]	Serious[e]	No serious indirectness	No serious imprecision	None	532	484	WMD −1.52 (−2.01 to −1.04)	⊕⊕OO LOW	CRITICAL
Operation time (measured with, time)											
7	Randomized trials	No serious risk of bias	Serious[f]	No serious indirectness	No serious imprecision	None	329	400	WMD −2.15 (−5.22 to 0.92)	⊕⊕⊕O MODERATE	IMPORTANT
Length of hospital stay (measured with, time)											
4	Randomized trials	No serious risk of bias	Serious[g]	No serious indirectness	No serious imprecision	None	169	160	SMD −0.42 (−0.76 to −0.09)	⊕⊕⊕O MODERATE	IMPORTANT

[a]Pedram, 2003 and Song may have selection bias.
[b]Song, 2014 may have selection bias.
[c]The standard of fusion varied.
[d]Nam, 2013 may have selection bias.
[e]I-squared = 93.8%.
[f]I-squared = 78.6%.
[g]I-squared = 54.4%.

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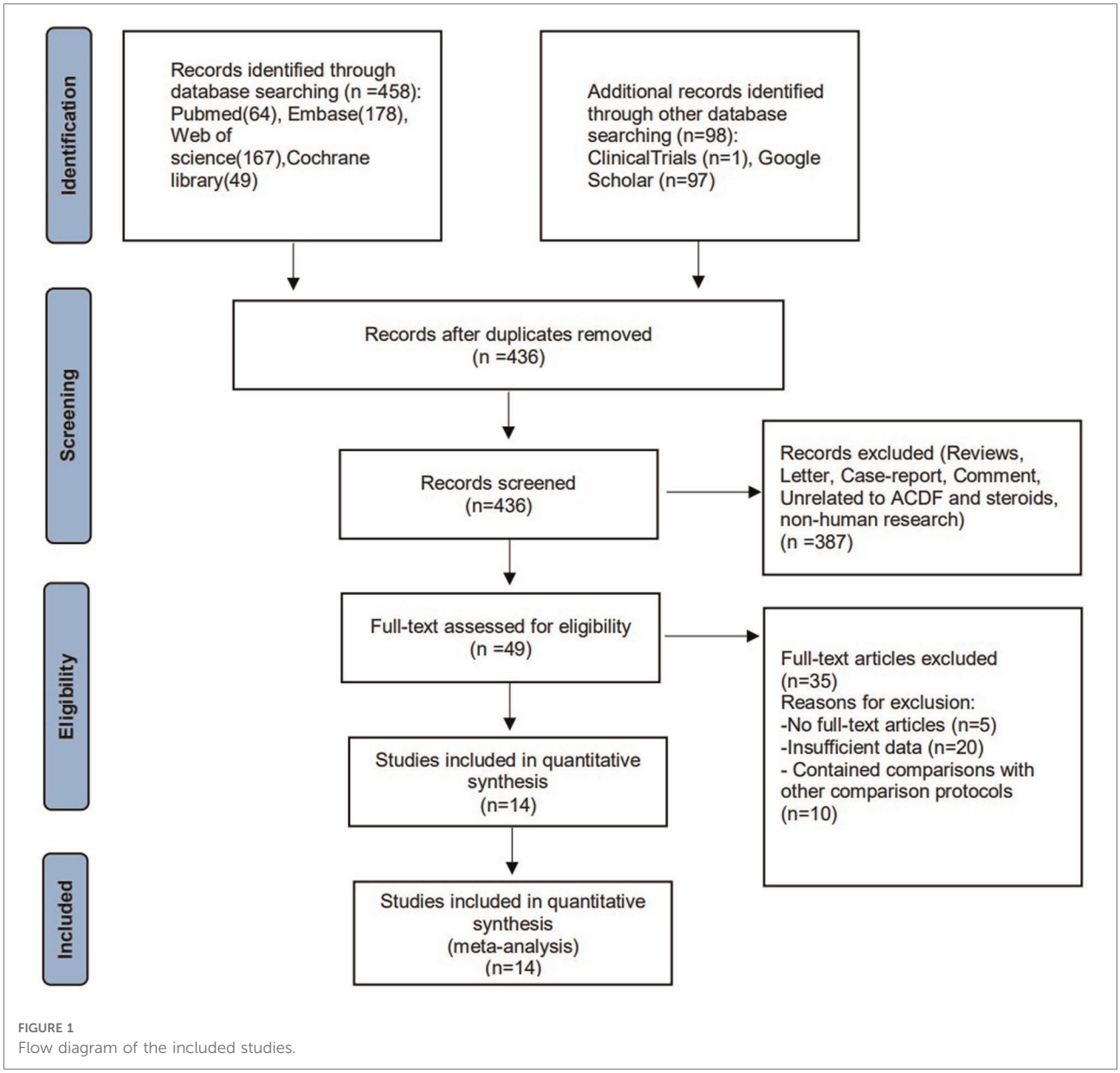

FIGURE 1
Flow diagram of the included studies.

1,181 patients were enrolled across all 14 randomized controlled studies. In total, 252 patients received intravenous steroids, 310 patients received topical steroids, and 619 patients served as controls. The corticosteroid treatment arms utilized IV dexamethasone (16, 22, 28, 29) or methylprednisolone (31, 33) or local injection of methylprednisolone (24–27, 30, 32) or triamcinolone (18, 23, 28).

Quality assessment to risk of bias

Two independent reviewers evaluated the quality of 14 RCTs according to the criteria of the Cochrane Collaboration for Systematic Reviews and any disagreements were solved through discussion and consensus. Three studies were found to have a "high" risk of bias, primarily attributed to the randomization process. The overall risk of bias of the included studies was determined to be low (**Figures 2**, **3**).

Quality of evidence assessment by GRADE

The results of dysphagia event, Bazaz stratification of severity of dysphagia, fusion rate, VAS, operation time and length of hospital stay were assessed the quality of evidence

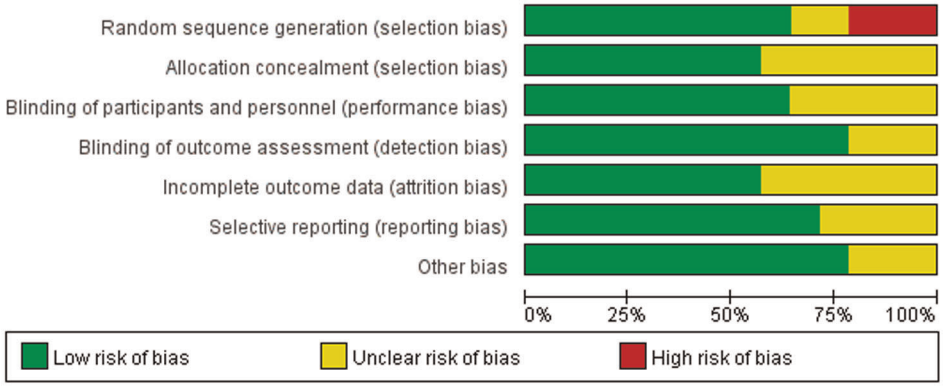

FIGURE 2
Risk of bias graph.

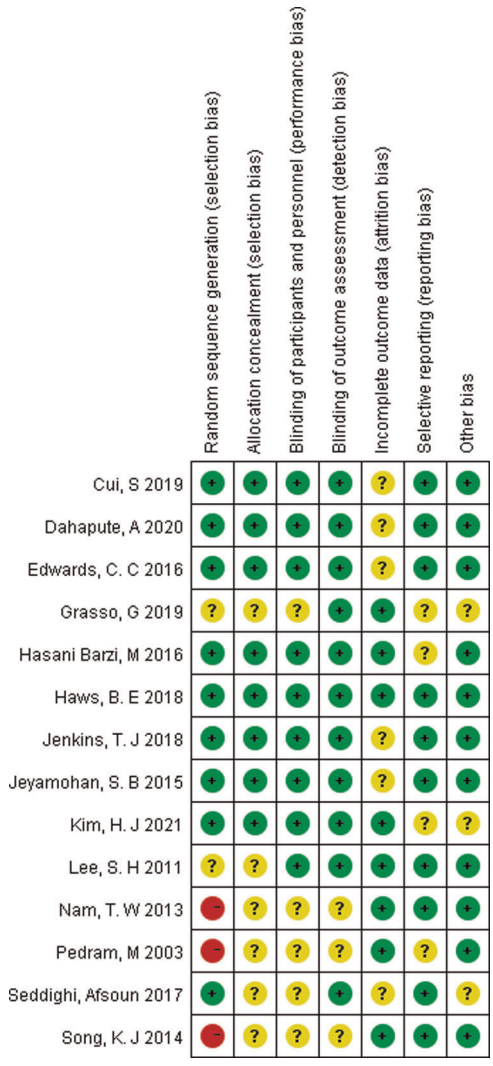

FIGURE 3
Risk of bias summary of randomized controlled trials.

by GRADE. The results qualities of VAS were low, and dysphagia event, Bazaz stratification of severity of dysphagia, fusion rate, operation time and length of hospital stay were moderate. None of high quality evidence was found in above outcomes (Table 3).

Results of meta-analysis

The use of steroids for dysphagia event from postoperative 1 day to 1 year

The most commonly used assessment tool for dysphagia was the Bazaz scale (25, 28, 29, 31–33). One study used its modified version, the Modified Dysphagia Scoring System (MDSS) (24). The pooled outcomes showed that steroid use achieved significantly lower dysphagia rates compared with the incidence in the control group (1 day, OR = 0.48, 95% CI: 0.32–0.73, 2 weeks, OR = 0.25, 95% CI: 0.13–0.47; 3 months, OR = 0.28, 95% CI: 0.12–0.70; 6 months, OR = 0.31, 95% CI: 0.11–0.85; 1 year, OR = 0.11, 95% CI: 0.02–0.50). With a fixed-effect model, a low heterogeneity among these studies was found in the pooled outcomes ($I^2 = 33.7\%$, $p = 0.072$) (Figure 4).

Bazaz stratification of severity of dysphagia (moderate + severe) from postoperative 1 day to 1 year

A fixed-effect model was used to pool the total moderate and severe Bazaz stratification because there was no significant heterogeneity across four studies ($I^2 = 0.00\%$, $p = 0.811$) (25, 28, 32, 33). The pooled analysis revealed less moderate and severe events in the steroid group compared with the control group within 1 year after surgery (1 day, OR = 0.29, 95% CI: 0.13–0.66; 2 weeks, OR = 0.27, 95% CI: 0.12–0.59; 3 months, OR = 0.07, 95% CI: 0.01–0.42; 6 months,

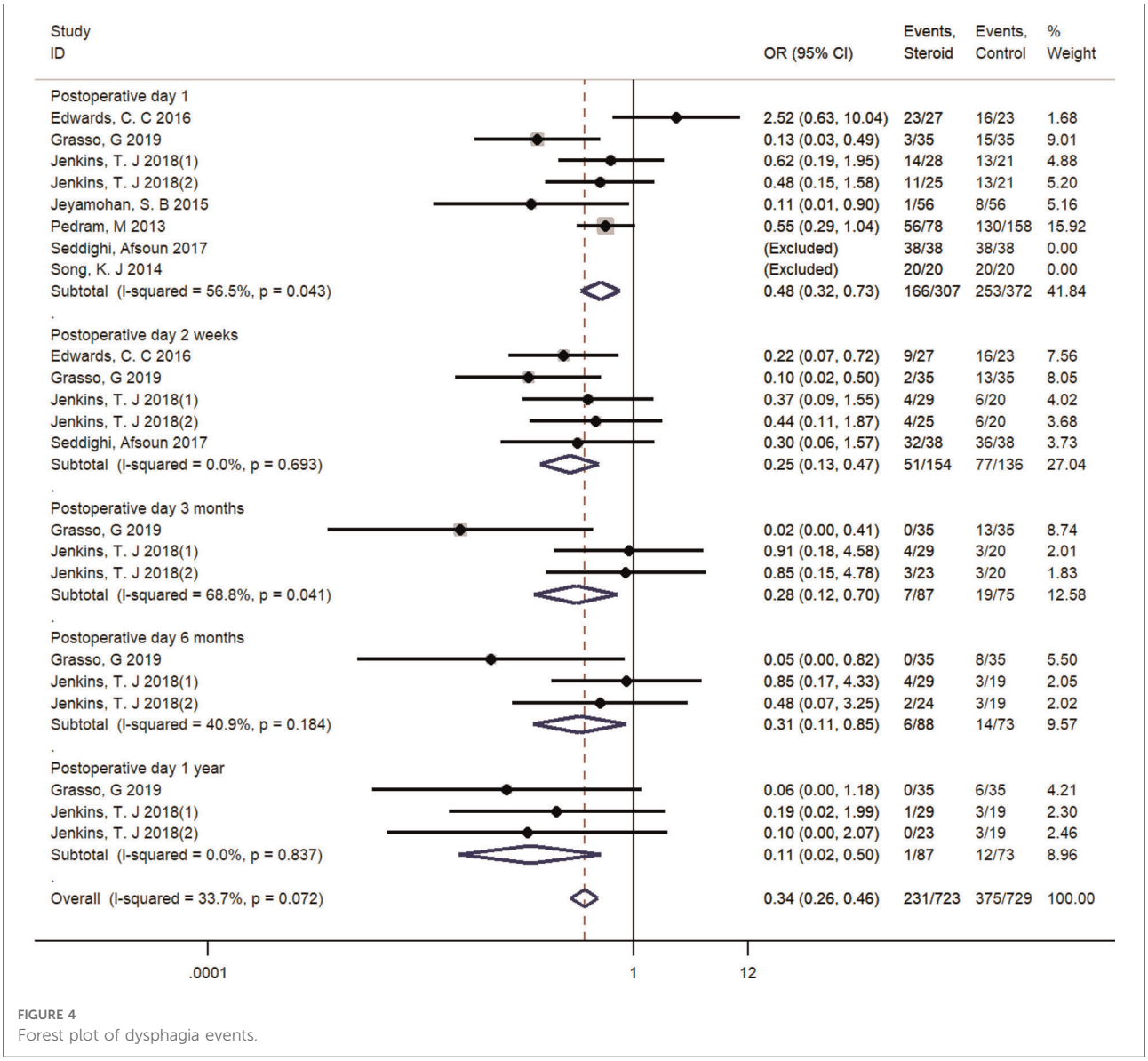

FIGURE 4
Forest plot of dysphagia events.

OR = 0.11, 95% CI: 0.02–0.63; 1 year, OR = 0.17, 95% CI: 0.04–0.84) (Figure 5).

The use of steroids for fusion rate at 1-year follow-up

Five studies reported numbers of fusion events at 1-year follow-up time and were included (18, 22, 23, 28, 29). There existed no significant difference between groups regarding fusion rate (OR = 0.87, 95% CI: 0.46–1.65), and no significant heterogeneity among these studies was found with a fixed-effect model ($I^2 = 0.0\%$, $p = 0.999$) (Figure 6).

The use of steroids for VAS from postoperative 1 day to 1 year

Six RCTs reported the detailed VAS score and were included (16, 18, 23, 25, 26, 28). A random-effect model was applied due to the high heterogeneity ($I^2 = 93.4\%$, $p < 0.001$). A significant decrease regarding VAS score in the steroid group was observed compared with that in the control group at both 1 day, 2 weeks after surgery (1 day, WMD = −1.49, 95% CI: −2.53 to −0.45; 2 weeks, WMD = −1.71, 95% CI: −2.46 to −0.97). However, Pooled analysis revealed no significant difference in the VAS score between two groups at both 6 months and 1 year after surgery (6 months, WMD = −1.03, 95% CI: −2.27 to 0.21; 1 year, WMD = −1.71, 95% CI: −3.51 to 0.08) (Figure 7).

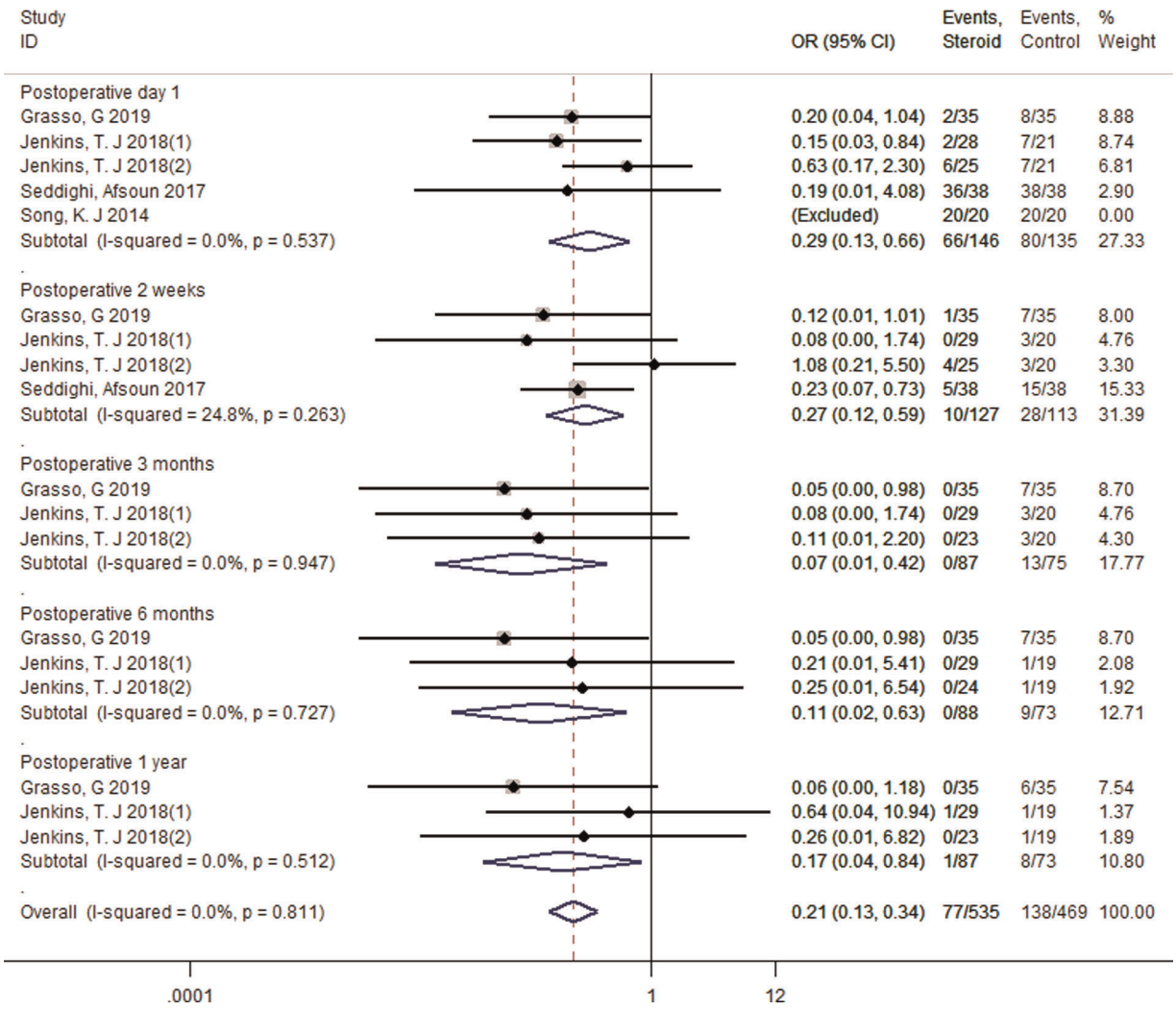

FIGURE 5
Forest plot of dysphagia events (moderate + severe) according to Bazaz stratification.

Operation time

Seven studies reported the detailed operation time and were included (16, 24, 25, 27, 30–32). There was significant heterogeneity between studies ($I^2 = 78.6\%$, $p < 0.01$), and a random-effect model was adopted. Pooled results demonstrated that there was no significant difference between groups in operating time (WMD = −2.15, 95% CI: −5.22 to 0.92) (**Figure 8**).

Length of hospital stay

Four studies reported the detailed length of hospital stay and were included (27, 30, 32, 33). A random-effect model was used because the heterogeneity across the three studies was high ($I^2 = 54.4\%$, $p = 0.087$). Pooled results demonstrated a significant reduction in the length of hospital stay compared with that in the control group (SMD = −0.42; 95% CI: −0.76 to −0.09) (**Figure 9**).

Subgroup analysis

We performed subgroup analyses by the route of administration (Local vs. Intravenous). Due to the limited number of included studies, we only have sufficient data exploring the effect of local and intravenous application of steroids on dysphagia rates at postoperative 1 day, VAS score at postoperative 1 day, fusion rate and operative time. There was no significant difference between intravenous and local steroid administration regarding dysphagia rates (Local: OR = 0.58, 95% CI: 0.12 to 2.88 vs. Intravenous: OR = 0.47, 95% CI: 0.26 to 0.84, $p = 0.82$, **Figure 10**), fusion rate (Local: OR = 0.88, 95% CI: 0.22 to 3.46 vs. Intravenous: OR = 0.87, 95% CI:

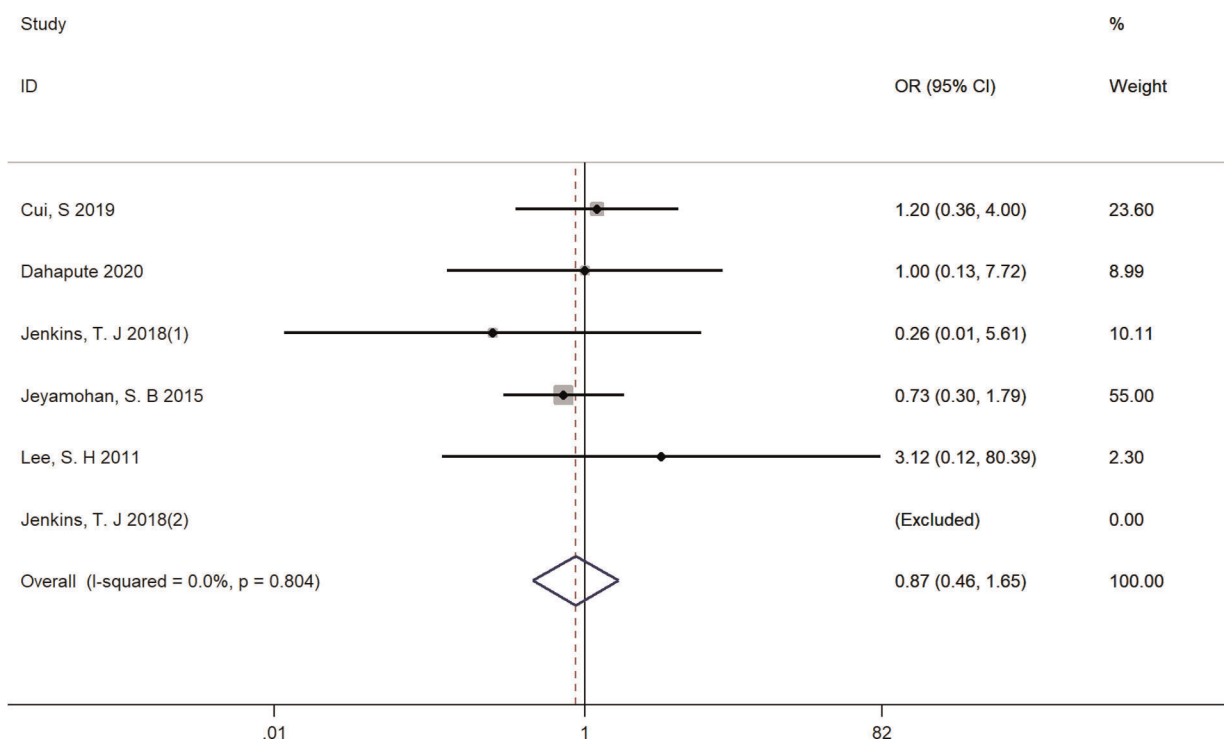

FIGURE 6
Forest plot of fusion rate at 1-year follow-up time.

0.43 to 1.79, $p = 1.00$, Figure 11), and operation time (Local: WMD = −3.55, 95% CI: −7.29 to 0.19 vs. Intravenous: WMD = 1.65, 95% CI: −3.35 to 6.65, $p = 0.10$, Figure 12). However, there existed a significant difference between intravenous and local steroid administration regarding VAS score at postoperative 1 day (Local: WMD = −2.22, 95% CI: −3.03 to −1.42 vs. Intravenous: WMD = −0.10, 95% CI: −0.46 to 0.25, $p < 0.001$, Figure 13).

Sensitivity analyses and publication bias

Through the sensitivity analyses, we found that excluding studies one by one did not significantly alter the effect of steroid intervention on evaluation indicators. We did not perform the funnel plot to illustrate the publication bias of the primary outcome because less than 10 articles were included in quantitative analysis of a single outcome.

Discussion

Anterior cervical surgery has been wildly accepted as the gold standard surgical treatment for patients with cervical disc disease who failed conservative measures (34, 35). Despite the satisfactory clinical outcomes of anterior cervical surgery, up to 79% of patients experienced postoperative dysphagia. Our meta-analysis of 14 RCTs showed that perioperative steroid use could reduce the incidence and severity of dysphagia within 1 year after ACDF, reduce VAS scores within 2 weeks after surgery, and shorten the length of hospital stay without increasing operating time, VAS scores at 6 months and 1 year, and affecting fusion rates.

The principal findings of the present meta-analysis were consistent with those of the previous meta-analysis. Song et al. (36) performed a meta-analysis of six RCTs and two case-control studies and concluded that retropharyngeal steroid use could reduce dysphagia rate, severe dysphagia rate following anterior cervical surgery, without increasing operating time. A meta-analysis of seven RCTs conducted by Garcia et al. (37) concluded that patients treated with corticosteroids intravenously or locally had significantly decreased severity of dysphagia. Yu et al. (38) performed a meta-analysis of 8 RCTs and concluded that perioperative local retropharyngeal steroids could reduce the incidence and severity of dysphagia compared with placebo control. Nevertheless, obvious differences between our meta-analysis and the meta-analysis mentioned above should be taken into account. Most importantly, we dynamically investigated the effect of steroids on dysphagia rate and its

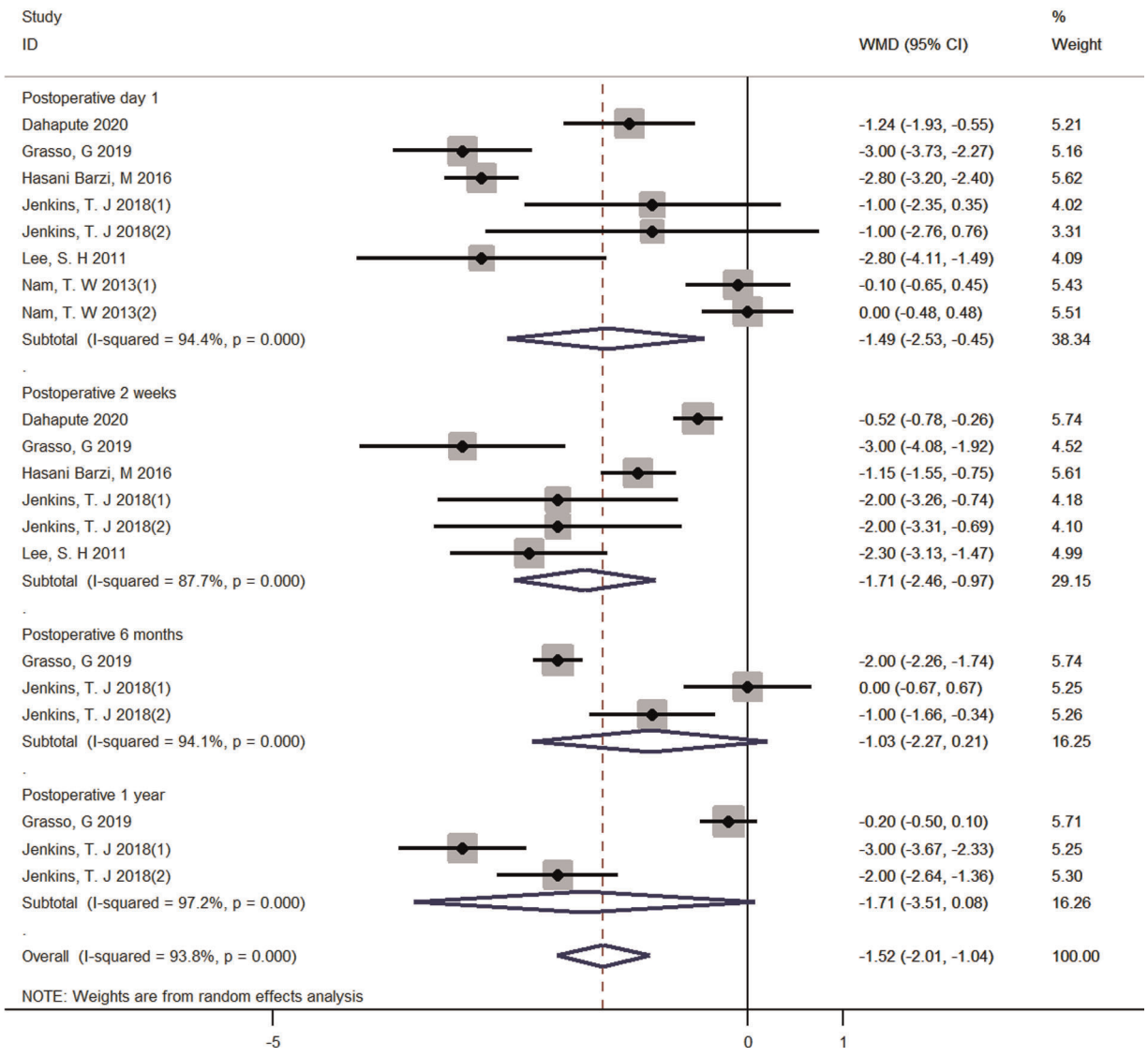

FIGURE 7
Forest plot of VAS score.

severity at 1 day, 2 weeks, 3 months, 6 months, and 1 year after anterior cervical surgery. The above studies may have included too few studies and ignored time as an influencing factor, often taking the last follow-up as the endpoint event. Second, we exhaustively searched various databases with a standardized and detailed search strategy and finally included 14 RCTs of 1,181 patients. The overall risk of bias of the included studies was determined to be low. Third, we performed a subgroup analysis to investigate the effects of intravenous and local steroids. The results showed that there was no significant difference between intravenous and local steroid administration regarding dysphagia rates ($p = 0.82$), fusion rate ($p = 1.00$), and operative time ($p = 0.10$). However, the above studies did not quantitatively compare the efficacy of topical or intravenous administration of the steroids.

From our analysis, the incidence and severity of dysphagia significantly decreased with steroids within 1 year following anterior cervical surgery. Previous reviews have consistently reported the benefit of steroids on dysphagia and its severity. Zadegan et al. (39) reviewed 7 RCTs and 2 non-RCTs, and concluded that the incidence and severity of dysphagia was significantly lower in the steroid group. Cheng et al. (40) reviewed 3 RCTs and 2 retrospective cohort studies, and concluded that local corticosteroid application could reduce the incidence and

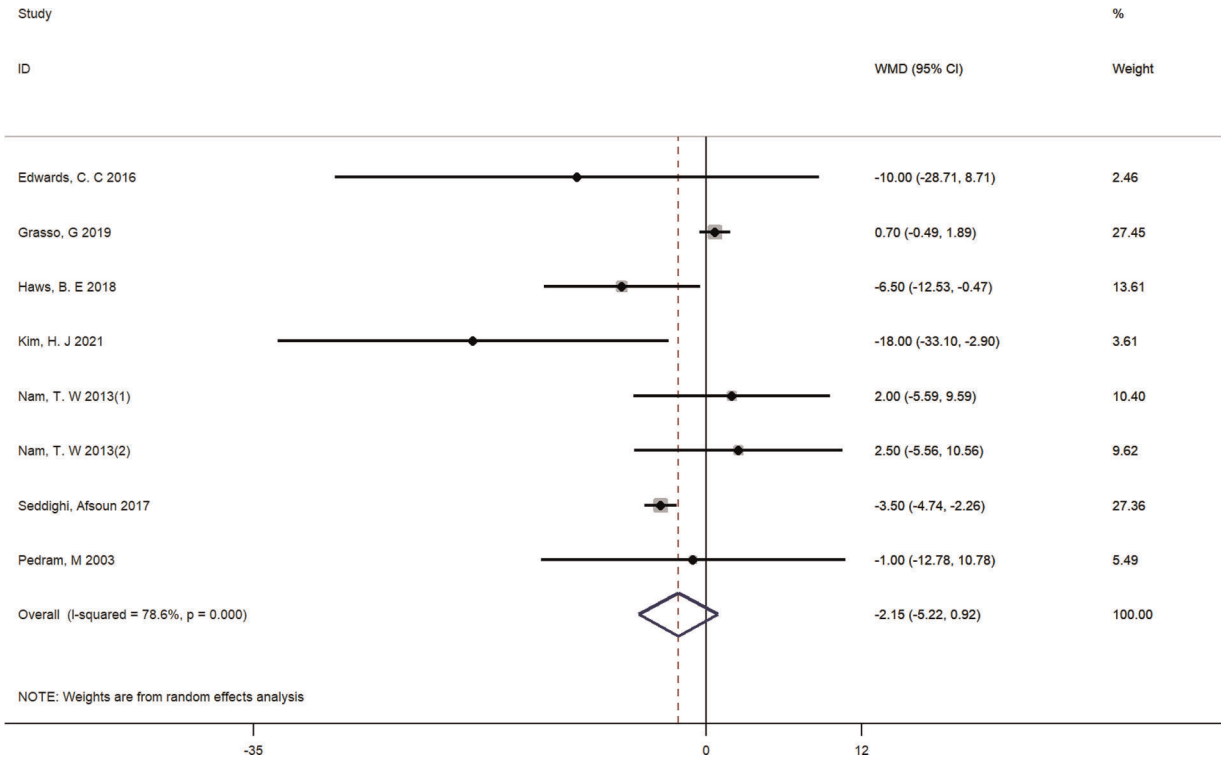

FIGURE 8
Forest plot of operation time.

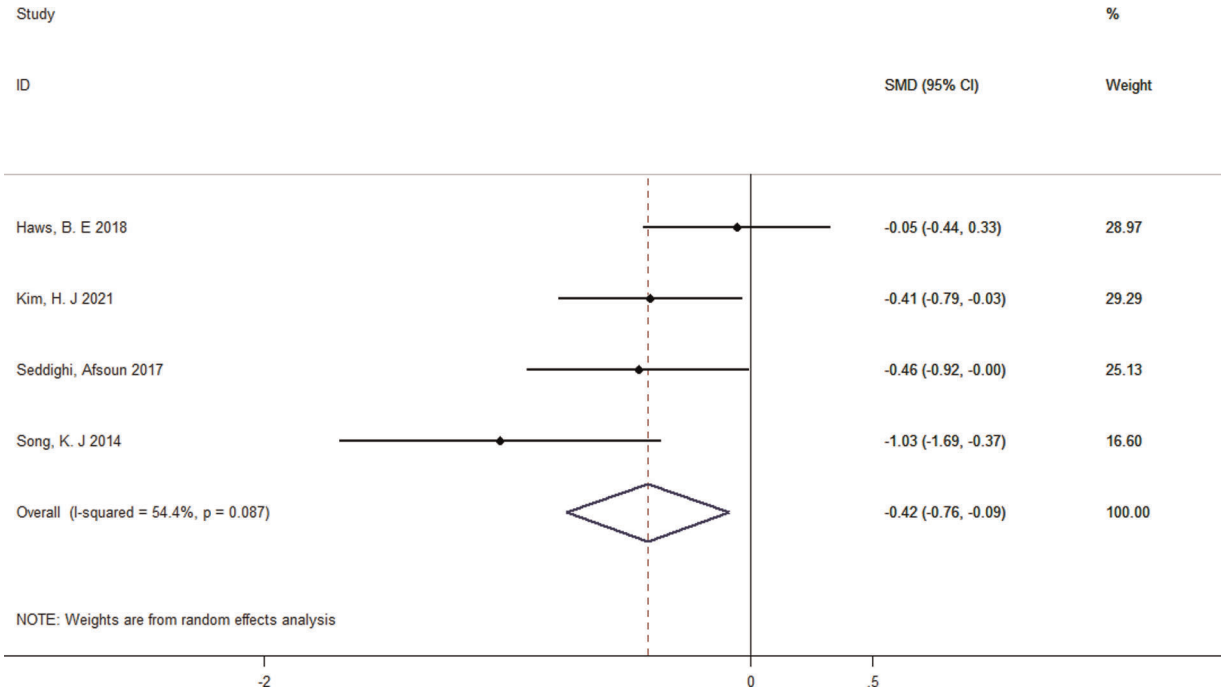

FIGURE 9
Forest plot of length of hospital stay.

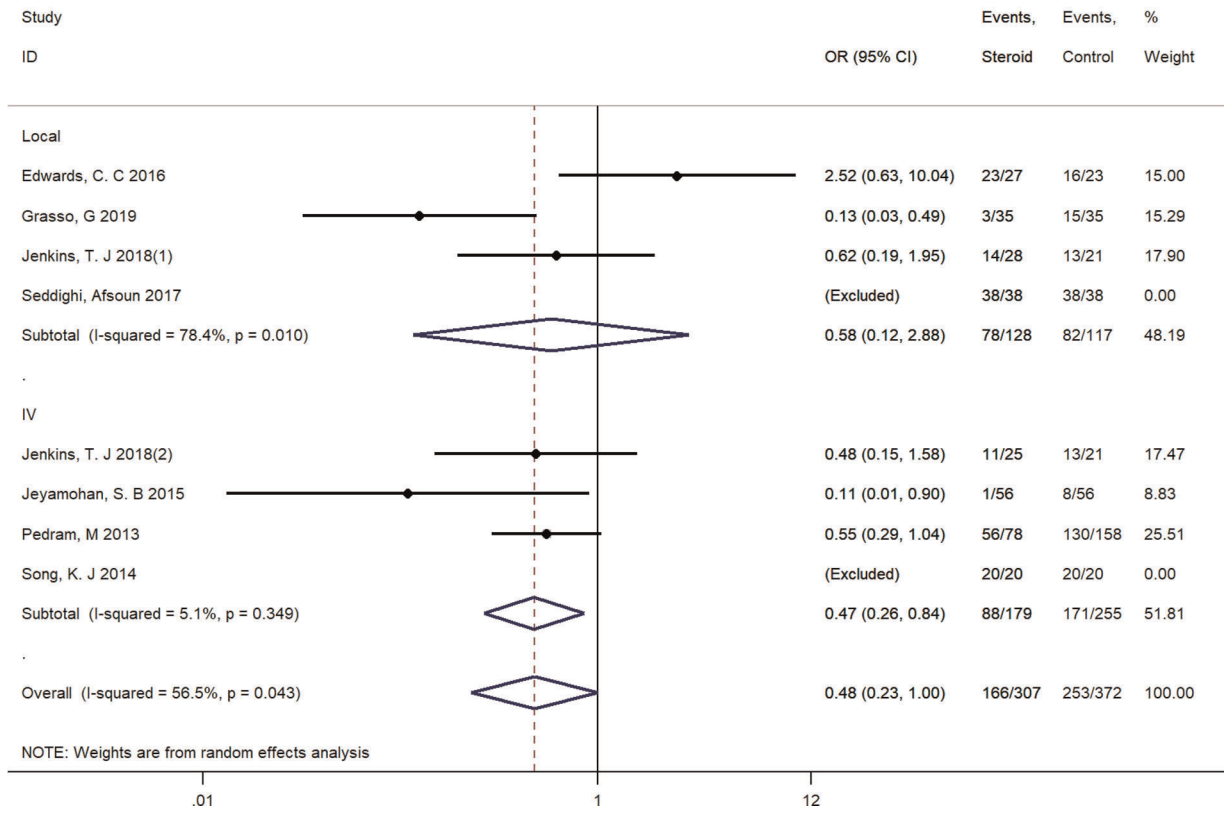

FIGURE 10
A subgroup analysis between intravenous and local steroid administration regarding dysphagia rates. IV, intravenous.

severity of dysphagia following ACDF. Adenikinju et al. (41) reviewed 5 RCTs and 2 retrospective cohort studies, and concluded that patients received systemic and local steroids benefit from reductions in rate and severity of dysphagia postoperatively. However, our finding is a novelty because we performed a qualitative synthesis of RCTs and discuss dysphagia without the differences in time points. In our subgroup analysis, we only have sufficient data exploring the effect of local and intravenous application of steroids on dysphagia rates at postoperative 1 day and found that there was no significant difference between intravenous and local steroid administration regarding dysphagia rates. This is consistent with the findings from 1 previous systematic review that Garcia et al. (37) performed a high-quality meta-analysis of 7 RCTs and found that there was no significant difference between intravenous and local steroid administration. Further high-quality RCTs are needed to directly compare the effect of local and intravenous application of steroids on dysphagia and its severity.

Many spine surgeons worry that steroids negatively impact bony fusion rates and are reluctant to use steroids. Our results demonstrated that there was no difference in fusion rates at 1-year follow-up between the steroids group and control group, which were consistent with those of prior studies of perioperative steroids (18, 22, 29, 39, 41). Nevertheless, the steroids may hinder early fusion. Jeyamohan et al. (29) reported that fusion rates at 6 months proved to decrease in the steroid group but lost significance at 12 months. In addition, it should be taken into account that the definition of fusion was not the same in these five included studies. Cui et al. (22) considered fusion to be achieved if radiographs demonstrated <1 mm of interspinous motion between flexion and extension or if CT or MRI demonstrated clear evidence of bone bridging from end plate to end plate. Dahapute et al. (23) and Jenkins et al. (28) used a CT scan to confirm fusion without giving a detailed definition of fusion. Jeyamohan et al. (29) considered the spine was fused if bridging osseous trabeculae were observed spanning each operative level without any intervening radiographic lucencies. Similarly, Lee et al. (18) considered that the presence of bony extension into the space between the graft and the absence of segmental motion supported the fusion. Future studies with large sample sizes, uniform standards and longer follow-up time for bony fusion are needed to validate our findings.

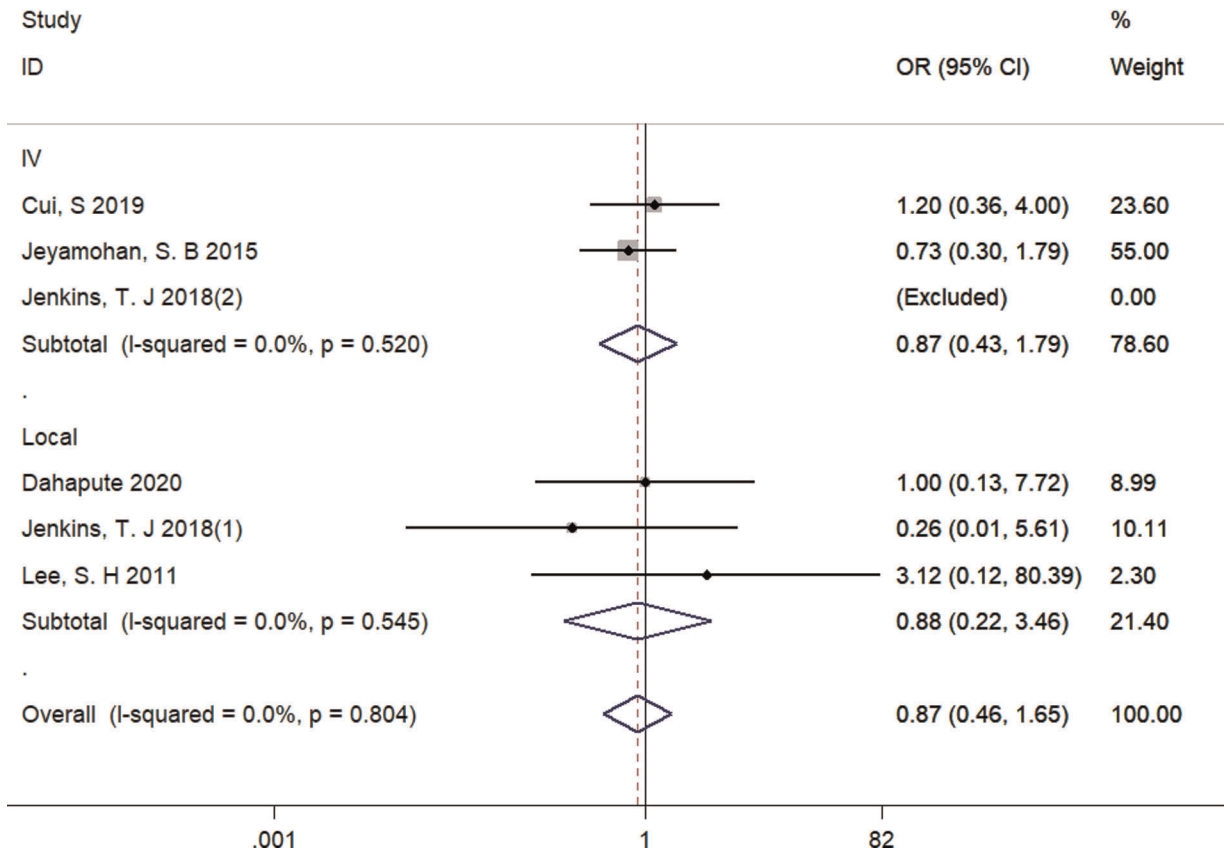

FIGURE 11
A subgroup analysis between intravenous and local steroid administration regarding fusion rates. IV, intravenous.

Our results showed that a significant decrease regarding VAS score in the steroid group was observed compared with that in the control group in the short-term follow up. Previous studies have demonstrated the benefits of steroid use regarding to direct feelings calculated by the VAS at postoperative 2 weeks (18, 23, 25, 26, 28). In our included RCTs, Dahapute et al. (23) found that VAS score at postoperative 1 day and 2 weeks proved to decrease in the steroid group but lost significance at 2 months. Jenkins found that there existed a significant difference between steroids and control group regarding VAS score at postoperative 1 day and 2 weeks but lost significance at 3 months. Both support the short-term of benefits of steroids on VAS score. Considering the heterogeneity of the results obtained by our quantitative calculation of VAS, it is unsafe to conclude that steroids can reduce VAS score with such a good effect, but it can be inferred that the steroids have a short-term effect in terms of VAS score after surgery. In our subgroup analysis, there existed a significant difference between intravenous and local steroid administration regarding VAS score at postoperative 1 day (Local: WMD = −2.22, 95% CI: −3.03 to −1.42 vs. Intravenous: WMD = −0.10, 95% CI: −0.46 to 0.25). However, in an RCT conducted by Jenkins et al. (28), their results showed that there was no significant difference between intravenous and local steroid administration regarding VAS score. Additionally, when removing the study of Nam et al. (16), the findings for VAS score were consistent with previous analysis. We should interprete the finding with caution and look forward more high-quality RCTs that directly compare the effect of local and intravenous application of steroids VAS score.

In our series, we found that patients receiving steroids had shorter length of hospital stay compared to the control groups. This is consistent with the findings of previous studies (13, 15, 29, 33). This may be explained by the improved symptoms of dysphagia incidence and severity in the steroid group. Next, we investigated the effect of steroids on operation time and the results showed there was no significant difference between groups in operating time, which indicated that steroids do not increase the risk of prolonged surgery. In the included 7 RCTs that reported the detailed operation time, only Kim et al. (30) reported fewer operation time in steroid group

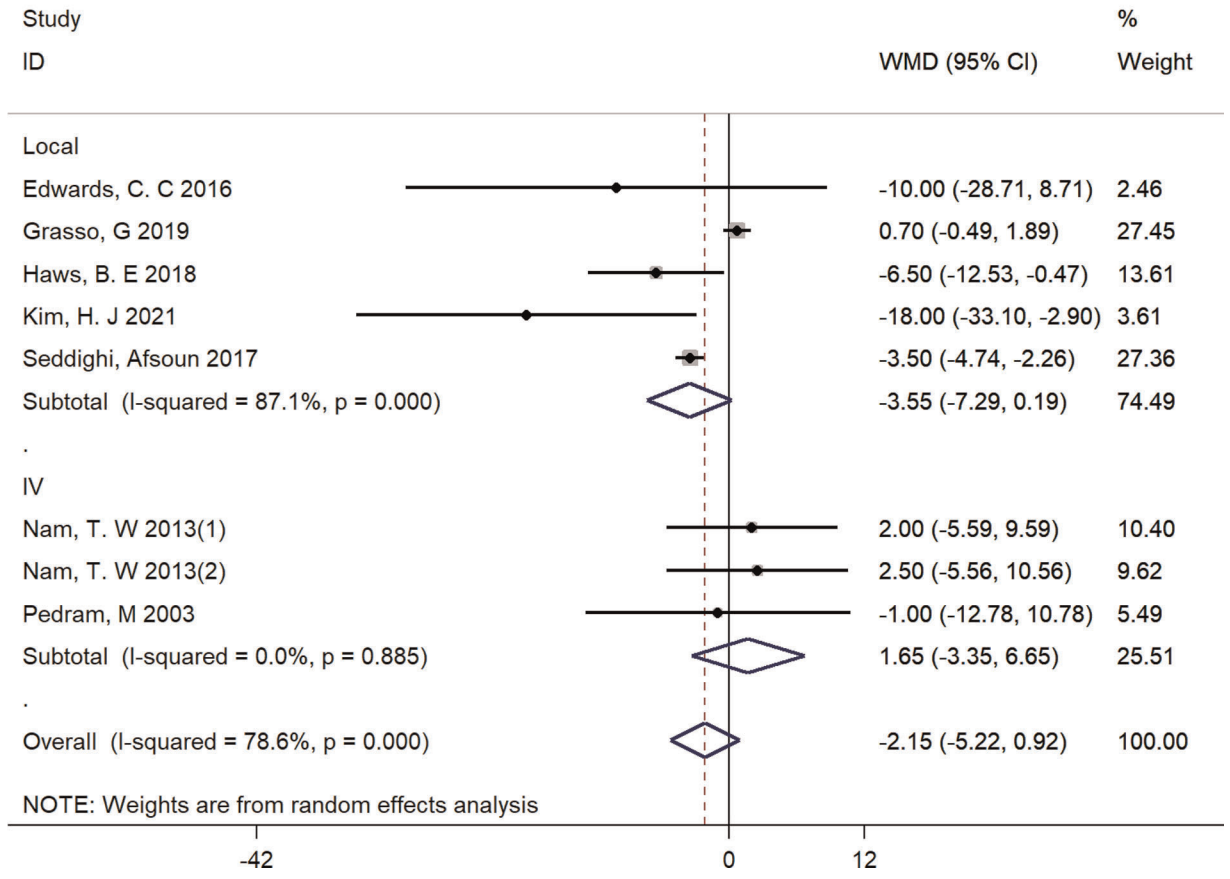

FIGURE 12
A subgroup analysis between intravenous and local steroid administration regarding operation time. IV, intravenous.

compared with control group. It is possible that the operation time in their study was about twice as long as in the other studies, amplifying the effect of steroids on operation time.

Major concerns regarding the use of steroids are steroid-related complications. Despite the reported increased infection rate related with steroid application in general (42, 43), the present meta-analysis showed that there was no significantly increased risk of infections with steroid use in any of the included studies. Esophageal perforation is one of the most dreadful complications of ACDF with an incidence of 0.02%–1.52% (44). Lee et al. (45) cautioned that esophageal perforation was a potential complication of local perioperative steroids in the late post-operative period of ACDF. However, this complication was not reported in any of the included studies. Actually, the two cases reported in the literature of esophageal perforation were both on chronic steroids, therefore, it is uncertain whether the esophageal perforation was directly associated with perioperative steroids. Taken together, steroids application does not increase the risk of early potential complications, but future studies are still necessary to evaluate the potential long-term complication associated with steroids administration.

The current meta-analysis observed some limitations. First, various doses and steroid types were adopted in the included studies, exact dose and type of steroid for desired effect on incidence and severity of dysphagia remains unclear. Though we performed a subgroup analysis by the route of administration (Local vs. Intravenous), it is still insufficient to account for a long-term effect of local and intravenous steroids on dysphagia. Second, even though we included 14 RCTs, only a few were used for quantitative analysis when comparing a specific outcome. This is due to differences in the way dysphagia was assessed and the variety of outcomes reported between studies. Finally, the number of fusion levels also varied across studies, exposing patients to different risks and potentially leading to different responses to interventions. In addition, the Grade results qualities of VAS were low, and dysphagia event, Bazaz stratification of severity of dysphagia, fusion rate, operation time and length of hospital stay were moderate. None of high quality evidence was found in above outcomes. Therefore, further high-quality studies are required

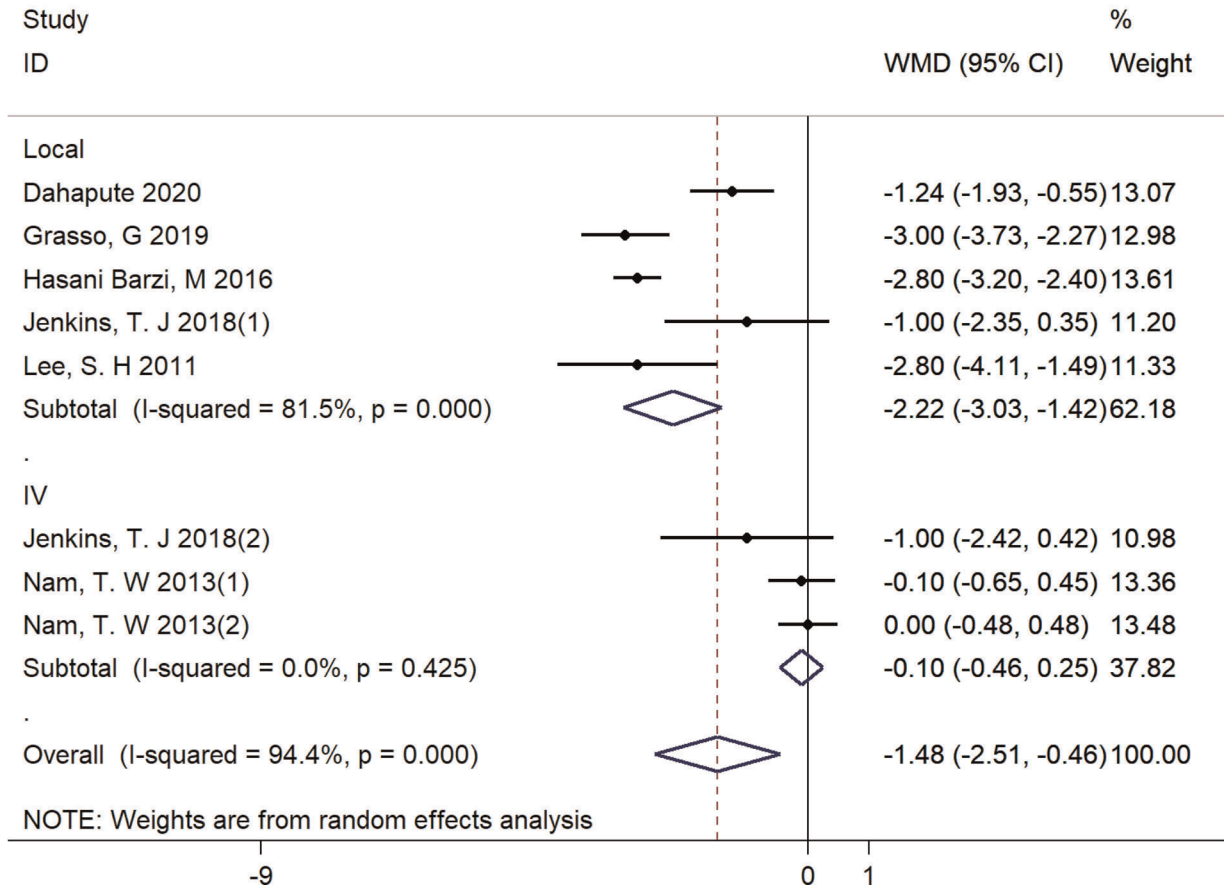

FIGURE 13
A subgroup analysis between intravenous and local steroid administration regarding VAS score at postoperative 1 day. IV, intravenous.

to determine which subpopulations are most likely to benefit or not, and more individualized treatment is needed.

Conclusion

The current meta-analysis demonstrates the benefits of perioperative steroid administration in anterior cervical surgery without increasing the risk of early potential complications. Future high-quality RCTs are warranted to recommend the administration of steroids in anterior cervical surgery.

Author contributions

XZ and HL: designed the study. XZ, YY and Y-WS: searched and screened relevant literature. K-RZ, and L-TM: data collection. XZ and YY: completed the first draft of the manuscript. All authors contributed to the article and approved the submitted version.

Funding

This work was supported by the National Natural Science Foundation of China (grant number 82172522) and the Chengdu Science and Technology Program (grant number 2021-YF05-00436-SN).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsurg.2022.1040166/full#supplementary-material.

References

1. Cloward RB. The anterior approach for removal of ruptured cervical disks. *J Neurosurg*. (1958) 15(6):602–17. doi: 10.3171/jns.1958.15.6.0602

2. Smith GW, Robinson RA. The treatment of certain cervical-spine disorders by anterior removal of the intervertebral disc and interbody fusion. *J Bone Joint Surg Am*. (1958) 40-a(3):607–24. doi: 10.2106/00004623-195840030-00009

3. Fountas KN, Kapsalaki EZ, Nikolakakos LG, Smisson HF, Johnston KW, Grigorian AA, et al. Anterior cervical discectomy and fusion associated complications. *Spine*. (2007) 32(21):2310–7. doi: 10.1097/BRS.0b013e318154c57e

4. Frempong-Boadu A, Houten JK, Osborn B, Opulencia J, Kells L, Guida DD, et al. Swallowing and speech dysfunction in patients undergoing anterior cervical discectomy and fusion: a prospective, objective preoperative and postoperative assessment. *J Spinal Disord Tech*. (2002) 15(5):362–8. doi: 10.1097/00024720-200210000-00004

5. Vaishnav AS, Saville P, McAnany S, Patel D, Haws B, Khechen B, et al. Predictive factors of postoperative dysphagia in single-level anterior cervical discectomy and fusion. *Spine*. (2019) 44(7):e400–7. doi: 10.1097/BRS.0000000000002865

6. Tasiou A, Giannis T, Brotis AG, Siasios I, Georgiadis I, Gatos H, et al. Anterior cervical spine surgery-associated complications in a retrospective case-control study. *J Spine Surg*. (2017) 3(3):444–59. doi: 10.21037/jss.2017.08.03

7. Starmer HM, Riley 3rd LH, Hillel AT, Akst LM, Best SR, Gourin CG. Dysphagia, short-term outcomes, and cost of care after anterior cervical disc surgery. *Dysphagia*. (2014) 29(1):68–77. doi: 10.1007/s00455-013-9482-9

8. Riley 3rd LH, Skolasky RL, Albert TJ, Vaccaro AR, Heller JG. Dysphagia after anterior cervical decompression and fusion: prevalence and risk factors from a longitudinal cohort study. *Spine*. (2005) 30(22):2564–9. doi: 10.1097/01.brs.0000186317.86379.02

9. Bazaz R, Lee MJ, Yoo JU. Incidence of dysphagia after anterior cervical spine surgery: a prospective study. *Spine*. (2002) 27(22):2453–8. doi: 10.1097/00007632-200211150-00007

10. Ratnaraj J, Todorov A, McHugh T, Cheng MA, Lauryssen C. Effects of decreasing endotracheal tube cuff pressures during neck retraction for anterior cervical spine surgery. *J Neurosurg*. (2002) 97(2 Suppl):176–9. doi: 10.3171/spi.2002.97.2.0176

11. Chin KR, Eiszner JR, Adams Jr SB. Role of plate thickness as a cause of dysphagia after anterior cervical fusion. *Spine*. (2007) 32(23):2585–90. doi: 10.1097/BRS.0b013e318158dec8

12. Gandhi SD, Wahlmeier ST, Louie P, Sauber R, Tooley TR, Baker KC, et al. Effect of local retropharyngeal steroids on fusion rate after anterior cervical discectomy and fusion. *Spine J*. (2020) 20(2):261–5. doi: 10.1016/j.spinee.2019.08.018

13. Koreckij TD, Davidson AA, Baker KC, Park DK. Retropharyngeal steroids and dysphagia following multilevel anterior cervical surgery. *Spine*. (2016) 41(9):E530–534. doi: 10.1097/BRS.0000000000001293

14. Schroeder J, Weinstein J, Salzmann SN, Kueper J, Shue J, Sama AA, et al. Effect of steroid-soaked gelatin sponge on soft tissue swelling following anterior cervical discectomy and fusion: a radiographic analysis. *Asian Spine J*. (2018) 12(4):656–61. doi: 10.31616/asj.2018.12.4.656

15. Cancienne JM, Werner BC, Loeb AE, Yang SS, Hassanzadeh H, Singla A, et al. The effect of local intraoperative steroid administration on the rate of postoperative dysphagia following ACDF: a study of 245,754 patients. *Spine*. (2016) 41(13):1084–8. doi: 10.1097/BRS.0000000000001407

16. Nam TW, Lee DH, Shin JK, Goh TS, Lee JS. Effect of intravenous dexamethasone on prevertebral soft tissue swelling after anterior cervical discectomy and fusion. *Acta Orthop Belg*. (2013) 79(2):211–5.

17. van Eck CF, Regan C, Donaldson WF, Kang JD, Lee JY. The revision rate and occurrence of adjacent segment disease after anterior cervical discectomy and fusion: a study of 672 consecutive patients. *Spine*. (2014) 39(26):2143–7. doi: 10.1097/BRS.0000000000000636

18. Lee SH, Kim KT, Suk KS, Park KJ, Oh KI. Effect of retropharyngeal steroid on prevertebral soft tissue swelling following anterior cervical discectomy and fusion: a prospective, randomized study. *Spine*. (2011) 36(26):2286–92. doi: 10.1097/BRS.0b013e318237e5d0

19. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JP, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. *Br Med J*. (2009) 339:b2700. doi: 10.1136/bmj.b2700

20. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, et al. *Cochrane handbook for systematic reviews of interventions version 6.3*. (2022). *Cochrane*. (2022). Available at: www.training.cochrane.org/handbook.

21. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *Br Med J*. (2003) 327(7414):557–60. doi: 10.1136/bmj.327.7414.557

22. Cui S, Daffner SD, France JC, Emery SE. The effects of perioperative corticosteroids on dysphagia following surgical procedures involving the anterior cervical spine: a prospective, randomized, controlled, double-blinded clinical trial. *J Bone Joint Surg Am*. (2019) 101(22):2007–14. doi: 10.2106/JBJS.19.00198

23. Dahapute A, Sonone S, Bhaladhare S, Sakhare K, Marathe N, Balasubramanian SG, et al. Prospective randomized controlled trial to study the effect of local steroids in the retropharyngeal space after anterior cervical discectomy and fusion. *Global Spine J*. (2021) 11(6):826–32. doi: 10.1177/2192568220925782

24. Edwards CC, Dean C, Phillips D, Blight A. Can dysphagia following anterior cervical fusions with rhBMP-2 be reduced with local depomedrol application? A prospective, randomized, placebo-controlled, double-blind trial. *Spine*. (2016) 41(7):555–62. doi: 10.1097/BRS.0000000000001284

25. Grasso G, Leone L, Torregrossa F. Dysphagia prevention in anterior cervical discectomy surgery: results from a prospective clinical study. *World Neurosurg*. (2019) 125:e1176–82. doi: 10.1016/j.wneu.2019.01.273

26. Hasani BM, Nikoobakht M, Hasani BN, Khanali F, Yazdi Z. The effect of local steroid injection on prevertebral soft tissue swelling after anterior cervical discectomy and fusion. *J Babol Univ Medical Sci*. (2016) 18(10):7–12.

27. Haws BE, Khechen B, Narain AS, Hijji FY, Bohl DD, Massel DH, et al. Impact of local steroid application on dysphagia following an anterior cervical discectomy and fusion: results of a prospective, randomized single-blind trial. *J Neurosurg Spine*. (2018) 29(1):10–7. doi: 10.3171/2017.11.SPINE17819

28. Jenkins TJ, Nair R, Bhatt S, Rosenthal BD, Savage JW, Hsu WK, et al. The effect of local versus intravenous corticosteroids on the likelihood of dysphagia and dysphonia following anterior cervical discectomy and fusion: a single-blinded, prospective, randomized controlled trial. *J Bone Joint Surg Am*. (2018) 100(17):1461–72. doi: 10.2106/JBJS.17.01540

29. Jeyamohan SB, Kenning TJ, Petronis KA, Feustel PJ, Drazin D, DiRisio DJ. Effect of steroid use in anterior cervical discectomy and fusion: a randomized controlled trial. *J Neurosurg Spine*. (2015) 23(2):137–43. doi: 10.3171/2014.12.SPINE14477

30. Kim HJ, Alluri R, Stein D, Lebl D, Huang RS, Lafage R, et al. Effect of topical steroid on swallowing following ACDF results of a prospective double-blind randomized control trial. *Spine*. (2021) 46(7):413–20. doi: 10.1097/BRS.0000000000003825

31. Pedram M, Castagnera L, Carat X, Macouillard G, Vital JM. Pharyngolaryngeal lesions in patients undergoing cervical spine surgery through the anterior approach: contribution of methylprednisolone. *Eur Spine J*. (2003) 12(1):84–90. doi: 10.1007/s00586-002-0495-6

32. Seddighi A, Nikouei A, Seddighi AS, Arjmand Y. Effect of local steroid injection on prevertebral soft tissue swelling following anterior cervical discectomy and fusion. *Int Clin Neurosci J*. (2017) 4(3):84–90. doi: 10.22037/icnj.v4i3.18461

33. Song KJ, Lee SK, Ko JH, Yoo MJ, Kim DY, Lee KB. The clinical efficacy of short-term steroid treatment in multilevel anterior cervical arthrodesis. *Spine J*. (2014) 14(12):2954–8. doi: 10.1016/j.spinee.2014.06.005

34. Bohlman HH, Emery SE, Goodfellow DB, Jones PK. Robinson anterior cervical discectomy and arthrodesis for cervical radiculopathy. Long-term follow-up of one hundred and twenty-two patients. *J Bone Joint Surg Am*. (1993) 75(9):1298–307. doi: 10.2106/00004623-199309000-00005

35. Emery SE, Bohlman HH, Bolesta MJ, Jones PK. Anterior cervical decompression and arthrodesis for the treatment of cervical spondylotic myelopathy. Two to seventeen-year follow-up. *J Bone Joint Surg Am*. (1998) 80 (7):941–51. doi: 10.2106/00004623-199807000-00002

36. Song J, Yi P, Wang Y, Gong L, Sun Y, Yang F, et al. The retropharyngeal steroid use during operation on the fusion rate and dysphagia after ACDF? A systematic review and meta-analysis. *Eur Spine J*. (2022) 31(2):288–300. doi: 10.1007/s00586-021-06727-1

37. Garcia S, Schaffer NE, Wallace N, Butt BB, Gagnier J, Aleem IS. Perioperative corticosteroids reduce dysphagia severity following anterior cervical spinal fusion: a meta-analysis of randomized controlled trials. *J Bone Joint Surg Am*. (2021) 103(9):821–8. doi: 10.2106/JBJS.20.01756

38. Yu H, Dong H, Ruan B, Xu X, Wang Y. Intraoperative use of topical retropharyngeal steroids for dysphagia after anterior cervical fusion: a systematic review and meta-analysis. *Dis Markers*. (2021) 2021:7115254. doi: 10.1155/2021/7115254

39. Zadegan SA, Jazayeri SB, Abedi A, Bonaki HN, Vaccaro AR, Rahimi-Movaghar V. Corticosteroid administration to prevent complications of anterior cervical spine fusion: a systematic review. *Global Spine J*. (2018) 8(3):286–302. doi: 10.1177/2192568217708776

40. Cheng L, Guan J, Zhang C, Ma L, Yao Q, Wang K, et al. The effect of local intraoperative corticosteroid application on postoperative dysphagia following anterior cervical spine surgery. *Neurosurg Rev*. (2022) 45(1):63–70. doi: 10.1007/s10143-019-01207-z

41. Adenikinju AS, Halani SH, Rindler RS, Gary MF, Michael KW, AhmadFU. Effect of perioperative steroids on dysphagia after anterior cervical spine surgery: a systematic review. *Int J Spine Surg*. (2017) 11(2):9. doi: 10.14444/4009

42. Anstead GM. Steroids, retinoids, and wound healing. *Adv Wound Care*. (1998) 11(6):277–85.

43. Scanzello CR, Figgie MP, Nestor BJ, Goodman SM. Perioperative management of medications used in the treatment of rheumatoid arthritis. *HSS J*. (2006) 2(2):141–7. doi: 10.1007/s11420-006-9012-5

44. Halani SH, Baum GR, Riley JP, Pradilla G, Refai D, Rodts Jr GE, et al. Esophageal perforation after anterior cervical spine surgery: a systematic review of the literature. *J Neurosurg Spine*. (2016) 25(3):285–91. doi: 10.3171/2016.1.SPINE15898

45. Lee SH, Mesfin A, Riew KD. Delayed esophageal perforation after anterior cervical fusion and retropharyngeal steroid use: a report of two cases. *Spine J*. (2015) 15(10):e75–80. doi: 10.1016/j.spinee.2015.06.058

frontiers | Frontiers in Surgery

TYPE Original Research
PUBLISHED 09 November 2022
DOI 10.3389/fsurg.2022.1049020

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

RECEIVED 20 September 2022
ACCEPTED 18 October 2022
PUBLISHED 09 November 2022

CITATION
Sun W, Li Y, Chen X, Wang B, Kong C, Wang P and Lu S (2022) Roussouly type 2 could evolve into type 1 shape as sagittal spinal alignment deterioration progresses with age.
Front. Surg. 9:1049020.
doi: 10.3389/fsurg.2022.1049020

Roussouly type 2 could evolve into type 1 shape as sagittal spinal alignment deterioration progresses with age

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Study design: Cross-sectional study.
Objective: To identify whether Roussouly type 2 could evolve into type 1 as the deterioration progresses.
Methods: The study group comprised subjects with a low pelvic incidence (PI). All subjects underwent a standing whole spinal radiograph and sagittal parameters were measured: T1 pelvic angle (TPA), lumbar lordosis (LL), PI, pelvic tilt (PT), L4–S1 angle, thoracolumbar kyphosis (TLK), thoracic kyphosis (TK), lumbar sagittal apex (LSA), lordosis distribution index (LDI) and number of vertebrae included in the lordosis (NVL). All subjects were distributed into two groups; with primary (*de novo*) degenerative scoliosis (PDS) and without PDS. Subjects without PDS were divided into young adult, adult, middle-aged and elderly groups. The differences in sagittal parameters of each subgroup were compared.
Results: In total, 270 subjects were included with a mean age of 58.6 years (range 20–87 years). There was a stepwise increase in the proportion of type 1 with age, whereas type 2 decreased. The TPA, PT, PI-LL, TK, TLK and LDI increased with age in subjects without PDS. The TPA, LDI, TLK and TK increased with age in subjects who displayed type 1, whereas the PT, LL, L4–S1 and PI-LL were unchanged. The TPA, PT, PI-LL and TLK increased with age in subjects who displayed type 2, whereas LL and L4-S1 were decreased, while the LDI and TK remained unchanged. The LSA of subjects without PDS became lower and the NVL decreased with age, with similar phenomena found in the subjects with type 2. There was no statistical difference among the groups for the LSA or NVL distribution of subjects with type 1. The TPA, PT and PI-LL of subjects with PDS were greater than those in Group IV, while the SS, LL and TK were less. The Roussouly-type, NVL and LSA distribution were identical between these two groups.
Conclusion: Roussouly type 1 shape may not be an actual individual specific spine type. Rather, type 2 could evolve into the "type 1" shape as deterioration of the sagittal spinal alignment progresses with age. Primary (*de novo*) degenerative scoliosis had little effect on whether type 2 became type 1. This should be taken into consideration during the assessment and restoration of sagittal balance.

KEYWORDS

cross-sectional study roussouly classification, sagittal alignment, elderly, degenerative, scoliosis

Introduction

Sagittal balance of the spine is a recent and ever more common viewpoint for understanding and treating spinal pathologies (1). In 2005, Roussouly et al. presented a classification based on the spinal shapes in the normal population (2). In the Roussouly classification, four classical types of spinal alignments were described depending on the sacral slope (SS) and the shape of lumbar lordosis (LL). However, degenerative spinal disease that affects the lumbar spine decreases LL (3), and this change modifies the SS due to the need for pelvic compensation to maintain the sagittal balance (4). Therefore, the basic criterion used to classify the sagittal profile of these patients (the SS) has been substituted by the pelvic incidence (PI), which is considered to be a constant parameter through adulthood independently of pelvic compensation (5–7).

Subjects with a low PI can present with either type 1 or 2 (2, 6, 8). Type 1 appears as a long thoracolumbar kyphosis (TLK) and a short lumbar lordotic curve; the lumbar spine of type 2 has a flat back appearance (2). There are also some factors that aid in determining the sagittal shape, including the lumbar sagittal apex (LSA), the number of vertebrae included in the lordosis (NVL) and the level of the inflexion point (IP) that dictates the transition between thoracic kyphosis (TK) and LL (1, 2, 4).

Life is a kyphosing event. Compensation potential depends greatly on the PI; low PI types have little compensation potential, whereas high PI types have greater potential, with type 4 having the greatest potential for compensation (8). When the kyphosing event affects the thoracolumbar area or the lumbar area, either LL increases on a small arch, generating a type 1 spine, or lumbar spine lordosis resolves, generating the "lumbar kyphosis" type (if the thoracic spine could compensate with a hypokyphosis) or "global kyphosis type" (8) (**Figure 1**). Roussouly et al. (8) hypothesized that type 1 could be a degenerative evolution of type 2. Therefore, the type 1 shape may not be an actual individual specific spine type. Nevertheless, this theory has to date not been supported by any radiological measurement study. In the current study, we aimed to examine the radiological characteristics of the Roussouly types with a PI $\leq 50°$ to identify whether type 2 could evolve into type 1 with the progress of deterioration.

Materials and methods

Study design

This cross-sectional study was approved by the relevant institutional Ethics Committee. We informed all the subjects

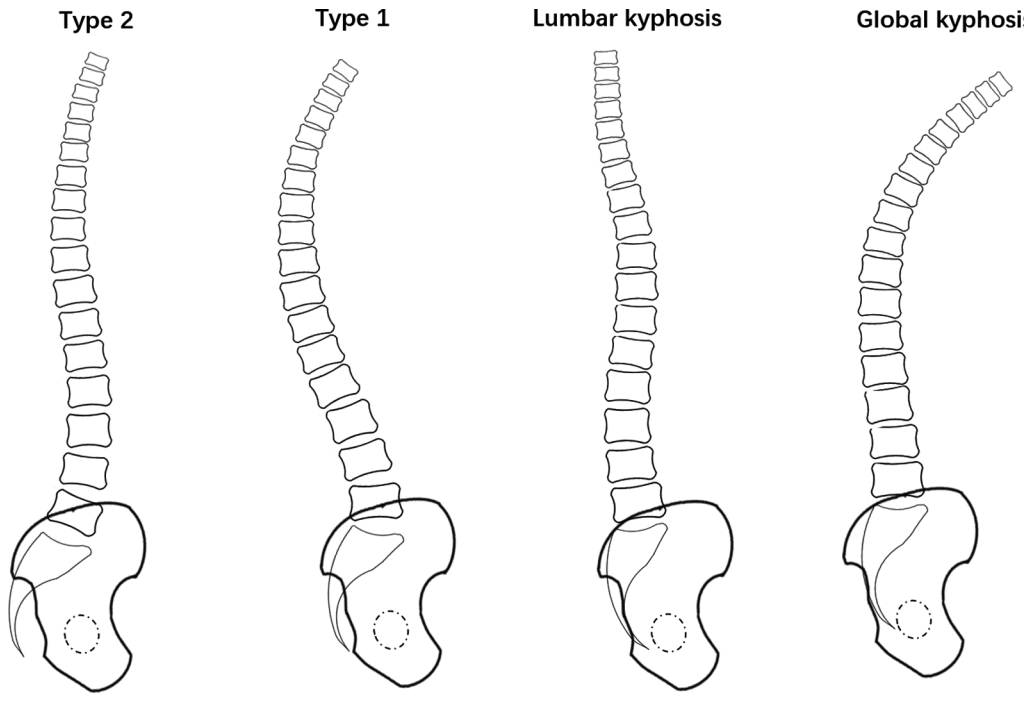

FIGURE 1
Drawing showing the possible evolution of type 2 shape. When the kyphosing event affects the thoracolumbar area or the lumbar area, either LL increases on a small arch, generating a type 1 spine, or lumbar spine lordosis resolves, generating the "lumbar kyphosis" type (if the thoracic spine could compensate with a hypokyphosis) or "global kyphosis type".

about the purposes, methods and risks of the study, and subsequently they provided written informed consent before their enrollment.

Subject recruitment

On the basis of the following inclusion and exclusion criteria, 270 subjects were recruited in the present study: Inclusion criteria included: (1) age ≥20 years, (2) PI ≤ 50°. Exclusion criteria were: (1) subjects who had already undergone spinal surgery; (2) history of trauma, tumor or infection of the spine; (3) lumbosacral transitional vertebrae; (4) neuromuscular disease; (5) acute pain or any other condition that may affect the accurate measurement of radiological parameters; (6) subjects with scoliosis except primary (*de novo*) degenerative scoliosis (PDS); (7) subjects with lumbar kyphosis or global spine kyphosis.

Radiographic measurements

All the subjects underwent full-length lateral and antero-posterior x-rays, including of their hip joints. All radiographs were analyzed using validated software (Surgimap, Nemaris Inc., New York, NY).

The following spinal and pelvic radiographic parameters were measured: Pelvic parameters consisted of the PI, pelvic tilt (PT) and SS. Spinal parameters included LL (Cobb angle between the superior endplate of L1 and S1), L4–S1 angle Cobb angle between the upper endplate of L4 and the sacral endplate), TLK (Cobb angle between the superior endplate of T10 and the inferior endplate of L2), TK (Cobb angle between the superior endplate of T5 and the inferior endplate of T12), NVL, LSA and IP. With LL and the L4–S1 angle, the percentage L4–S1 contribution to the total lordosis was calculated and termed the lordosis distribution index (LDI) (9). Lumbar mismatch was calculated as the PI-LL. Global sagittal balance was evaluated using the T1 pelvic angle (TPA, the angle formed by the line from the center of T1 to the femoral head axis and the line from the center of the sacral endplate to the femoral head axis (10)).

Coronal parameters were also assessed: thoracolumbar coronal (TLC) Cobb angle, lumbar-sacrum coronal (LSC) Cobb angle and the apical vertebra rotation (AVR) of the thoracolumbar curve. The Nash–Moe classification (Grades 0–IV; the higher the grade, the more severe the vertebral rotation degree) was determined, which reflected the degree of vertebral rotation (11).

The classical type 1 was defined by a long TLK, a short lumbar lordotic curve and a PI ≤ 50°; classical type 2 was defined by a long and flat lordosis and a PI ≤ 50° (2, 12). Two independent examiners (B.B.W and Y.J.L) determined the classification twice, with an interval of 1 week. Disagreements were resolved through discussion until a consensus opinion was reached. The ideal LSA of type 2 was L4/5 and the ideal LSA of type 1 was L5 (12). For statistical weight, the LSA were defined: 1 for "LSA above L4/5″, 2 for "LSA located at L4/5″ and 3 for "LSA below L4/5″.

Statistical analysis

All the data were collected in Microsoft Excel 2019, and statistical analysis was performed using the SPSS 21.0 software (SPSS Inc., Chicago, IL, United States). The variables were described as the mean and standard deviation. Chi-square test, Fisher exact probability test and one-way analysis of variance were applied to examine the degenerative changes of the sagittal alignment in subjects among different groups. Parameters between subjects with PDS and those without PDS in Group IV were compared using the student t test and chi-square test. The Pearson correlation coefficient was used to analyze the relationships between the variations. The significance threshold was set at 5% ($P < 0.05$).

Results

Demographics

A total of 270 subjects (154 females and 116 males), with a mean age of 58.6 years ranging from 20 to 87 years, met the inclusion criteria and were included in the final analysis.

The subjects were distributed into two groups; those with PDS and those without PDS. Those without PDS were in turn distributed into four age groups; Group I ($N = 35$) were young adults (aged 20–35 years), Group II ($N = 41$) were adults (aged 36–50 years), Group III ($N = 78$) were middle-aged (aged 51–65 years) and Group IV ($N = 71$) were elderly patients (aged >65 years). Subjects with PDS ($N = 45$) included 15 males and 30 females with a mean age of 71.9 years (range 66–87 years). Group I included 17 males and 18 females with a mean age of 28.8 years. Group II included 16 males and 25 females with a mean age of 42.8 years. Group III included 35 males and 43 females with a mean age of 60.2 years. Group IV included 33 males and 38 females with a mean age of 73.0 years.

Change in spinal alignment in subjects without PDS

The demographics and radiological parameters among Groups I, II, III and IV are compared in **Table 1**. Among the four groups, there was a stepwise increase in the age, TPA,

TABLE 1 Sagittal alignment in subjects without PDS.

Parameters	Group I	Group II	Group III	Group IV	*P* value
N	35	41	78	71	
Age (years)	28.8 ± 4.3	42.8 ± 4.7	60.2 ± 3.7	73.0 ± 5.5	0.000**
Sex (M: F)	17:18	16:25	35:43	33:38	0.841
TPA (°)	4.2 ± 4.6	4.4 ± 5.0	10.0 ± 6.1	12.3 ± 7.0	0.000**
PI (°)	40.4 ± 5.1	40.2 ± 6.0	41.2 ± 6.2	40.5 ± 6.4	0.834
PT (°)	7.4 ± 5.4	9.3 ± 5.8	12.9 ± 6.5	15.4 ± 7.7	0.000**
SS (°)	32.7 ± 6.7	30.3 ± 7.3	27.6 ± 8.8	24.5 ± 7.9	0.000**
LL (°)	45.9 ± 9.8	42.1 ± 11.7	36.6 ± 15.9	36.1 ± 11.7	0.000**
PI-LL (°)	−5.5 ± 8.6	−1.9 ± 10.0	4.6 ± 13.3	4.8 ± 13.0	0.000**
L4-S1 (°)	31.7 ± 7.7	30.5 ± 7.3	30.8 ± 11.6	30.4 ± 10.3	0.926
LDI	0.7 ± 0.2	0.7 ± 0.2	1.2 ± 1.7	1.7 ± 4.4	0.037*
TLK (°)	6.3 ± 8.0	8.0 ± 8.4	14.1 ± 10.9	17.8 ± 13.1	0.000**
TK (°)	21.6 ± 12.6	22.1 ± 14.9	26.1 ± 13.3	31.9 ± 15.6	0.000**

PDS, primary degenerative scoliosis; TPA, T1 pelvic angle; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis; PI-LL, pelvic incidence minus lumbar lordosis; LDI, lordosis distribution index; TLK, thoracolumbar kyphosis; TK, thoracic kyphosis.
**Indicates $P < 0.01$.
*Indicates $P < 0.05$.

PT, PI-LL, TK and TLK with increasing grade (all $P < 0.001$). There was also a stepwise increase in the LDI among the groups ($P < 0.05$). The PI and sex distribution were identical among the four groups (all $P > 0.05$).

In Group I, all subjects were Roussouly type 2. In Group II, 14.6% of the subjects were type 1, while 85.4% were type 2. In Group III, 28.2% of the subjects were type 1, while 71.8% were type 2. In Group IV, 45.1% and 54.9% of the subjects were type 1 and type 2, respectively. The proportion of type 1 subjects increased with age among the groups ($P < 0.001$) (Figure 2A). In Group I, the number of subjects with the LSA above L4/5 was 25 and for 10 it was located at L4/5, whereas none had the LSA below L4/5. In Group IV, 23 subjects had the LSA above L4/5, for 16 the LSA was located at L4/5 and for 32 the LSA was below L4/5. The LSA tended to be lower in the spine with increasing age ($P < 0.001$) (Figure 2B). There was also a stepwise decrease in the NVL among the groups ($P < 0.001$) (Figure 2C).

Change in spinal alignment in subjects without PDS who displayed roussouly type 1

Two subjects displayed type 1 in Group II, 22 subjects in Group III and 32 subjects in Group IV. There was a stepwise increase in the age, TPA, LDI, TLK and TK from Group I through to Group IV ($P < 0.05$). The sex distribution, PI, PT, SS, LL, L4–S1 and PI-LL were identical among the four groups (all $P > 0.05$) (Table 2). There was also no statistical difference among the four groups for the NVL or LAS distribution (both $P > 0.05$) (Figures 3A,B).

Change in spinal alignment in subjects without PDS who displayed roussouly type 2

There were 35 subjects who displayed type 2 in Group I, 35 subjects in Group II, 56 subjects in Group III and 39 subjects in Group IV. There was a stepwise increase in the age, TPA, PT and PI-LL from Group I through to Group IV ($P < 0.001$). There was also a tendency for an increase in the TLK among the four groups ($P < 0.05$). There was a stepwise decrease in the SS, LL and L4–S1 among the four groups (all $P < 0.05$). The sex distribution, PI, LDI and TK were identical among the four groups (all $P > 0.05$) (Table 3). The LSA tended to be lower in the spine with increasing age ($P < 0.05$) (Figure 4A). There was also a stepwise decrease in the NVL among the groups ($P < 0.05$) (Figure 4B).

Sagittal alignment comparison between subjects with and without PDS in group iv

All the subjects with PDS were older than 65 years and had a similar age range to that of Group IV, therefore, we compared the sagittal alignment between these two groups (Table 4). The age, sex distribution, PI, L4-S1, LDI and TLK showed no statistical difference between the two groups (all $P > 0.05$). For subjects with PDS, the TPA, PT and PI-LL were greater than for the subjects without PDS in Group IV (all $P < 0.05$), whereas the SS, LL and TK were less (all $P < 0.05$). The Roussouly-type, NVL and LSA distribution were identical between the two groups (all $P > 0.05$) (Figures 5A–C).

Impact of PDS on Roussouly's sagittal shape classification

In 17 subjects, the AVR of the thoracolumbar curve displayed Nash-Moe degree I, 22 subjects showed degree II and six subjects had degree III. None of the subjects showed degree 0 or degree IV. There was no difference in the LL, L4-S1, LDI, TLK, TK or NVL among these three degree groups (all $P > 0.05$) (Table 5).

When exploring the change in parameters using the coronal Cobb angle, we found that the PT and TPA increased with an increasing TLC Cobb angle, whereas the LL, SS and NVL decreased. Moreover, as shown in Table 6, the LSC Cobb

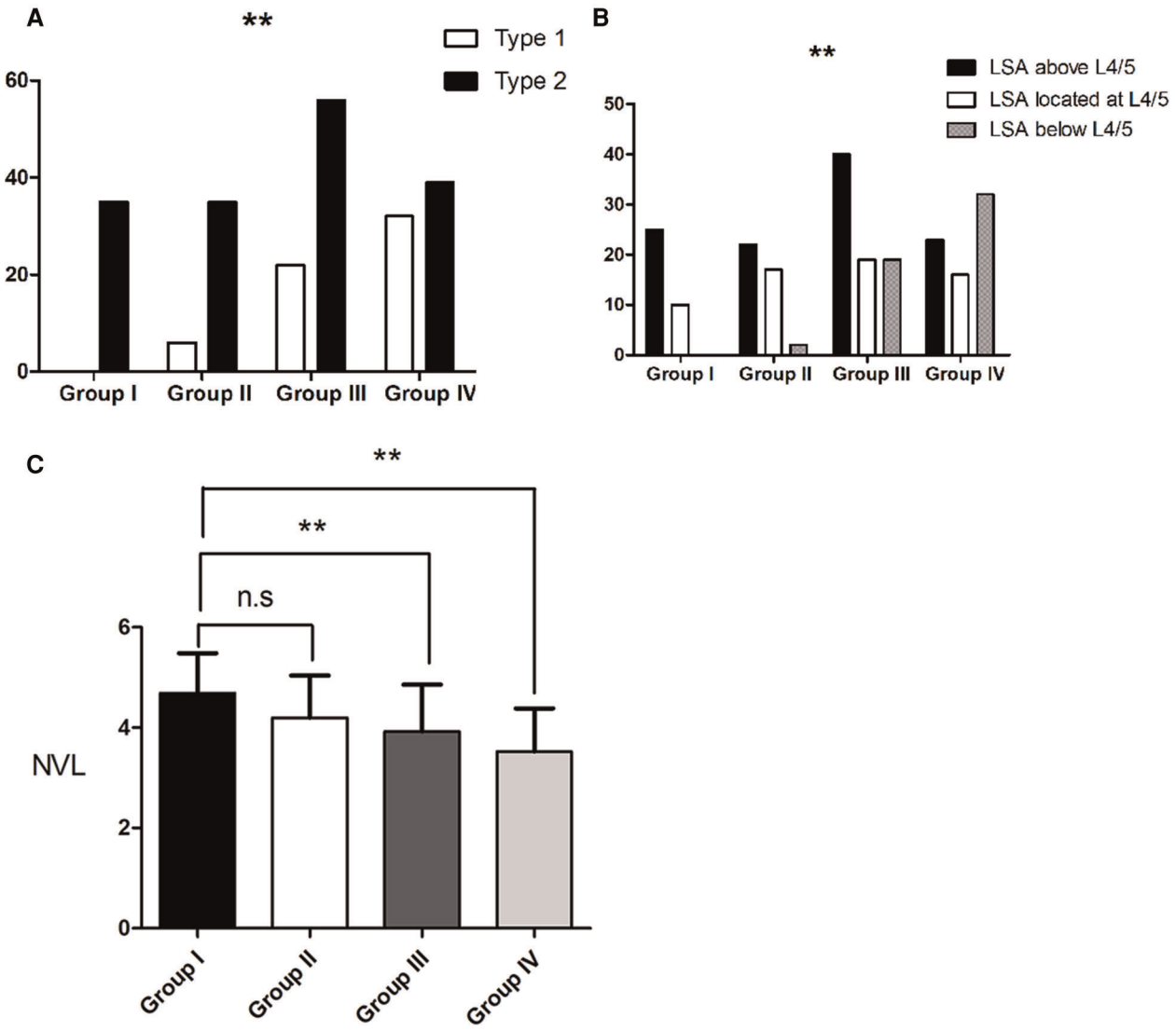

FIGURE 2
Change in spinal alignment in subjects without primary degenerative scoliosis (A). The proportion of type 1 subjects increased with age among the groups. (B). LSA tends to be lower with an increase in age. (C). There was also a stepwise decrease in the NVL among the groups. Group I were young adults (aged 20–35 years), Group II were adults (aged 36–50 years), Group III were middle-aged (aged 51–65 years) and Group IV were elderly patients (aged >65 years). LSA, lumbar sagittal apex; NVL, number of vertebrae included in the lordosis; ** indicates $P < 0.01$.

angle positively correlated with the TK, PI-LL and TPA and negatively correlated with LL. The other parameters did not correlate with the TLC Cobb angle or the LSC Cobb angle ($P > 0.05$).

Discussion

Restoring the sagittal spinal contour to the normal and original Roussouly shape according to the PI could reduce specific degeneration changes in the spine (5). Knowing the physiological shape of a patient can also help to plan the surgical restoration of a proper sagittal profile, in the belief that such restoration can lead to better functional outcomes and fewer mechanical complications (5, 8, 13, 14). With each Roussouly-type having a specific LSA, IP and NVL (1, 2, 6), this should be taken into consideration when restoring the ideal sagittal profile. Not considering this algorithm has a threefold risk for increased mechanical complications (12, 15, 16). The level of the LSA was also found to be a significant risk factor for proximal junctional kyphosis after adult spinal deformity surgery (17).

Due to our specific selection criteria, the entire analyzed population had a low PI (≤50°). These subjects with a low PI

have two possible types: 1 and 2. What would be the original shape of a degenerated type 1? The present study attempted to examine the radiological characteristics of Roussouly types with a PI $\leq 50°$ to identify whether type 2 could evolve into type 1 with an increase in age.

It was reported that type 2 was the least common category, which accounted for approximately 11% of the normal population in the original study, whereas type 1 accounted for approximately 21%, type 3 accounted for approximately 38% and type 4 accounted for approximately 30% (2). By contrast, type 2 accounted for 13.9% and type 1 for 15.4% of the degenerative population (8). However, neither study showed how the proportions of the different types changed with age. In our study, all subjects were type 2 in Group I, whereas subjects with type 1 represented 14.6% and type 2 accounted for 85.4% in Group II. In Group III, subjects with type 1 represented 28.2%, while type 2 accounted for 71.8%. In Group IV, subjects with type 1 and type 2 represented 45.1% and 54.9%, respectively. There was a stepwise increase in the proportion of type 1 with age, whereas type 2 decreased ($P <$

TABLE 2 Change in spinal alignment in subjects without PDS who displayed roussouly type 1.

Parameters	Group II	Group III	Group IV	*P* value
N	6	22	32	
Age (years)	44.0 ± 4.4	61.1 ± 3.4	73.5 ± 5.9	0.000**
Sex (M: F)	3:3	12:10	17:15	1.000
TPA (°)	4.7 ± 2.2	10.6 ± 6.7	12.9 ± 8.4	0.048*
PI (°)	37.3 ± 5.5	37.6 ± 6.1	38.8 ± 7.0	0.763
PT (°)	10.5 ± 3.6	14.5 ± 7.6	16.3 ± 9.2	0.280
SS (°)	25.5 ± 3.4	22.7 ± 7.9	21.8 ± 9.0	0.603
LL (°)	36.7 ± 10.7	29.3 ± 15.1	35.2 ± 16.6	0.336
PI-LL (°)	0.7 ± 9.8	8.3 ± 13.0	3.6 ± 15.9	0.367
L4-S1 (°)	32.3 ± 8.3	36.7 ± 9.9	36.3 ± 9.9	0.617
LDI	0.9 ± 0.1	1.5 ± 0.7	2.8 ± 6.5	0.001**
TLK (°)	14.5 ± 9.0	24.0 ± 13.1	27.7 ± 11.0	0.041*
TK (°)	18.3 ± 13.9	22.1 ± 13.9	37.7 ± 16.1	0.000**

Please refer to Table 1 for definitions of the terms.
**Indicates $P < 0.01$.
*Indicates $P < 0.05$.

TABLE 3 Change in spinal alignment in subjects without PDS who displayed roussouly type 2.

Parameters	Group I	Group II	Group III	Group IV	*P* value
N	35	35	56	39	
Age (years)	28.8 ± 4.3	42.6 ± 4.7	59.9 ± 3.8	72.5 ± 5.3	0.000**
Sex (M: F)	17:18	13:22	23:33	18:21	0.768
TPA (°)	4.2 ± 4.6	4.4 ± 5.4	9.7 ± 5.8	11.9 ± 5.8	0.000**
PI (°)	40.4 ± 5.1	40.7 ± 6.0	42.6 ± 5.8	42.0 ± 5.4	0.225
PT (°)	7.4 ± 5.4	9.1 ± 6.1	12.4 ± 6.0	14.7 ± 6.4	0.000**
SS (°)	32.7 ± 6.7	31.1 ± 7.5	29.6 ± 8.4	26.8 ± 6.0	0.005**
LL (°)	45.9 ± 9.8	43.0 ± 11.7	39.4 ± 15.4	36.1 ± 9.4	0.000**
PI-LL (°)	−5.5 ± 8.6	−2.3 ± 10.2	3.1 ± 13.3	5.9 ± 10.1	0.000**
L4-S1 (°)	31.7 ± 7.7	30.2 ± 7.2	28.5 ± 11.5	25.5 ± 7.7	0.006**
LDI	0.7 ± 0.2	0.7 ± 0.1	1.0 ± 2.0	0.7 ± 0.2	0.529
TLK (°)	6.3 ± 8.0	6.9 ± 7.9	10.3 ± 6.8	9.7 ± 8.3	0.042*
TK (°)	21.6 ± 12.6	22.7 ± 15.2	27.6 ± 12.8	27.2 ± 13.6	0.100

Please refer to Table 1 for the definitions of the terms.
**Indicates $P < 0.01$.
*Indicates $P < 0.05$.

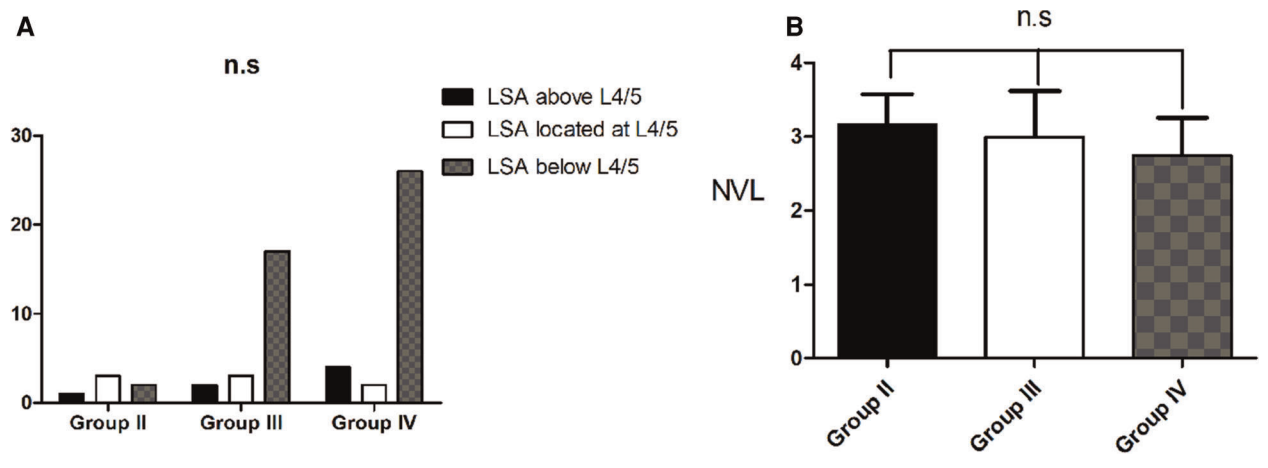

FIGURE 3
Change in spinal alignment in subjects without primary degenerative scoliosis who displayed roussouly type 1. (A). There was no statistical difference among the four groups for the LAS distribution. (B). There was no statistical difference among the groups for the NVL distribution.

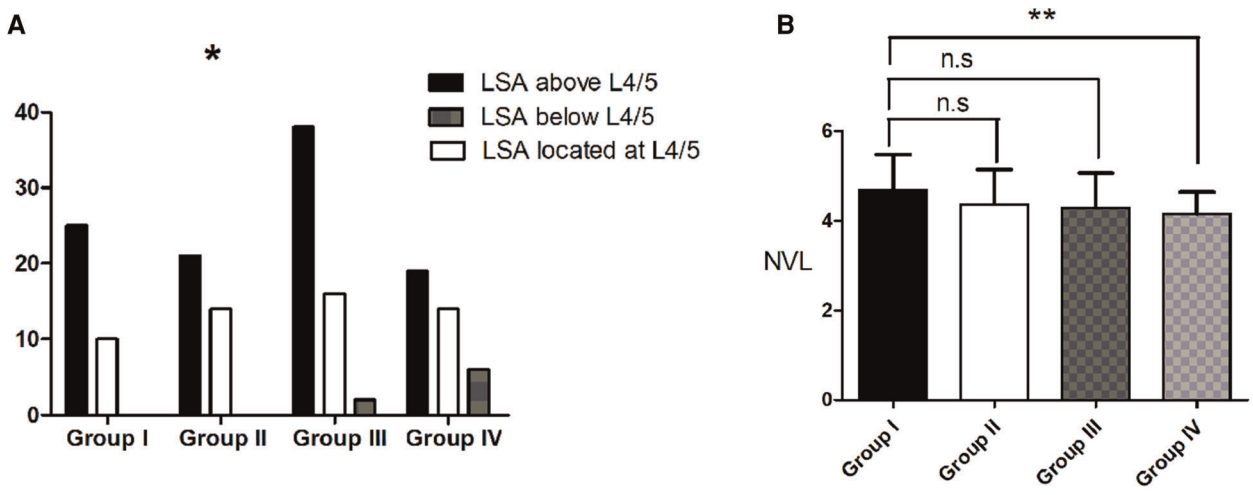

FIGURE 4
Change in spinal alignment in subjects without primary degenerative scoliosis who displayed roussouly type 2. (A). LSA tended to become lower with an increase in age. (B). There was also a stepwise decrease in the NVL among the groups. * indicates $P < 0.05$.

TABLE 4 Sagittal alignment comparison between all subjects with PDS and those subjects without PDS who were in group IV.

Parameters	PDS	Group IV	*P* value
N	45	71	
Age (years)	71.9 ± 5.6	73.0 ± 5.5	0.335
Sex (M: F)	15:30	33:38	0.161
TPA (°)	17.5 ± 10.0	12.3 ± 7.0	0.003**
PI (°)	41.7 ± 7.4	40.5 ± 6.4	0.373
PT (°)	20.3 ± 8.2	15.4 ± 7.7	0.002**
SS (°)	20.8 ± 9.5	24.5 ± 7.9	0.025*
LL (°)	27.7 ± 15.8	35.7 ± 13.1	0.006**
PI-LL (°)	14.0 ± 15.5	4.8 ± 13.0	0.001**
L4-S1 (°)	30.9 ± 10.8	30.4 ± 10.3	0.798
LDI	2.2 ± 4.6	1.7 ± 4.4	0.553
TLK (°)	18.3 ± 13.3	17.8 ± 13.1	0.843
TK (°)	23.8 ± 12.5	31.9 ± 15.6	0.004**

Please refer to Table 1 for the definitions of the terms.
**Indicates $P < 0.01$.
*Indicates $P < 0.05$.

0.05). This finding suggested that part of type 1 at least may be a regression of type 2.

Life is a kyphosing event. For all the subjects without PDS in this study, there was a stepwise increase in the TPA, PI-LL, PT, TLK and TK with age, whereas LL and the SS decreased. For the type 1 subjects, there was a stepwise increase in the TPA, TLK and TK with age, whereas the LL, PT, SS and PI-LL remained constant among the different age groups. These results were slightly different from a previous study, which reported that there was a stepwise increase in the PT and TLK with age, whereas LL and the SS decreased and TK were identical among the groups for subjects with type 1 (18). A similar phenomenon was found in the subjects with type 2 in our study. This may be due to type 1 being dependent on the shape of LL: short LL with the apex at L5 in a previous study (18), whereas we defined type 1 as a long TLK and a short lumbar lordotic curve. Another reason is the different age groups in the two studies.

There is a consensus that the LSA and IP of type 2 are higher than those of type 1 and there is a greater NVL of type 2 than that of type 1, whereas the LDI of type 2 is lower than that of type 1 (2). In our study, the LSA and IP of subjects without PDS became lower and the NVL decreased with age, with a similar phenomenon being found in the subjects with type 2. There was no statistical difference among the groups for the LAS or IP distribution of subjects with type 1. At the same time, the TLK of subjects with type 2 increased with age. This provides further evidence that some type 1 evolved from type 2.

What could be the original shape of a degenerated type 1? A prior study reported that the answer is probably different in the case of pure TLK without scoliosis compared to lumbar or thoraco-lumbar scoliosis (13). In the case of scoliosis, the increasing apical rotation may induce a thoracolumbar torsion, flexing a previously flat lordosis in TLK (13). In the case without scoliosis, the original shape was probably a type 1 with a respective increasing TLK and distal hyperlordosis (13). However, some authors described in the literature that even in type 2 subjects without scoliosis, as degeneration progresses, the kyphosing event affects the thoracolumbar area or lumbar area, the L4–S1 angle may increase on a small arch, which can generate a type 1 spine (8), thus this opinion is a little different from the former. That is, the reason why

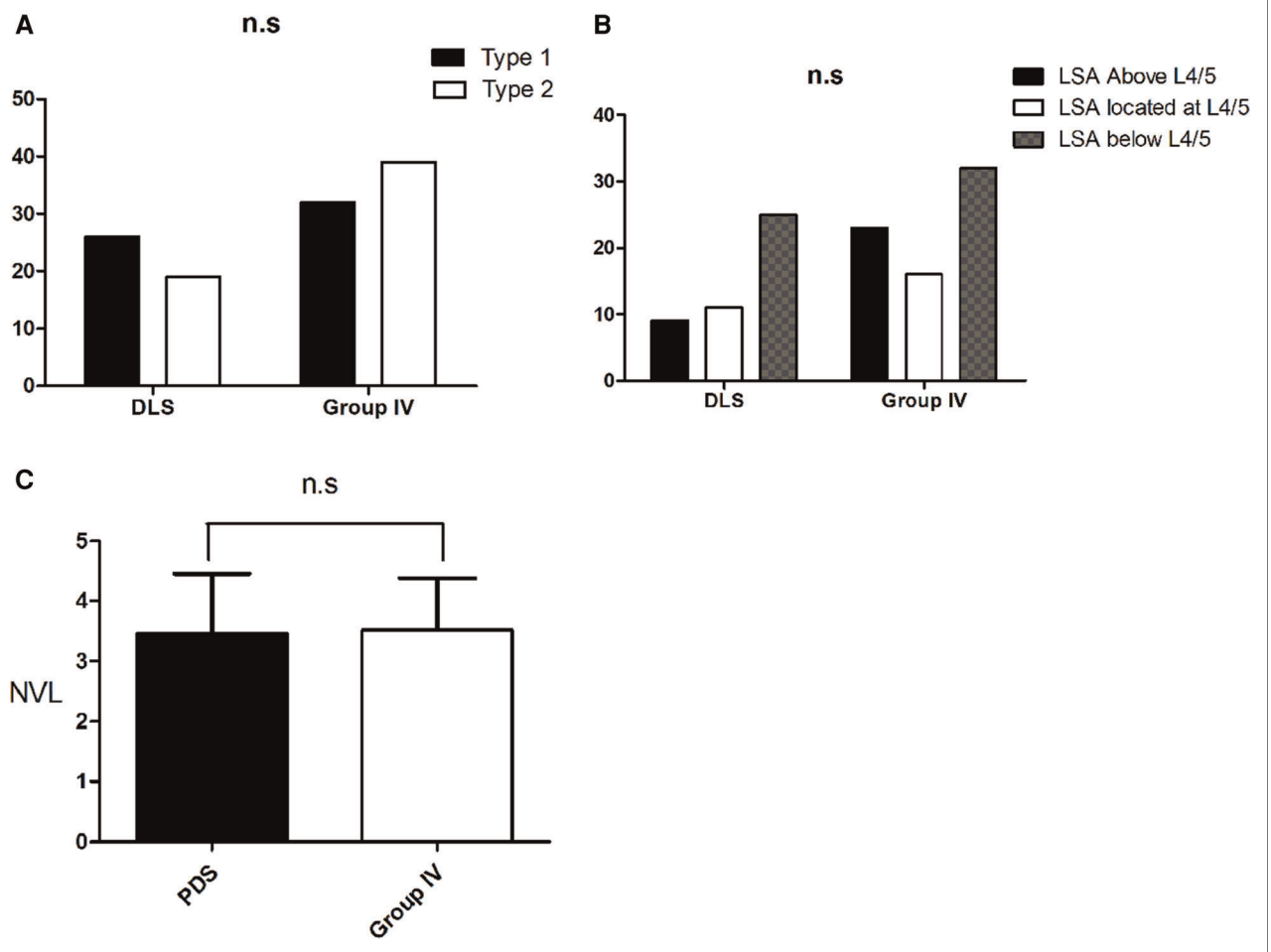

FIGURE 5
Sagittal alignment comparison between subjects with primary degenerative scoliosis and subjects in Group IV. (A). The Roussouly-type distribution was identical between the two groups (B). There was no statistical difference between the two groups for the LSA distribution. (C). There was also no statistical difference between the two groups for the NVL distribution.

TABLE 5 Impact of AVR on sagittal alignment.

AVR	LL	L4-S1	LDI	TLK	TK	NVL
Degree I	33.7 ± 16.5	32.1 ± 10.9	2.9 ± 7.3	16.1 ± 17.8	27.6 ± 13.5	3.8 ± 1.0
Degree II	22.6 ± 14.6	29.3 ± 10.0	1.6 ± 1.2	17.9 ± 12.0	20.8 ± 12.0	3.3 ± 1.0
Degree III	21.7 ± 14.8	33.3 ± 13.8	2.4 ± 2.0	26.3 ± 15.5	24.0 ± 10.3	3.2 ± 0.8
P value	0.124	0.615	0.706	0.264	0.245	0.281

AVR, apical vertebra rotation; NVL, number of vertebrae included in the lordosis; for definitions of other terms please refer to Table 1.

type 2 subjects without scoliosis can become type 1 was increased kyphosis in the thoracolumbar region and increased lordosis of the lower lumbar spine, while type 2 subjects with scoliosis can become type 1 because of the increasing apical rotation. In the present study, there was a tendency for an increase in TLK with age for subjects displaying type 2. However, LL and L4–S1 decreased in this group, and the main reason may be that some type 2 subjects become type 1, the kyphosing event continuing to affect the lumbar area in the rest of type 2 subjects as degeneration progresses. Of course, part of the degenerated type 1 was an original type 1. We found that there was a stepwise increase in TLK and TK with an increase in age for the type 1 subjects. There was no statistical difference in sagittal alignment besides the TPA, PT and PI-LL between the PDS and Group IV, who had the same age in this study. This suggests that PDS only exacerbates the sagittal imbalance. Furthermore, the AVR made no difference to the sagittal alignment in PDS. We believe that the reason was that there was very little rotation of the apical vertebra in PDS and only six subjects displayed Grade III in the present study. Moreover, we found that neither the TLC Cobb angle nor the LSC angle correlated with TLK. Therefore, we believe that PDS had little effect on

TABLE 6 Correlation between the TLC Cobb angle, the LSC Cobb angle and other parameters.

Cobb angle	LL	L4-S1	LDI	TLK	TK	PI-LL	PT	SS	TPA	NVL
TLC	−0.297*	0.028	0.116	−0.224	0.169	0.250	0.387**	−0.432**	0.299*	−0.318*
LSC	−0.340*	−0.053	0.002	−0.125	0.342*	0.322*	0.274	−0.280	0.310*	−0.099

TLC, thoracolumbar coronal; LSC, lumbar-sacrum coronal; NVL, number of vertebrae included in the lordosis; for definitions of other terms please refer to Table 1.
**Indicates $P < 0.01$.
*Indicates $P < 0.05$.

whether type 2 becomes type 1. This is very similar to what was found in adolescent idiopathic scoliosis (19) and adult scoliosis (20), where the curve type was not associated with a specific pattern of sagittal morphology.

On the basis of the specific geometry of the type 1 back, degenerative patterns associated with the worsening of TLK were hypothetically proposed: degenerative discopathy in the thoracolumbar kyphosis area, retrolisthesis in the junctional area and joint facet arthritis in the hyperlordosis area (5). There is a strong belief that the correct sagittal shape must be restored with surgery to match the physiological or theoretical one. Surgical treatment of TLK remains unclear for patients with a low PI. On the basis of this new sagittal evaluation, the strategy of balance restoration in type 1 (TLK combined with a low PI) points to two treatment options: maintain a type 1 or transform into type 2. Distinguishing between a false and an original type 1 is of great importance for the surgeons. We propose that the following points may help to distinguish the two. For the original type 1, severity of degeneration, including degenerative discopathy, retrolisthesis, joint facet arthritis and degenerative paravertebral muscles, are less than for the false one. Additionally, no obvious tenderness is present in the thoracolumbar region in the original type 1 subjects.

There were some limitations in our study. First, this is a cross-sectional study which cannot precisely ascertain the evolution of the degenerations over time because the evaluated spinal and pelvic parameters were fixed in time. Longitudinal cohort studies are thus warranted to confirm the actual degenerative changes. Second, determination of Roussouly types 1 and 2 using a cutoff value of PI of $\leq 50°$ is also arbitrary. There were some studies that set a cutoff value of PI of <45° to determine the Roussouly types 1 and 2 (6). Finally, the retrospective design and the small sample size likely affected the strength of the statistical analysis of the study. More investigations are needed to prove our hypothesis.

Conclusion

Subjects who display Roussouly type 2 could evolve into the type 1 shape as the deterioration of the sagittal spinal alignment progresses with age. PDS had little effect on whether type 2 becomes type 1. Sagittal shape recognition will help restore the appropriate theoretical shape through surgery, which can eventually lead to better surgical outcomes.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author/s.

Ethics statement

Written informed consent was obtained from the individual (s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

SL and WS: conceived and designed this study. WS: wrote the draft of the manuscript. SL: critically reviewed and revised the manuscript. YL, BW, and XC: created the figures and tables. CK, and PW: searched the literatures. All authors contributed to the article and approved the submitted version.

Acknowledgments

This study was supported by Xuanwu Hospital Science Program for Fostering Young Scholars (QNPY2020024).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Roussouly P, Pinheiro-Franco JL. Sagittal parameters of the spine: biomechanical approach. *Eur Spine J*. (2011) 20(Suppl 5):578–85. doi: 10.1007/s00586-011-1924-1

2. Roussouly P, Gollogly S, Berthonnaud E, Dimnet J. Classification of the Normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. *Spine*. (2005) 30(3):346–53. doi: 10.1097/01.brs.0000152379.54463.65

3. Barrey C, Jund J, Noseda O, Roussouly P. Sagittal balance of the pelvis-spine complex and lumbar degenerative diseases. A comparative study about 85 cases. *Eur Spine J*. (2007) 16(9):1459–67. doi: 10.1007/s00586-006-0294-6

4. Diebo BG, Henry J, Lafage V, Berjano P. Sagittal deformities of the spine: factors influencing the outcomes and complications. *Eur Spine J*. (2015) 24 (Suppl 1):S3–15. doi: 10.1007/s00586-014-3653-8

5. Roussouly P, Pinheiro-Franco JL. Biomechanical analysis of the spino-pelvic organization and adaptation in pathology. *Eur Spine J*. (2011) 20(Suppl 5):609–18. doi: 10.1007/s00586-011-1928-x

6. Laouissat F, Sebaaly A, Gehrchen M, Roussouly P. Classification of Normal sagittal spine alignment: refounding the roussouly classification. *Eur Spine J*. (2018) 27(8):2002–11. doi: 10.1007/s00586-017-5111-x

7. Legaye J, Duval-Beaupere G, Hecquet J, Marty C. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. *Eur Spine J*. (1998) 7(2):99–103. doi: 10.1007/s005860050038

8. Sebaaly A, Grobost P, Mallam L, Roussouly P. Description of the sagittal alignment of the degenerative human spine. *Eur Spine J*. (2018) 27(2):489–96. doi: 10.1007/s00586-017-5404-0

9. Yilgor C, Sogunmez N, Yavuz Y, Abul K, Boissiere L, Haddad S, et al. European Spine Study Group (2017) Relative lumbar lordosis and lordosis distribution index: individualized pelvic incidence-based proportional parameters that quantify lumbar lordosis more precisely than the concept of pelvic incidence minus lumbar lordosis. *Neurosurg Focus* 43(6):E5. doi: 10.3171/2017.8.FOCUS17498

10. Protopsaltis T, Schwab F, Bronsard N, Smith JS, Klineberg E, Mundis G, et al. International Spine Study Group (2014) Thet1 pelvic angle, a novel radiographic measure of global sagittal deformity, accounts for both spinal inclination and pelvic tilt and correlates with health-related quality of life. *J Bone Joint Surg Am* 96(19):1631–40. doi: 10.2106/JBJS.M.01459

11. Nash Jr CL, Moe JH. A study of vertebral rotation. *J Bone Joint Surg Am*. (1969) 51(2):223–9. doi: 10.2106/00004623-196951020-00002

12. Pizones J, Moreno-Manzanaro L, Sanchez Perez-Grueso FJ, Vila-Casademunt A, Yilgor C, Obeid I, et al. ESSG European spine study group (2020) Restoring the ideal roussouly sagittal profile in adult scoliosis surgery decreases the risk of mechanical complications. *Eur Spine J* 29(1):54–62. doi: 10.1007/s00586-019-06176-x

13. Scemama C, Laouissat F, Abelin-Genevois K, Roussouly P. Surgical treatment of thoraco-lumbar kyphosis (TLK) associated with low pelvic incidence. *Eur Spine J*. (2017) 26(8):2146–52. doi: 10.1007/s00586-017-4984-z

14. Yilgor C, Sogunmez N, Boissiere L, Yavuz Y, Obeid I, Kleinstuck F, et al. European Spine Study Group (ESSG) (2017) Global alignment and proportion (GAP) score: development and validation of a new method of analyzing spinopelvic alignment to predict mechanical complications after adult spinal deformity surgery. *J Bone Joint Surg Am* 99(19):1661–72. doi: 10.2106/JBJS.16.01594

15. Sebaaly A, Gehrchen M, Silvestre C, Kharrat K, Bari TJ, Kreichati G, et al. Mechanical complications in adult spinal deformity and the effect of restoring the spinal shapes according to the roussouly classification: a multicentric study. *Eur Spine J*. (2020) 29(4):904–13. doi: 10.1007/s00586-019-06253-1

16. Bari TJ, Hansen LV, Gehrchen M. Surgical correction of adult spinal deformity in accordance to the roussouly classification: effect on postoperative mechanical complications. *Spine Deform*. (2020) 8(5):1027–37. doi: 10.1007/s43390-020-00112-6

17. Sebaaly A, Riouallon G, Obeid I, Grobost P, Rizkallah M, Laouissat F, et al. Proximal junctional kyphosis in adult scoliosis: comparison of four radiological predictor models. *Eur Spine J*. (2018) 27(3):613–21. doi: 10.1007/s00586-017-5172-x

18. Chung NS, Lee HD, Jeon CH. Degenerative changes of sagittal alignment in patients with roussouly type 1. *Spine Deform*. (2020) 8(6):1325–31. doi: 10.1007/s43390-020-00151-z

19. Mac-Thiong JM, Labelle H, Charlebois M, Huot MP, de Guise JA. Sagittal plane analysis of the spine and pelvis in adolescent idiopathic scoliosis according to the coronal curve type. *Spine*. (2003) 28(13):1404–9. doi: 10.1097/01.BRS.0000067118.60199.D1

20. Pizones J, Martin MB, Perez-Grueso FJS, Yilgor C, Vila-Casademunt A, Serra-Burriel M, et al. ESSG European Spine Study Group (2019) Impact of adult scoliosis on roussouly sagittal shape classification. *Spine* 44(4):270–9. doi: 10.1097/BRS.0000000000002800

frontiers | Frontiers in Surgery

TYPE Original Research
PUBLISHED 06 January 2023
DOI 10.3389/fsurg.2022.1076257

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

RECEIVED 21 October 2022
ACCEPTED 24 November 2022
PUBLISHED 06 January 2023

CITATION
Wu Z, He J, Cheng H, Lin S, Zhang P, Liang D, Jiang X and Cui J (2023) Clinical efficacy of general anesthesia versus local anesthesia for percutaneous transforaminal endoscopic discectomy.
Front. Surg. 9:1076257.
doi: 10.3389/fsurg.2022.1076257

Clinical efficacy of general anesthesia versus local anesthesia for percutaneous transforaminal endoscopic discectomy

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Objective: Local anesthesia (LA) is recommended for percutaneous transforaminal endoscopic discectomy(PTED), but satisfactory pain management is not mostly achieved. The goal of this study was to examine the clinical efficacy of PTED for lumbar disc herniation when performed under local anaesthetic vs. general anesthesia (GA).
Methods: From August 2018 to August 2020, the clinical data of 108 patients treated with PTED were retrospectively evaluated and separated into two groups: LA and GA based on the anesthesia method. General information and clinical outcomes of patients were included. Visual analog scale (VAS) and Oswestry disability index (ODI) were recorded before operation, 1 week after operation, and 1 year after operation. In addition, VAS for back pain and leg pain on the second postoperative day were also recorded.
Results: We divided the patients into two groups: 72 in LA and 36 in GA. There were no significant differences in gender, age, course of disease, body mass index, surgical segment, duration of operation, intraoperative bleeding, time of fluoroscopy, length of hospital stay, total hospitalization cost reoperation, surgical satisfaction, Macnab satisfaction, complications, preoperative and 1 year postoperatively VAS for back pain and leg pain and ODI, VAS for leg pain on the second day and 1 week postoperatively between the two groups ($P > 0.05$). VAS for back pain in GA group on the second day postoperatively, as well as the VAS for back pain and ODI at one week postoperatively, were better than those in LA group ($P < 0.05$). However, the total hospitalization cost in LA group was significantly lower than that in GA group ($P < 0.05$). Further analysis of different ages in the two groups showed that there were significant differences in the VAS for back pain on the second day postoperatively and ODI at 1 week postoperatively in the middle-aged group ($45 \leq Y \leq 59$), as well as the VAS for back pain on the second day postoperatively in the senior group ($Y \geq 60$) ($P < 0.05$). However, there were no significant difference among other groups ($P > 0.05$).
Conclusion: Long-term outcomes were similar for both PTED under LA and GA, while GA group had better short-term outcomes, especially in middle-aged and elderly patients.

KEYWORDS

lumbar disc herniation, percutaneous transforaminal endoscopic discectomy, local anesthesia, general anesthesia, pain management

Introduction

Lumbar disc herniation (LDH) is becoming more and more common as people change their lifestyles. When conservative treatment fails and the condition progresses, surgery may be indicated. Percutaneous transforaminal endoscopic discectomy (PTED) is a minimally invasive technique for LDH that is comparable to open surgery and microendoscopic lumbar discectomy in terms of efficacy. At the same time, it has the advantages such as a tiny incision, less bleeding, quick postoperative recovery, getting out of bed early and so on (1–3).

Most PTED are performed under local anaesthesia (LA). To avoid harm to the spinal cord and nerve roots, patients remain conscious throughout the treatment and can provide abnormal input to the operator concerning pain, numbness, and electrical sensations in the leg at any time. PTED under LA, on the other hand, is not without debate, given the increased desire for comfort and painlessness. LA is insufficient for pain relief, and some patients are unable to take it, resulting in complications during surgery and even the need to abandon the procedure (4, 5). Therefore, some researchers believe that general anesthesia (GA) is better for PTED, especially for patients who have a low pain threshold (6). Although PTED under GA can offer appropriate analgesia, due to full sensory blockade, the risk of surgery may be considerably enhanced (7). How to better manage pain during PTED has become a major clinical issue for spine surgeons.

As far as we know, few researches have examined the efficacy of PTED in LA or GA. Therefore, we conducted a retrospective case-control study to compare the clinical outcomes of PTED patients treated with LA vs. GA.

Materials and methods

Inclusion and exclusion criteria

The inclusion criteria were: (1) patients with single-segment LDH whose clinical symptoms and signs were consistent with the imaging findings. (2) PTED was conducted when conservative treatment failed for more than three months. (3) GA could be tolerated after assessment by an anesthesiologist. (4) the data and follow-up results were complete. The exclusion criteria were: (1) the segment with spondylolisthesis or instability required fusion surgery. (2) surgery was required for degenerative scoliosis. (3) other spinal diseases, such as ankylosing spondylitis, spinal tumors and tuberculosis and so on. (4) history of lumbar surgery.

General information

All patients diagnosed with LDH and treated with PTED from August 2018 to August 2020 who met the inclusion and exclusion criteria were retrospectively included in this study. LA and GA were chosen according to the patient's preference. There were 72 cases in LA group and 36 cases in GA group. The study was approved by the hospital ethics committee and all patients were operated on by the same group of senior doctors. General data of the two groups were shown in Table 1. There were no significant differences in gender, age, course of disease, body mass index and surgical segment between the two groups ($P > 0.05$).

Surgical procedure

To permeate the epidermis, 2–3 ml of 1% lidocaine was administered in LA group, followed by 8–10 ml layer by layer. When the superior articular process was reached, 2–3 ml was utilized to anesthetize the facet joints. If necessary, dosage could be increased appropriately. In GA group, experienced anesthesiologists performed anesthesia according to standardize intravenous compound endotracheal general anesthesia.

The patient was positioned prone on the operating table. The entrance location was around 12–14 cm distant from the midline. The needle had reached the medial and ventral surfaces of the superior articular process, according to fluoroscopy. Then a guidewire was used to replace the needle. A serial dilator was adopted and twisted to enlarge the subcutaneous tract. A protective tube was inserted into the intervertebral foramen and trephine (Spinendos, Munich, Germany) was introduced through the tube. After that, the trephine was utilized to do foraminoplasty. An endoscope (Elliquence, New York, USA) was connected. Then nerve root was revealed and herniated nucleus pulposus was excised endoscopically. The endoscope was removed and the operation ended.

The assessment of clinical outcomes

Our study focused on factors including duration of operation, intraoperative bleeding, time of intraoperative

TABLE 1 General data of patients in the two groups.

Subjects	LA Group ($n = 72$)	GA Group ($n = 36$)	P
Male/Female	48/24	21/15	0.405
Age (years)	47.82 ± 15.55	48.78 ± 16.08	0.766
Course of disease (months)	15.53 ± 19.67	15.17 ± 18.25	0.928
Body mass index (kg/m^2)	21.72 ± 2.34	21.70 ± 2.25	0.967
Surgical segment			0.199
L1-2	0	2	
L2-3	2	3	
L3-4	4	2	
L4-5	58	26	
L5-S1	8	3	

fluoroscopy, length of hospital stay, total hospitalization cost, surgical satisfaction and complications. The length of hospital stay was from the day of admission to the day of discharge. Visual analog scale (VAS, ranging from 0 to 100, with higher scores indicating more back pain and leg pain) (8) for back pain and leg pain and Oswestry Disability Index (ODI, ranging from 0 to 100, with higher scores indicating more disability) (9) were recorded preoperatively, 1 week postoperatively and 1 year postoperatively. On the second day after surgery, the patients were asked about their satisfaction with the operation and answered "satisfactory", "average" and "unsatisfactory". Patients were followed up for reoperation at 1 year postoperatively, and surgical outcomes were assessed according to MacNab criteria.

Statistical analysis

SPSS 25.0 statistical software was used for data analysis. The quantitative data were described as means ± standard deviation ($\bar{x} \pm s$), and the qualitative data were expressed as the number of cases. Quantitative data were compared by independent sample T-test. For those failing to meet the t-test conditions, rank sum test was used. Qualitative data were compared by $\chi 2$ test. $P < 0.05$ was considered statistically significant.

Results

All patients underwent surgery successfully. The comparison of clinical outcomes between the two groups was shown in **Table 2**. There were no significant differences in duration of operation, intraoperative bleeding, time of intraoperative fluoroscopy, length of hospital stay, surgical satisfaction and complications between the two groups ($P > 0.05$). However, the total hospitalization cost of LA group was significantly lower than that of GA group ($P < 0.05$). One patient in each group was reoperated for recurrence of the operated segment at one year postoperative follow-up ($P > 0.05$). Meanwhile, there was no significant difference in efficacy assessment of Macnab criteria between two groups ($P > 0.05$). Transient paresis occurred in five and three patients in the LA and GA groups, respectively.

The comparison of efficacy between the two groups was shown in **Figures 1**, **2**. There were no significant differences in preoperative VAS for back pain and leg pain and ODI between the two groups ($P > 0.05$). Although there was no statistical difference in VAS for leg pain between the two groups on the second day after surgery ($P > 0.05$), VAS for back pain of GA group was markedly better than that of LA group ($P < 0.05$). One week after surgery, VAS for back pain and ODI in GA group were better than those in LA group ($P < 0.05$), but there was no significant difference in VAS for leg pain between the two groups ($P > 0.05$). There were no significant differences in VAS for back pain and leg pain and ODI between the two groups at 1 year follow-up ($P > 0.05$).

TABLE 2 Comparison of clinical outcomes between the two groups.

Subjects	LA Group ($n = 72$)	GA Group ($n = 36$)	*P*
Duration of operation (minutes)	94.10 ± 33.21	96.94 ± 33.64	0.677
Intraoperative bleeding (ml)	9.79 ± 4.55	10.75 ± 6.02	0.358
time of intraoperative fluoroscopy (times)	25.75 ± 7.13	22.75 ± 8.05	0.063
Length of hospital stay (days)	6.13 ± 2.47	6.22 ± 2.27	0.843
Total hospitalization cost (RMB)	34,018.5 ± 7259.26	44,715.54 ± 21,656.04	<0.001
Reoperation	1 (1.39%)	1 (2.78%)	0.614
Satisfaction of surgical			0.082
Satisfactory	57	32	
Average	15	3	
Unsatisfactory	0	1	
Macnab satisfaction			0.858
Excellent	37	18	
Good	31	15	
Fair	4	3	
Poor	0	0	
Transient paresis	5	3	0.448

All the patients included were separated into three groups, according to WHO age classification criteria (10). The young group was under 45 years old; the middle-aged group was 45–59 years old; and the senior group was over 59 years old. Comparison of efficacy between GA group and LA in different age groups was shown in **Figures 3–5**. There were significant differences in the VAS for back pain on the second day postoperatively, ODI at one week postoperatively in the middle-aged group, as well as the VAS for back pain on the second day postoperatively in the senior group ($P < 0.05$). However, there were no significant difference among other groups ($P > 0.05$).

Discussion

It is difficult to puncture and implant the working channel under direct vision in PTED, and there is a risk of nerve irritation during the operation. As a result, it's critical to keep the patient conscious during the procedure. Currently, most surgeons utilize LA for PTED, but some employ epidural anesthesia, lumbar anesthesia or GA. Yu et al. (11) discovered that PTED performed under local anesthesia with 0.5% lidocaine was lesser invasion, shorter hospital stays, quicker pain relief, and functional recovery compared to microendoscopic discectomy under general anesthesia. Zhang

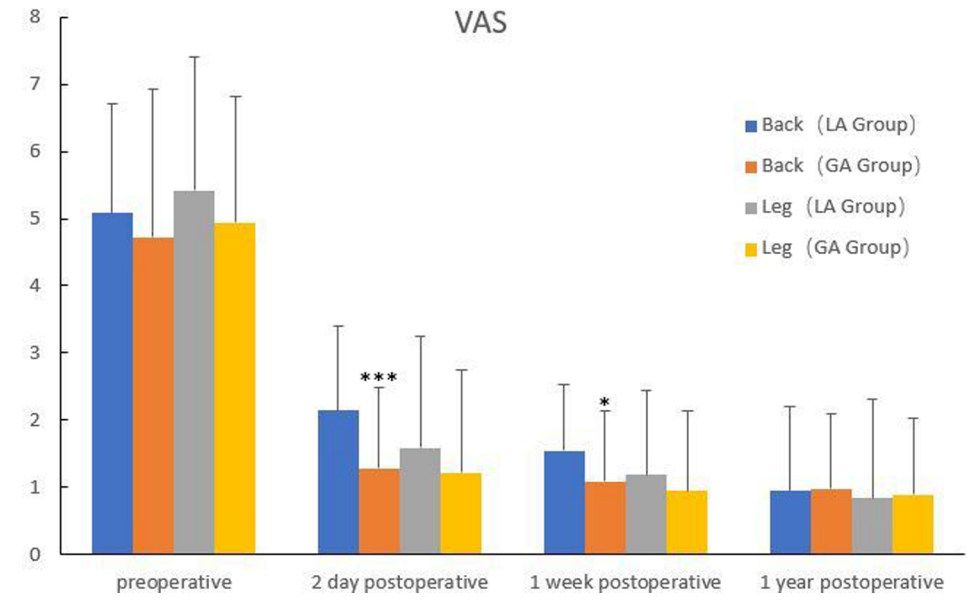

FIGURE 1
Comparison of VAS between the two groups. ***Compared with the back of LA group on the second day postoperatively, $P<0.001$. *Compared with the back of LA group at one week postoperatively, $P<0.05$.

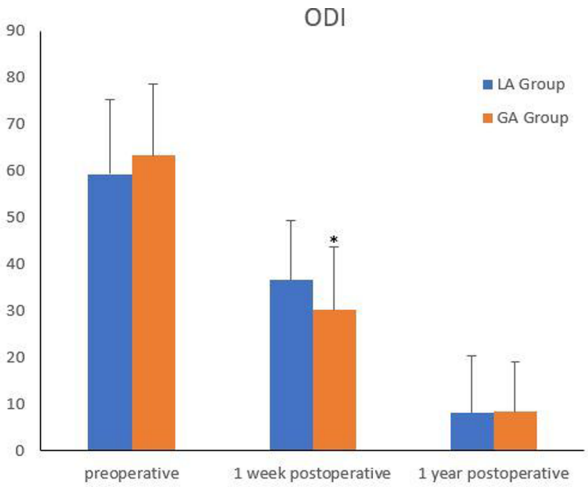

FIGURE 2
Comparison of ODI between the two groups. *Compared with the LA group at one week postoperatively, $P<0.05$.

et al. (12) concluded that epidural anesthesia with low-concentration ropivacaine and sufentanil is safe and effective for PTED. Wang et al. (13) found that PTED and percutaneous endoscopic interlaminar discectomy under general anesthesia were equally cost-effective and valuable interventions for L5-S1 lumbar disc herniation. Our study showed that duration of operation, intraoperative bleeding, time of intraoperative fluoroscopies, length of hospital stay, reoperation, surgical satisfaction, Macnab satisfaction, complications and long-term outcomes were similar between LA and GA groups. Although the efficacy of GA group was better than that of LA group on the second day and 1 week postoperatively, the total hospitalization cost was higher than that of LA group.

PTED can be performed under LA because it exerts little damage to tissue. The surgeon can completely communicate with the patient during the procedure, reducing the danger of nerve injury. Meanwhile, LA offers minimal risk and low cost. As a result, LA is frequently suggested in clinical settings. However, we discovered that pain management under LA was ineffective. This could be related to the large amount of nerve fibers in the tissues surrounding the lumbar joints, which are difficult to totally block. Especially in the process of establishing working channels, foraminoplasty and releasing adherent nerve roots, severe pain is often produced, which is consistent with the study of Zhu (14). Due to the painful operation under LA, patients may have anxiety and fear about it, which may reduce the satisfaction of the surgery, so that patients may refuse to accept it again. This could have a negative impact on the promotion of PTED. In addition, this study also found that intraoperative muscle tension would limit the operation of endoscopic instruments, prolong the duration of operation, and increase the dose of radiation and surgical difficulty. Pain management that is effective can increase clinical outcomes and patient satisfaction (15).

Although there was no significant difference in the number of fluoroscopies between the two groups in this study, we did

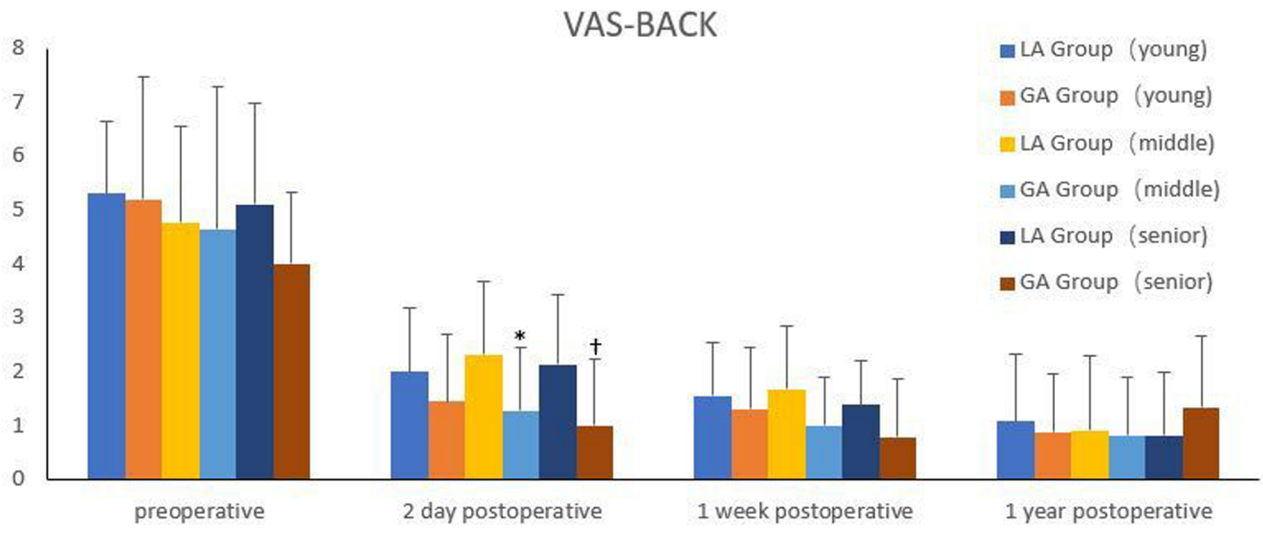

FIGURE 3
Comparison of VAS for back pain between the two groups in different age groups. *Compared with the LA group on the second day postoperatively in the middle-aged group, $P<0.05$. †Compared with the LA group on the second day postoperatively in the senior group, $P<0.05$.

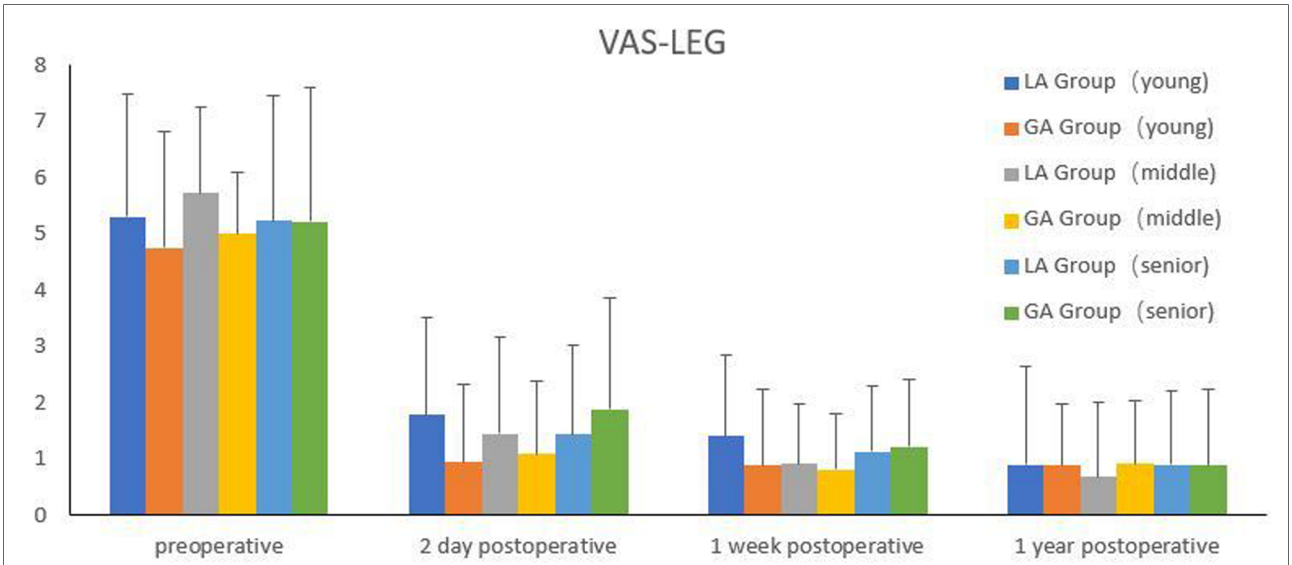

FIGURE 4
Comparison of VAS for leg pain between the two groups in different age groups.

find that GA group had a slightly lower frequency than LA group, which could be due to the intraoperative analgesic effect (16). In LA group, muscle tension and postural changes might occur because of pain, which might affect the fluoroscopic effect. The frequency of fluoroscopy is closely related to the patient's coordination. In LA group, patients might ask the surgeon to stop the puncture and insertion of the working channel due to unbearable pain. Besides, the patient could move autonomously during the operation, and muscle tension due to fear might increase the frequency of fluoroscopy. The International Commission on Radiological Protection (ICRP) also recommends annual radiation limits, and the repeated fluoroscopy during surgery is too damageable to ignore (17). Our study showed that although the long-term outcomes of the two groups was consistent, the VAS for back pain on the second day postoperatively, the VAS for back pain and ODI at one week postoperatively in GA group were better than those in LA group. We may

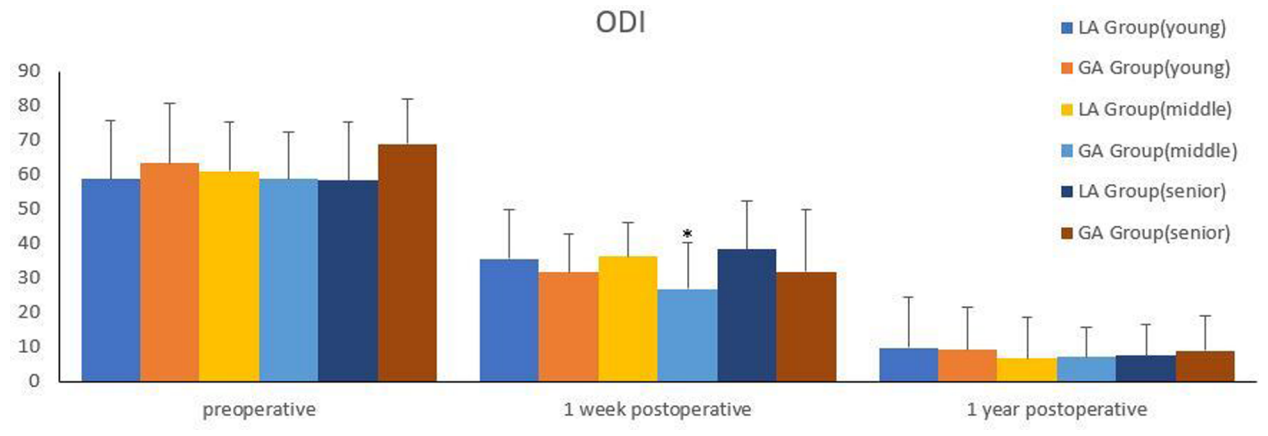

FIGURE 5
Comparison of ODI between the two groups in different age groups. *Compared with the LA group at one week postoperatively in the middle-aged group, $P<0.05$.

consider the following two reasons: On the one hand, patients in the GA group cooperated better during the procedure. As a result, the surgeon would be able to perform better, removing more nucleus pulposus and better releasing the nerve root. After surgery, the GA group, on the other hand, had no bad memories and felt better about themselves. Therefore, it is an option to operate PTED under GA. To reduce nerve injury, the assistant can be asked to touch the ipsilateral leg during the operation. The operation was suspended, and the position was adjusted in time when the leg beating appeared. However, owing to the steeper learning curve of PTED, it is still recommended to perform it under LA in the early stage (18). If the situation allows, it can be done under the supervision of PTED-trained surgeons to assure the surgery's safety. As experience we gain, we can transition to GA. It is good for postoperative recovery when the patient is undergoing painless surgery.

Further examination of the two age groups revealed that there was no significant difference between the young and the older groups. However, in middle-aged and older people, short-term outcomes in the GA group were better than those of the LA group. It could be linked to the degree of degeneration in middle-aged and elderly people. As they have a lower pain tolerance than young people, their postoperative back discomfort is more noticeable (14). Therefore, young people can have a variety of anesthesia options, more inclined to LA. GA is more suitable to the elderly. In addition, as our findings revealed, the total hospitalization cost in the GA group was significantly higher than in the LA group, amounting to approximately 10,697 RMB, due to the need for full participation of anesthesiologists. In terms of complications, both groups of patients suffered transitory paresis, which was assumed to be related to mechanical nerve root extraction. To avoid injury the nerve, we should carefully examine the radiography before surgery, measure the size of the foramen, and then determine the puncture direction and angle. Hussain (19) reported that PTED under GA, supplemented by neuro electrophysiological monitoring, could preferably ensure the safety of spinal cord and nerve root.

Although the aforementioned findings are clinically significant, there still exist flaws. To begin with, this was a retrospective study with a selective bias in data gathering. Second, because all of the cases came from a single center, the total number of cases was insufficient. Finally, there was no follow-up on mid-term results after surgery in the study. As a result, future research should include a comparison of the impacts at multiple time periods, as well as a prospective, large-sample multicenter cohort study to confirm our findings.

Conclusion

Both PTED under LA and GA are safe and effective for treating patients with LDH in Long-term outcomes,while GA group had better short-term outcomes, especially in middle-aged and elderly patients. Therefore, GA can be considered a feasible alternative to LA for PTED.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author/s.

Ethics statement

This study was performed in line with the principles of the Declaration of Helsinki. The studies involving human

participants were reviewed and approved by the Ethics Committee of Guangzhou University of Chinese Medicine (NO.K【2020】107). Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

DL and XJ contributed to the conceptualization and methodology. Material preparation, data collection and analysis were performed by JH, HC, SL and PZ. The first draft of the manuscript was written by ZW and all authors commented on previous versions of the manuscript. The corresponding author, JC, was responsible for proofreading and revising the manuscript. All authors contributed to the article and approved the submitted version.

Funding

Scientific Research Project of Excellent Young Scholars Project of Guangzhou University of Chinese Medicine's First Affiliated Hospital (Grant No. 2019QN17), Scientific Research Project of Traditional Chinese Medicine Bureau of Guangdong Province (Grant No. 20201097).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Jarebi M, Awaf A, Lefranc M, Peltier J. A matched comparison of outcomes between percutaneous endoscopic lumbar discectomy and open lumbar microdiscectomy for the treatment of lumbar disc herniation: a 2-year retrospective cohort study. *Spine J.* (2021) 21:114–21. doi: 10.1016/j.spinee.2020. 07.005

2. Rasouli MR, Rahimi-Movaghar V, Shokraneh F, Moradi-Lakeh M, Chou R. Minimally invasive discectomy versus microdiscectomy/open discectomy for symptomatic lumbar disc herniation. *Cochrane Database Syst Rev.* (2014) 9: CD010328. doi: 10.1002/14651858.CD010328.pub2

3. Jing Z, Li L, Song J. Percutaneous transforaminal endoscopic discectomy versus microendoscopic discectomy for upper lumbar disc herniation: a retrospective comparative study. *Am J Transl Res.* (2021) 13:3111–9.

4. Sairyo K, Chikawa T, Nagamachi A. State-of-the-art transforaminal percutaneous endoscopic lumbar surgery under local anesthesia: discectomy, foraminoplasty, and ventral facetectomy. *J Orthop Sci.* (2018) 23:229–36. doi: 10.1016/j.jos.2017.10.015

5. Fang G, Ding Z, Song Z. Comparison of the effects of epidural anesthesia and local anesthesia in lumbar transforaminal endoscopic surgery. *Pain Physician.* (2016) 19:E1001–4. doi: 10.36076/ppj/2016.19.49

6. Hua W, Zhang Y, Wu X, Gao Y, Li S, Wang K, et al. Full-Endoscopic visualized foraminoplasty and discectomy under general anesthesia in the treatment of L4-L5 and L5-S1 disc herniation. *Spine.* (2019) 44:E984–91. doi: 10.1097/BRS.0000000000003014

7. Sharma N, Piazza M, Marcotte PJ, Welch W, Ozturk AK, Chen HI, et al. Implications of anesthetic approach, spinal versus general, for the treatment of spinal disc herniation. *J Neurosurg Spine.* (2018) 30:78–82. doi: 10.1007/s00264-017-3723-8

8. Carlsson AM. Assessment of chronic pain. I. Aspects of the reliability and validity of the visual analogue scale. *Pain.* (1983) 16:87–101. doi: 10.1016/0304-3959(83)90088-X

9. Fairbank JC, Couper J, Davies JB, O'Brien JP. The Oswestry low back pain disability questionnaire. *Physiotherapy.* (1980) 66:271–3.

10. Tao S, Jin L, Hou Z, Zhang W, Chen T, Zhang Y. A new radiographic feature of lower lumbar disc herniation in young patients. *Int Orthop.* (2018) 42:583–6. doi: 10.1007/s00264-017-3723-8

11. Yu P, Zan P, Zhang X, Qiang H, Samsonraj RM, Tang J, et al. Comparison of percutaneous transforaminal endoscopic discectomy and microendoscopic discectomy for the surgical management of symptomatic lumbar disc herniation: a multicenter retrospective cohort study with a Minimum of 2 Years' follow-up. *Pain Physician.* (2021) 24:E117–25. doi: 10.36076/ppj.2021.24. e117-e125

12. Zhang L, Chang T, Xu Y, Jing Q, Zhao X, Li C. Epidural anesthesia with low concentration ropivacaine and sufentanil for percutaneous transforaminal endoscopic discectomy: a randomized controlled trial. *Front Med (Lausanne).* (2020) 7:362. doi: 10.3389/fmed.2020.00362

13. Wang D, Xie W, Cao W, He S, Fan G, Zhang H. A cost-utility analysis of percutaneous endoscopic lumbar discectomy for L5-S1 lumbar disc herniation: transforaminal versus interlaminar. *Spine.* (2019) 44:563–70. doi: 10.1097/BRS.0000000000002901

14. Zhu Y, Zhao Y, Fan G, Gu G, Sun S, Hu S, et al. Comparison of the effects of local anesthesia and epidural anesthesia for percutaneous transforaminal endoscopic discectomy in elderly patients over 65 years old. *Int J Surg.* (2017) 48:260–3. doi: 10.1016/j.ijsu.2017.11.029

15. Burnett G, Jr DS, Levine AI. Regional anesthesia and acute pain management. *Otolaryngol Clin North Am.* (2019) 52:1065–81. doi: 10.1016/j.otc.2019.08.013

16. Zhu Y, Zhao Y, Fan G, Sun S, Zhou Z, Wang D, et al. Comparison of 3 anesthetic methods for percutaneous transforaminal endoscopic discectomy: a prospective study. *Pain Physician.* (2018) 21:E347–53. doi: 10.36076/ppj.2018.4. e347

17. Ahn Y, Kim CH, Lee JH, Lee SH, Kim JS. Radiation exposure to the surgeon during percutaneous endoscopic lumbar discectomy: a prospective study. *Spine.* (2013) 38:617–25. doi: 10.1016/j.wneu.2017.03.050

18. Ahn SS, Kim SH, Kim DW. Learning curve of percutaneous endoscopic lumbar discectomy based on the period (early vs. Late) and technique (in-and-out vs. In-and-out-and-in): a retrospective comparative study. *J Korean Neurosurg Soc.* (2015) 58:539–46. doi: 10.3340/jkns.2015.58.6.539

19. Hussain I, Rapoport BI, Krause K, Kinney G, Hofstetter CP, Elowitz E. Transforaminal endoscopic lumbar discectomy and foraminotomy with modified radiofrequency nerve stimulator and continuous electromyography under general anesthesia. *World Neurosurg.* (2020) 137:102–10. doi: 10.1016/j.wneu.2020.01.186

frontiers | Frontiers in Surgery

TYPE Original Research
PUBLISHED 06 January 2023
DOI 10.3389/fsurg.2022.1067775

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

RECEIVED 12 October 2022
ACCEPTED 21 November 2022
PUBLISHED 06 January 2023

CITATION
Meng S, Han J, Xu D, Wang Y, Han S, Zhu K, Lin A, Su K, Li Y, Han X, Ma X and Zhou C (2023) Fully endoscopic transforaminal discectomy for thoracolumbar junction disc herniation with or without calcification under general anesthesia: Technical notes and preliminary outcomes. Front. Surg. 9:1067775. doi: 10.3389/fsurg.2022.1067775

Fully endoscopic transforaminal discectomy for thoracolumbar junction disc herniation with or without calcification under general anesthesia: Technical notes and preliminary outcomes

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Objective: To evaluate the feasibility, safety, and outcomes of percutaneous endoscopic transforaminal discectomy (PETD) for thoracolumbar junction disc herniation (TLDH) with or without calcification.

Methods: This study included 12 patients diagnosed with TLDH with or without calcification who met the inclusion criteria and underwent surgery for PETD from January 2019 to December 2021. The mean patient age, operation time, hospitalization time, time in bed, and complications were recorded. Patients were followed up for at least 9 months. Visual analog scale (VAS) scores for low-back and leg or thoracic radicular pain and modified Japanese Orthopedic Association score (m-JOA) scores were preoperatively evaluated, at 1 day and 3, 6, and 12 months postoperatively or at last follow-up. The modified MacNab criteria were used to evaluate clinical efficacy at 12 months postoperatively or at last follow-up.

Results: The mean patient age, operation time, hospitalization time, and time in bed were 53 ± 13.9 years, 101.3 ± 9.2 min, 4.5 ± 1.3 days, and 18.0 ± 7.0 h, respectively. The mean VAS scores of low-back and leg or thoracic radicular pain improved from 5.8 ± 1.5 and 6.5 ± 1.4 to 2.0 ± 0.9 and 1.3 ± 0.5, respectively ($P < 0.05$). The m-JOA score improved from 7.5 ± 1.2 to 10.0 ± 0.7 ($P < 0.05$). The overall excellent–good rate of the modified MacNab criteria was 83.3%. No severe complications occurred.

Conclusion: Fully endoscopic transforaminal discectomy and ventral decompression under general anesthesia is a safe, feasible, effective, and minimally invasive method for treating herniated discs with or without calcification at thoracolumbar junction zone.

KEYWORDS

endoscopic spinal surgery, transforaminal, discectomy, ventral decompression, thoracolumbar junction zone, intervertebral disc displacement

Introduction

The thoracolumbar junction usually refers to the region from T11 to L2 in clinical practice (1). Thoracolumbar junction disc herniation (TLDH) with an incidence of <5% of all lumbar disc herniations is much less common than in the lower cervical and lower lumbar spines (1–4). However, TLDH is sometimes encountered in our clinical practice. Generally, the risks of surgical operation at the thoracolumbar junction zone are greatly increased because the spinal canal at these levels accommodates the spinal cord, conus medullaris, or cauda equina. Additionally, clinical manifestations of TLDH are complex and various, including low back pain, intercostal neuralgia, leg pain, groin region pain, lower limb numbness with or without weakness, and walking difficulty, which causes severe suffering for patients (1). Moreover, postoperative TLDH outcome is worse than lower lumbar disc herniation (5). The classical posterior approach, including laminectomy and discectomy with or without internal fixation, requires extensive paravertebral muscle and facet joint resection to fully expose the herniated disc and dura sac, leading to spinal instability and leaving the patient susceptible to persistent low back pain and a higher risk of nerve injury (6, 7).

Nowadays, percutaneous endoscopic discectomy is well accepted by surgeons and patients for cervical and lumbar disc herniation treatment because of advantages like less trauma, less bleeding, faster recovery, and lower complication rates (8). Percutaneous endoscopic discectomy and decompression were introduced for treating thoracic disc herniation and thoracic stenosis with advances in endoscopic visualization and instrumentation (9, 10). However, percutaneous endoscopic transforaminal discectomy (PETD) for TLDH is rarely reported. Thus, this study performed a fully endoscopic transforaminal ventral discectomy technique, PETD, to treat patients with thoracolumbar junction zone disc herniation. This paper reports our technical notes of fully endoscopic transforaminal ventral discectomy for TLDH and the preliminary outcomes of 12 cases.

Materials and methods

Participants

We treated 15 patients diagnosed with TLDH using PETD from January 2019 to December 2021; of them, 12 met the inclusion criteria. More than one spinal surgeon was invited to diagnose based on clinical manifestations and imaging findings. All surgeries were completed by two skilled surgeons with extensive experience in the endoscopic technique. **Table 1** shows the patients' clinical characteristics. All procedures were authorized by the ethics committee of our institution. Written informed consent was obtained from all included patients. The privacy and critical interests of our patients were protected following the Declaration of Helsinki.

TABLE 1 Demographic findings of the study patients ($n = 12$).

Characteristic	Mean ± SD or *n*
Age (years)	53 ± 13.9
Sex, male:female	7:5
Side of the surgery, left:right	5:7
Levels involved, T11–12:T12–L1:L1–2	4:5:3
Low back pain	9
Leg pain	7
Thoracic radiculopathy	5
Paresthesia in lower limb	8
Lower limb weakness	5
Neurogenic claudication	7
Bladder dysfunction	2
Duration of surgery (mins)	101.3 ± 9.2
Blood loss (ml)	13.3 ± 3.9
Time in bed (h)	18.0 ± 7.0
Hospitalization time (days)	4.5 ± 1.3
Follow-up period (months)	14 ± 4.7

SD, standard deviation; *n*, number of patients.

The inclusion criteria were as follows: (1) TLDH diagnosis; (2) consistent symptoms, signs, and imaging findings; (3) complaints of a leg or thoracic radicular pain with or without low back pain, lower limb numbness with or without weakness, and walking difficulty, which cause severe suffering for patients; (4) conservatively treated for >3 months with limited therapeutic effect or no therapeutic effect; (5) learning the details of the procedure, including the surgical mechanism, possible clinical results, potential risks, and complications; and (6) ≥9-month follow-up postoperatively.

Exclusion criteria were patients (1) with complete cauda equina syndrome; (2) with dynamic instability or spondylolisthesis; (3) with anesthesia or medical conditions contraindicated for surgery; and (4) who were not cooperative.

Surgical technique

We performed all operations using the Endo-surgi Plus system or Endo-surgi Standard system (Shanghai Maoyu Medical [Group] Co., LTD, China) with or without an endoscopic high-speed bur or piezosurgery, depending on surgical necessity. Tranexamic acid was used preoperatively to prevent bleeding (11). Nerve function monitoring was used to prevent intraoperative nerve injury as in our previous study (11).

Skin marking and placement of working cannula

All patients were placed in the prone position on a radiolucent table after general anesthesia. The operation table was adjusted to enlarge the intervertebral foramen. The disc herniation segment was located under C-arm fluoroscopy (Figure 1A), and the puncture point approximately 6–8 cm lateral to the midline and tilted 10°–15° toward the cranial end was marked. An 18-G puncture needle was inserted onto the lateral side of the superior articular process (SAP) under C-arm fluoroscopy (Figure 1B) after disinfection and draping. The puncture needle was withdrawn after the guide wire was put into the needle, and the primary guide rod was introduced (Figure 1C) through the guide wire after making an incision. Then, a second guide rod and *U*-shaped working cannula were sequentially introduced (Figure 1D). The appropriate and safe location to avoid dura sac injury was confirmed with C-arm fluoroscopy, including the beveled end of the working channel not exceeding the line between the midpoints of pedicles on the same side in the anteroposterior view, and the beveled end of the working channel not exceeding the posterior edge of the vertebral body in the lateral view (Figures 1E,F).

Endoscopic procedure

A T-shaped working cannula and an endoscope were introduced into the U-shaped cannula in sequence. The soft tissue in the foramen was cleaned to expose the anatomical structure of the foramen after complete hemostasis. Then, the SAP was exposed and partly resected with a fully visualized trepan or a Kerrison rongeur, or endoscopic high-speed bur, depending on the surgical need (Figure 2A). Next, part of the ligamentum flavum ventral to the articular processes was resected (Figure 2B) to expose the herniated disc and compressed dural sac (Figure 2C). The degenerated nucleus pulposus in the intervertebral space and the hump of the intervertebral disc protruding into the spinal canal were sequentially removed with punch forceps and grasping forceps

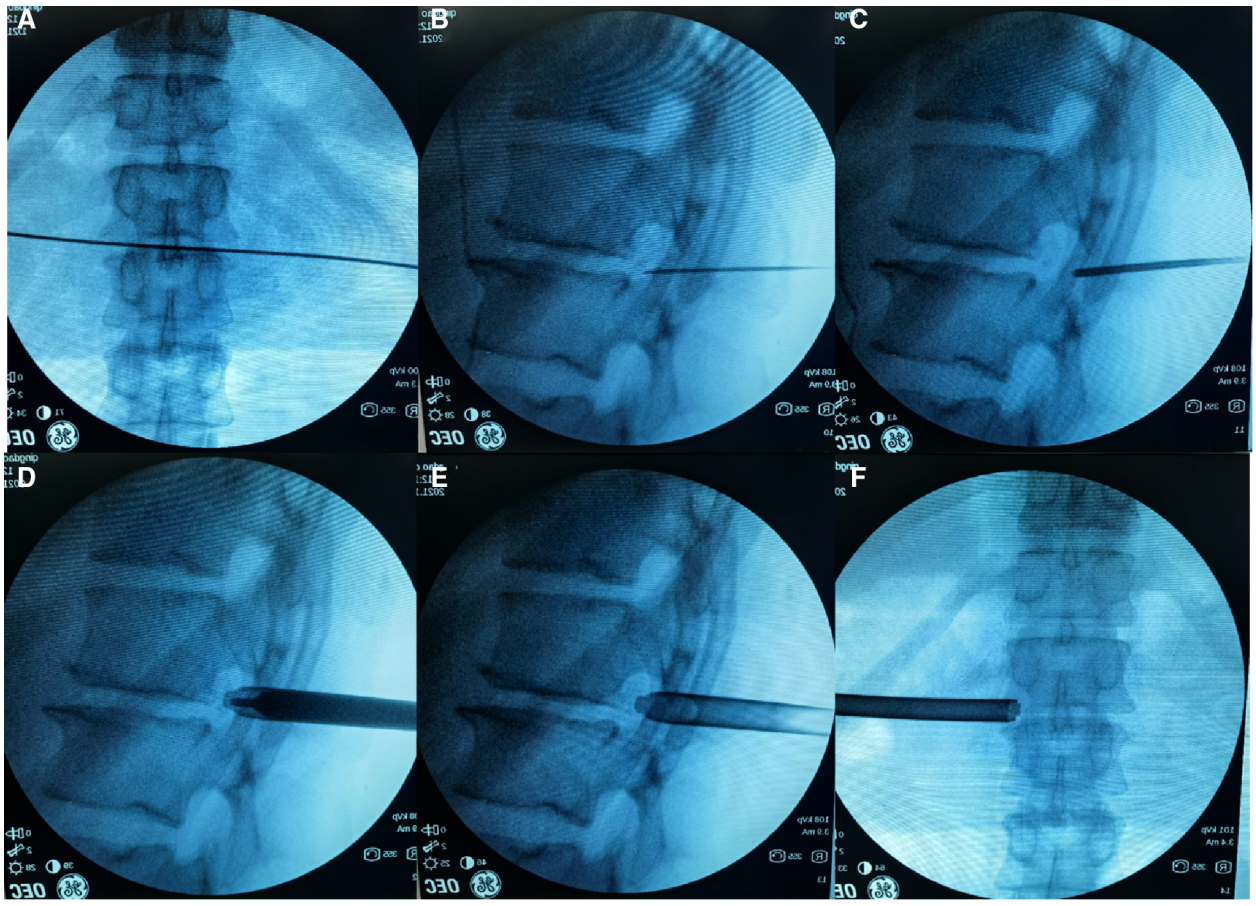

FIGURE 1
The procedure of establishing the working cannula with C-arm fluoroscopy assistance. (A) The location of segment to be operated. (B) The 18 G puncture needle inserted onto the lateral side of superior articular process. (C) The primary guide rod introduced through the guide wire. (D) The *U*-shaped working cannula introduced through the second guide rod. (E,F) The final location of the *U*-shaped working cannula under the anteroposterior and lateral view of C-arm fluoroscopy.

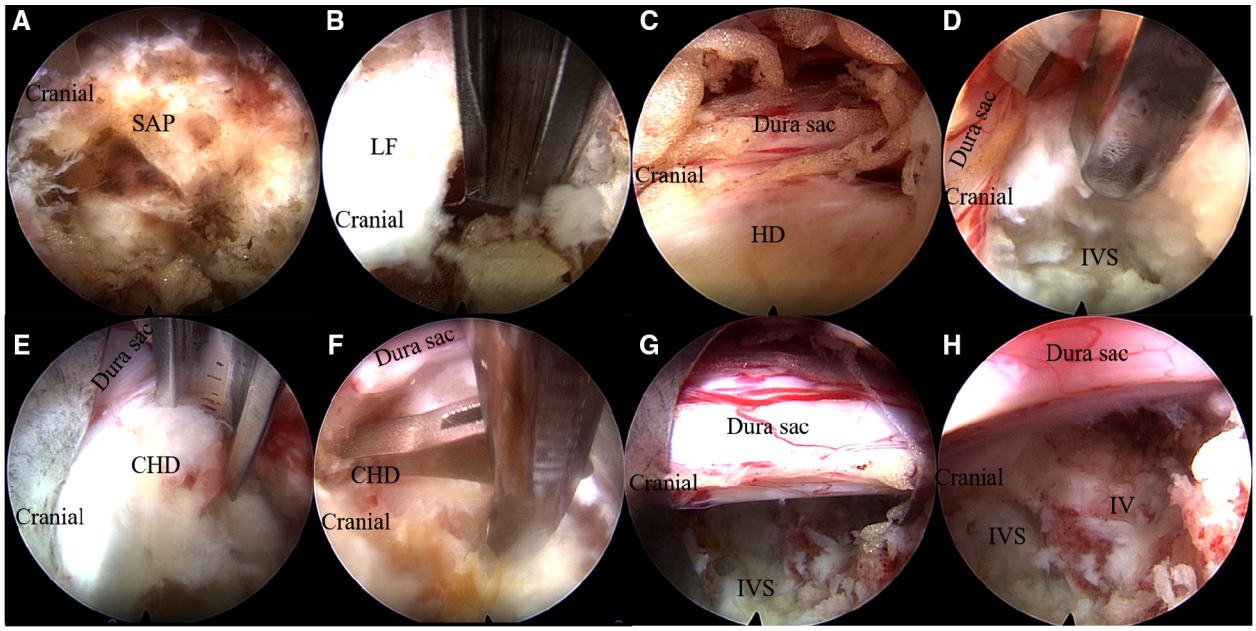

FIGURE 2
Main surgical procedures under endoscope. (A) The exposure of SAP and resection of SAP with a fully visualized trepan. (B) The ligamentum flavum ventral to the articular processes was resected with a Kerrison rongeur. (C) Exposure of the herniated disc and compressed dura sac. (D) Resection of the degenerated nucleus pulposus in the intervertebral space and the intervertebral disc protruded into the spinal canal with punch forceps. (E) Removal of the calcified herniated disc and ossified posterior longitudinal ligament at the posterior margin of the caudal vertebra with a chisel. (F) Removal of the calcified herniated disc at the posterior margin of the cranial vertebra with punch forceps. (G,H) Complete decompression of dura sac at the intervertebral space level and caudal side. SAP, superior articular process; LF, ligamentum flavum; HD, herniated disc; CHD, calcified herniated disc; IV, inferior vertebra; IVS, intervertebral space.

to decompress the dural sac and nerve ventrally after the annulus fibrosus incision (Figure 2D). Afterward, the calcified disc or ossified posterior longitudinal ligament or osteophyte at the posterior margin of the caudal vertebra and cranial vertebra was sequentially chiseled away with a chisel or resected with punch forceps (Figures 2E,F). This sequence reduced the incidence of neck pain due to water pressure for patients under local anesthesia. The hypertrophic ligamentum flavum on the dorsal side of the dural sac was further resected to obtain adequate dural sac and nerve decompression after the elevated dural sac returned. Next, complete hemostasis was performed using radiofrequency electrodes. Satisfactory decompression was obtained (Figures 2G,H) and then the endoscope and the working cannula were withdrawn. Finally, the incision was sutured without placing a drainage tube.

Outcome assessment

All included patients were evaluated preoperatively, at 1 day and 3, 6, and 12 months postoperatively or at last follow-up. Clinical outcomes were evaluated with the modified Japanese Orthopedic Association score (m-JOA) (12). The degree of low back and leg or thoracic radicular pain was evaluated with a visual analog scale (VAS). The modified MacNab criteria were used to assess clinical effectiveness 12 months postoperatively or the last follow-up (13). All patients were evaluated using magnetic resonance imaging (MRI) and computed tomography (CT) before discharge and at least once during the follow-up.

Statistical analysis

We used Statistical Package for the Social Sciences (version 24.0; SPSS Inc., Chicago, IL, United States) for all clinical data statistical analyses. All data of pre- and postoperative VAS and m-JOA scores were expressed as mean ± standard deviation and were analyzed with the paired *t*-test if the data were normally distributed or were analyzed with Wilcoxon signed-rank test. Statistical significance was set at *P*-values of <0.05.

Results

Demographic characteristics and summary of primary clinical manifestations

This study included 12 patients, including 5 with soft disc herniation and 7 with disc herniation combined with

TABLE 2 Summary of preoperative primary clinical manifestations and imaging features of the 12 patients who were treated with fully endoscopic transforaminal discectomy and ventral decompression surgery.

Case No.	Age (years)	Sex	Location	Primary clinical manifestations	Soft/calcified (or with other type of calcification)
1	36	M	T12–L1	Leg pain, paresthesia in lower limb, neurogenic claudication	Calcified (OPLL)
2	40	F	T12–L1	Low back pain, leg pain, paresthesia in lower limb, neurogenic claudication	Calcified (OPLL)
3	63	M	T11–L2	Low back pain, thoracic radiculopathy, lower limb weakness	Soft
4	70	M	L1–2	Low back pain, leg pain, paresthesia in lower limb, neurogenic claudication	Calcified
5	42	M	T12–L1	Leg pain, paresthesia in lower limb, neurogenic claudication	Calcified (EPO)
6	38	F	T12–L1	Low back pain, leg pain paresthesia in lower limb, neurogenic claudication	Soft
7	40	M	T11–12	Leg pain, paresthesia in lower limb, neurogenic claudication	Calcified (EPO)
8	64	F	L1–L2	Low back pain, leg pain, paresthesia in lower limb, neurogenic claudication	Soft
9	62	F	T11–L2	Low back pain, thoracic radiculopathy paresthesia in lower limb, lower limb weakness	Soft
10	44	M	T12–L1	Low back pain, thoracic radiculopathy, lower limb weakness, bladder dysfunction	Calcified
11	71	F	T11–L2	Low back pain, thoracic radiculopathy, lower limb weakness	Calcified
12	66	M	L1–2	Low back pain, thoracic radiculopathy, lower limb weakness, bladder dysfunction	Soft

F, female; M, male; OPLL, ossification of posterior longitudinal ligament; EPO, endplate osteophyte.

calcification, according to the inclusion and exclusion criteria. Table 1 shows the patient demographic characteristics. Table 2 shows the preoperative primary clinical manifestations and imaging features of the 12 patients.

Clinical results

The excellent and good rate of patients evaluated with the modified MacNab criteria was 83.3%. Two patients presented fair results and occasionally demanded pain medication or physical therapy. Table 3 shows the detailed results. VAS scores for both low back pain and leg or thoracic radicular pain improved, with more significant improvement in the latter. Additionally, m-JOA showed significant improvement postoperatively than preoperatively. Significant differences were found in the preoperative and postoperative scores of m-JOA, low back pain VAS, and leg or thoracic radicular pain VAS at different time points (1 day and 3, 6, and 12 months postoperatively or at last follow-up) (Table 4). Moreover, Table 5 shows the major outcome preoperatively and 12 months postoperatively or last follow-up.

TABLE 3 Modified MacNab outcomes of 12 months after operation or at last follow-up ($n = 12$).

Outcomes	Description	*n* (%)
Excellent	Complete relief of symptoms	6 (50)
Good	Marked improvement but occasional pain	4 (33.3)
Fair	Improved functional capacity and the need for pain medications	2 (16.7)
Poor	Unimproved symptoms or worsening	0 (0)

n, number of patients.

Complications

This study revealed a 16.7% incidence of minor complications, where two patients experienced transient lower limb dysesthesia postoperatively. The dysesthesia was relieved upon the 3-month follow-up visit. No severe complications, such as lung injury, pleura injury, viscera injury, spinal cord injury, nerve injury, dural tear, and cerebrospinal fluid (CSF) leakage occurred.

Representative case

A 38-year-old male patient suffered from low back pain and both lower limb weakness, combined with intermittent claudication for >1 year. His symptoms gradually worsened, and his VAS score for low back pain was 6 out of 10. The distance of intermittent claudication is approximately 300 m. Physical examination demonstrated bilateral lower leg and feet hypoesthesia, which is more severe on the left side, as well as decreased muscle power of tibialis anterior and extensor hallucis longus to grades 3 and 4 on the left and right sides, respectively. The dynamic lumbar radiography showed no segmental instability at the T12–L1 level. MRI and CT revealed severe central disc herniation combined with calcification and ossification of posterior longitudinal ligament at the T12–L1 level (Figure 3). Thus, we performed PETD at the T12–L1 level. The patient got out of bed and ambulated

TABLE 4 Mean change of outcome measurement (mean ± SD).

Outcome measurement	Pre-op	Before discharge	3-month post-op	6-month post-op	12-month post-op or last follow-up
Low back pain VAS	5.8 ± 1.5	4.2 ± 1.2*	2.8 ± 0.9*	2.2 ± 0.9*	2.0 ± 0.9*
Leg or thoracic radicular pain VAS	6.5 ± 1.4	3.9 ± 0.8*	2.5 ± 0.5*	1.3 ± 0.5*	1.3 ± 0.5*
m-JOA	7.5 ± 1.2	7.8 ± 0.9	9.0 ± 0.7*	9.3 ± 0.9*	10.0 ± 0.7*

*$P < 0.05$ versus preoperative data.
VAS, visual analog scale; SD, standard deviation; m-JOA, modified Japanese orthopedic association score; op, operation.

TABLE 5 Operation time, blood loss, time in bed, hospital stay time, follow-up period, and pre- and postoperative m-JOA and VAS assessed 12 months postoperatively or at last follow-up.

Case No.	Op time (mins)	Blood loss (ml)	Time in bed (h)	Hospital stay time (days)	Follow-up period (months)	m-JOA		Low back pain VAS		Leg or thoracic radicular pain VAS	
						Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op
1	125	20	12	3	24	6	10	3	1	4	1
2	104	15	24	3	18	9	11	8	2	9	1
3	100	10	16	4	18	8	10	5	2	6	1
4	110	10	20	6	18	7	9	7	3	7	2
5	98	15	14	5	15	6	10	4	2	5	1
6	92	20	15	3	12	9	11	7	0	7	1
7	105	10	19	5	12	7	9	6	2	8	1
8	102	10	12	4	12	6	10	4	2	5	1
9	96	15	22	4	12	8	10	6	2	6	1
10	94	10	12	4	9	9	11	7	2	7	2
11	95	15	36	7	9	7	9	7	4	8	2
12	94	10	14	6	9	8	10	6	2	6	1

m-JOA, modified Japanese orthopedic association score; VAS, visual analog scale; op, operation.

approximately 16 h postoperatively. His VAS score for low back pain decreased from 6 to 4, and his bilateral muscle power of the tibialis anterior and extensor hallucis longus recovered partly postoperatively. MRI and CT at 1 day postoperatively revealed sufficient decompression (**Figures 4A–F**). His back pain completely disappeared 3 months postoperatively. Additionally, his bilateral muscle power of the tibialis anterior and extensor hallucis longus recovered to grade 5 at 6 months postoperatively, and MRI showed perfect dural sac decompression and normal CSF signals surrounding the dura (**Figures 4G–I**).

Discussion

Generally, the anatomical structure of the thoracolumbar junction zone is different from the lower lumbar vertebrae. First, the spinal cord transitions to the cauda equina in the thoracolumbar junction zone (1). Second, the dural sac diameter in the thoracolumbar junction zone is larger than in the lower lumbar spine (6). Third, the space between the 2 pars interarticularis, as well as the interlaminar window, gets smaller, and the inferior edge of the lamina covers more of the intervertebral space (6). Therefore, the clinical manifestations of disc herniation in this region are different from the thoracic and lower lumbar vertebrae (1). Additionally, performing a discectomy and ventral decompression surgery for disc herniation in this region is more challenging than in the lower lumbar vertebrae. Therefore, selecting the appropriate surgical method to remove herniated discs in the thoracolumbar junction zone is very important.

Conventional open thoracic discectomy and decompression surgery incurs great trauma, has a high rate of complications, and always demands additional internal fixation (7, 14). PETD was widely accepted by surgeons and patients due to its advantages of being less invasive, rapid recovery, less bleeding, short hospital stay, and low cost, with the popularization of minimally invasive concepts and advances in endoscopic techniques (15, 16). The excellent as well as

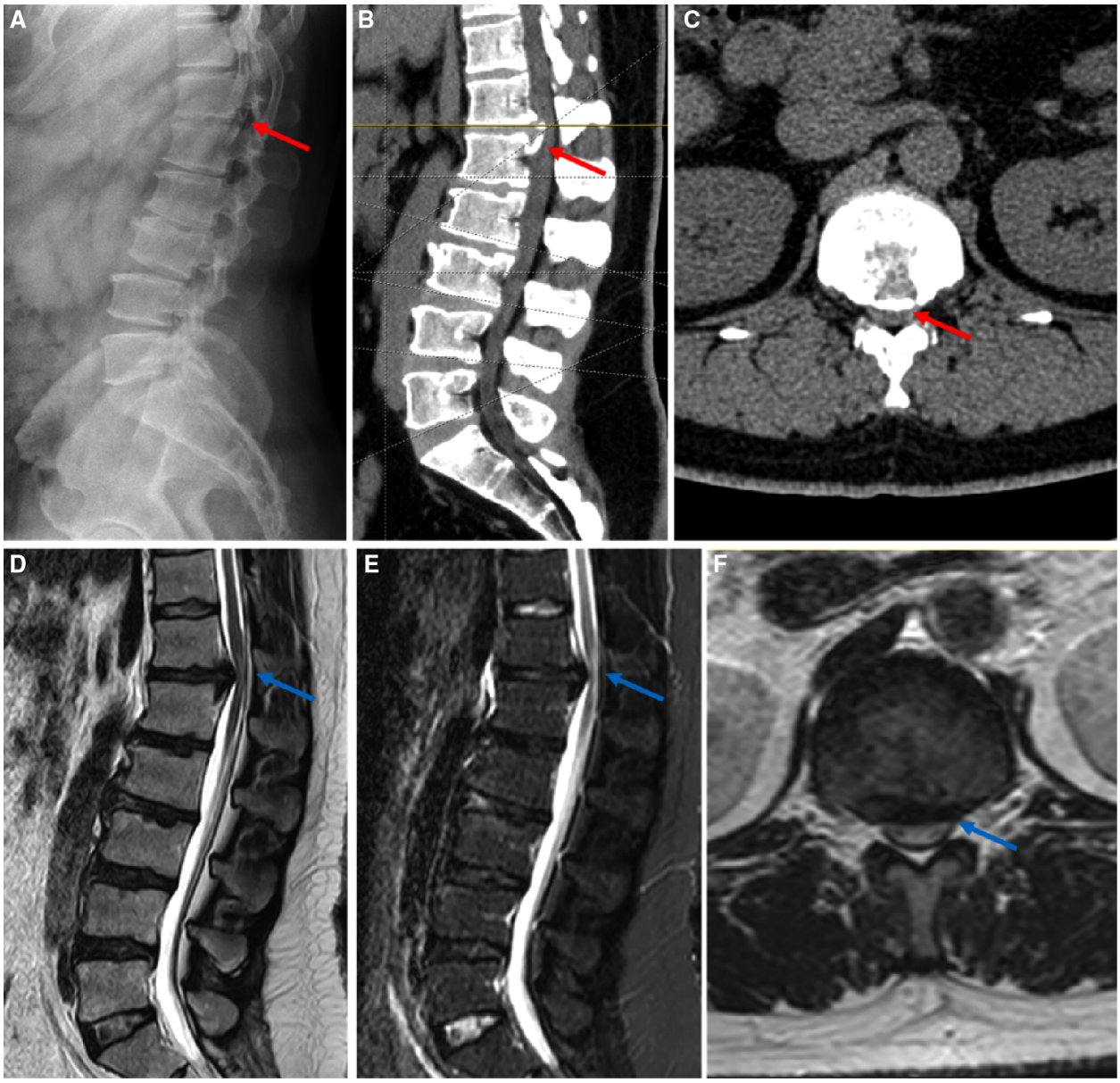

FIGURE 3
Preoperative imaging of the typical patient with disc herniation at the T12–L1 level. A 38-year male patient diagnosed with TLDH with calcification at the T12–L1 level underwent PETD under general anesthesia. (**A–C**) Preoperative x-ray and CT. The red arrow in (**A–C**) highlighted calcified herniated disc and ossified posterior longitudinal ligament. (**D–F**) Preoperative MRI. The blue arrows in (**D–F**) highlighted severe compression of spinal cord and the normal signal of cerebrospinal fluid cannot be seen. (**A,B,D,E**) sagittal view; (**C,F**) axial view; TLDH, thoracolumbar junction disc herniation; PETD, percutaneous endoscopic transforaminal discectomy; CT, computed tomography; MRI, magnetic resonance imaging.

good outcomes and the advantages of full-endoscopic spine surgery have been proven for the treatment of herniated discs and stenoses in the lumbar and cervical vertebrae (11, 17, 18). Additionally, the next step after mastering lumbar and cervical endoscopic spinal surgery is managing the thoracic pathology with the full-endoscopic technique (19). Recently, many surgeons worldwide tried various minimally invasive surgery techniques, such as surgery-transforaminal lumbar interbody fusion, video-assisted thoracoscopic surgery, microendoscopic surgery, and full-endoscopic surgery, to treat thoracic pathology (4, 9, 20–22).

Few studies were conducted to investigate TLDH as a specific type of disc herniation due to the low incidence rate of TLDH (4, 6, 22). This retrospective study regarded the disc herniation at the thoracolumbar junction zone (T11–12, T12–L1, and L1–2) as a special entity of disc herniation and

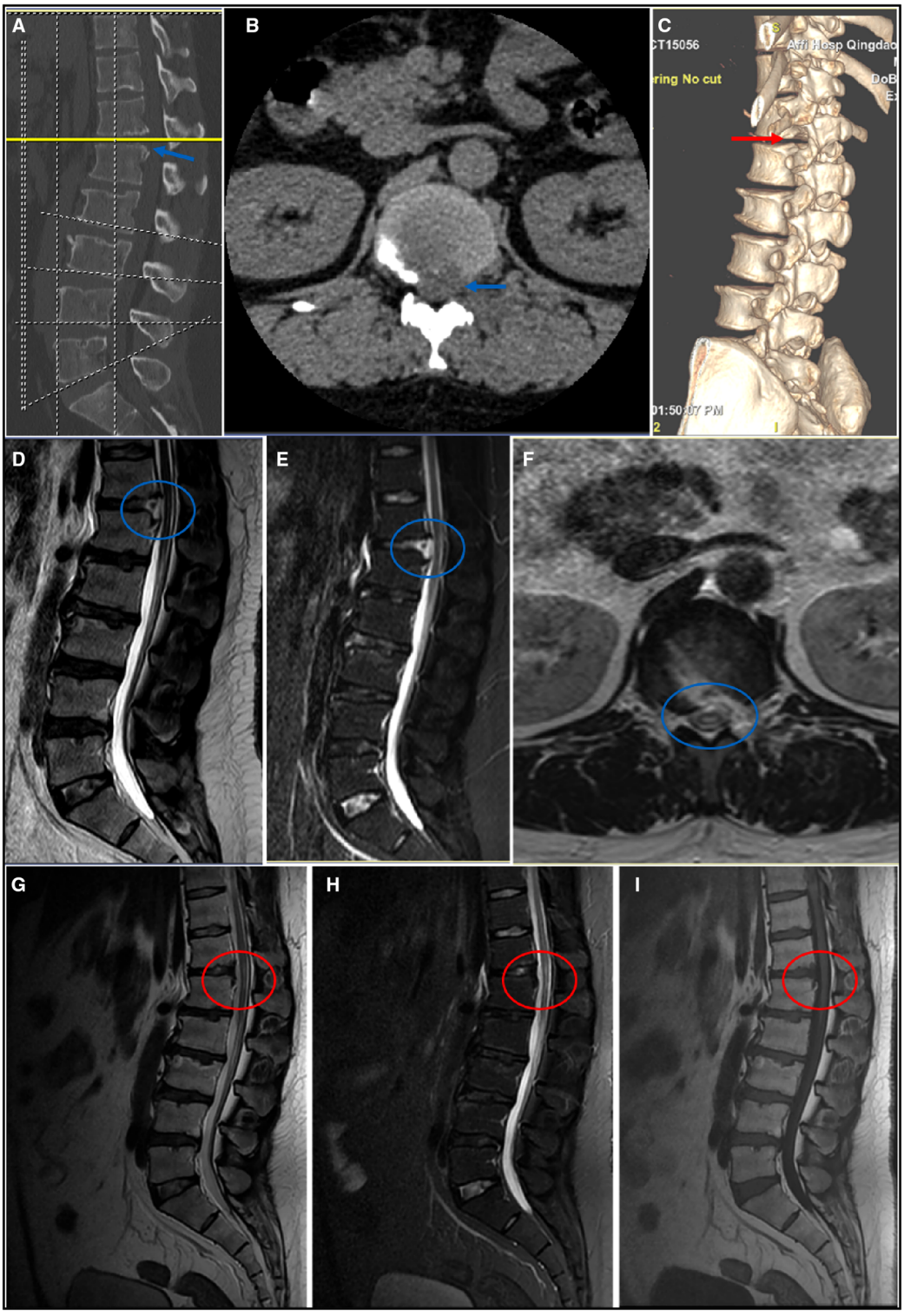

FIGURE 4
Postoperative imaging of the typical patient with disc herniation at the T12–L1 level. (**A–C**) CT at 1 day postoperatively. The blue arrow shows sufficient removal of calcific herniated disc. The red arrow shows that the SAP is partly resected and the stability of the spine is preserved. (**D–F**) MRI at 1 day postoperatively. The blue circle shows complete decompression of dura sac with a small amount of fluid signal in the ventral side of dura sac. (**G–I**) MRI at 6 months postoperatively. The red circle shows perfect decompression of dura sac and normal signal of cerebrospinal fluid surrounding the dura. (**A**,**D**,**E**,**G–I**) sagittal view; (**B**,**F**) axial view; (**C**) three-dimensional reconstruction. SAP, superior articular process; CT, computed tomography; MRI, magnetic resonance imaging.

reported the early clinical outcomes of 12 patients with TLDH and treated with PETD. Encouragingly, our cases revealed 83.3% excellent and good rates with the modified MacNab criteria. A review reported that excellent or good outcomes were achieved for full-endoscopic procedures in a mean of 81% of patients with thoracic pathology (range 46%–100%) (23). Ahn et al. reported 77.8% excellent and good rates of L1–L2 and the L2–L3 levels treated with PETD (24). The clinical efficacy of this article was comparable with the published results (23, 24). Gao et al. reported 11 cases of symptomatic thoracic disc herniation treated with a full-endoscopic transforaminal ventral decompression technique (9). The mean m-JOA improved from 7.4 preoperatively to 10.2 at last follow-up (9). Additionally, the mean m-JOA of six thoracic disc herniation cases reported by Guo et al. improved from 4.4 preoperatively to 6.6 1 year postoperatively (25). The mean m-JOA in the present study improved from 7.5 preoperatively to 10.0 12 months postoperatively or at last follow-up, which was similar to previous studies (9, 25). A mean VAS improvement from 5.8 to 2.0 for low back pain and 6.5 to 1.3 for leg or thoracic radicular pain in this study was close to the study by Choi et al. (26). Furthermore, postoperative MRI in all patients showed sufficient ventral spinal cord decompression and unobstructed cerebrospinal fluid circulation in the spinal canal.

Ruetten et al. reported a 20% complication rate, of which 8% were severe complications, including one epidural hematoma without revision and one myelopathy deterioration (27). However, severe complications were not documented in the present study and studies by Guo et al. (25) and Gao et al. (9). This is because of the small sample size of our study and careful manipulation as well as nerve function monitoring in operation. Two patients complained of unsatisfactory relief of their low back pain, which could be relieved with nonsteroidal analgesics and physical therapy.

Our study revealed satisfactory clinical outcomes without severe complications because of the following four main aspects. First, the beveled end of the working cannula was not inserted into the spinal canal before introducing the endoscope, and foraminoplasty was performed with a fully visualized trepan under the endoscope, not only enlarging the foramen according to decompression requirement but also avoiding the dural sac, as well as nerve injury. Second, the diameter of the dural sac in the thoracolumbar junction region is larger and the diameter of the spinal canal is smaller than the lower lumbar vertebrae (6). Thus, the epidural space is small, and the surrounding anatomical environment lacks sufficient buffer space. Therefore, removing the disc in the intervertebral space as indirect "box-shaped decompression" described by Ruetten et al. before direct removal of herniated disc compressing the dural sac, avoiding spinal cord injury, especially for herniated disc combined with calcification or endplate osteophyte or local ossification of posterior longitudinal ligament, is very important (27). Third, the calcific herniated disc is more difficult to remove than the soft herniated disc. Thus, after removing the herniated disc on the intervertebral level, the direction of the working cannula needs to be adjusted to meticulously resect the calcific herniated disc (or osteophyte or local ossification of the posterior longitudinal ligament) at the posterior margin of the caudal and cranial vertebra in sequence. This sequence can help avoid or at least reduce the incidence of neck pain due to water pressure in patients under local anesthesia. Fourth, tranexamic acid was used preoperatively to reduce bleeding and nerve function monitoring was used intraoperatively to prevent spinal cord and nerve injury in all the operations, as in our previous study (11).

Foraminoplasty has become increasingly safe with advances in the full-visualized trephine technique. It also enables patients to receive percutaneous endoscopic lumbar discectomy under general anesthesia. General anesthesia could reduce patients' intraoperative pain and tension and significantly improve patients' surgical experience (28). Additionally, general anesthesia provides surgeons with the opportunity to focus more on the operation and shorten the operative time without worrying about the patient's intraoperative feelings during the operation. From our point of view, full-endoscopic discectomy under general anesthesia is safe and does not significantly increase the incidence of complications. However, postoperative complications, such as nerve root injury in 10% of patients and nausea, vomiting, dizziness, and drowsiness in 15% of patients under general anesthesia, were observed in another study (29).

Our study limitations are obvious. The sample size was small; thus, our conclusion is less persuasive. Additionally, potential risks and complications are associated with this technique. Furthermore, this observational study had early results; therefore, prospective randomized controlled studies with larger sample sizes and long-term follow-up should be conducted in the future to obtain more convincing conclusions.

Conclusion

Fully endoscopic transforaminal discectomy and ventral decompression under general anesthesia is a safe, feasible, effective, and minimally invasive method for treating herniated discs with or without calcification at the thoracolumbar junction zone.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

We have acquired the ethics statement from Medical Ethics Committee of Affiliated Hospital of Qingdao University and the number of ethics statement was QYFY WZLL 27330. The article did not contain identifiable human images.

Author contributions

SM and JH drafted the manuscript. XM and CZ performed the surgery. AL, KS, YL, and XH collected and interpreted the patient's clinical data. SH and KZ were responsible for statistical analysis. DX and YW contributed to the revision. All authors contributed to this article and approved the submitted version.

Funding

This work was supported by the funds from the National Key Research and Development Program of China (2019YFC0121400), the National Natural Science Foundation of China (81871804 and 82100940), and the Natural Science Foundation of Shan Dong Province (ZR2021MH020).

Acknowledgment

Thanks to all staffs of the Department of Spinal Surgery of the Qingdao University Affiliated Hospital for their support and help for this study. Thanks to enago (www.enago.cn) for providing English language touch-ups.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

1. Tokuhashi Y, Matsuzaki H, Uematsu Y, Oda H. Symptoms of thoracolumbar junction disc herniation. *Spine (Phila Pa 1976)*. (2001) 26(22):E512–8. doi: 10.1097/00007632-200111150-00021

2. Iyer S, Kim HJ. Cervical radiculopathy. *Curr Rev Musculoskelet Med*. (2016) 9 (3):272–80. doi: 10.1007/s12178-016-9349-4

3. Hsu K, Zucherman J, Shea W, Kaiser J, White A, Schofferman J, et al. High lumbar disc degeneration. Incidence and etiology. *Spine (Phila Pa 1976)*. (1990) 15 (7):679–82. doi: 10.1097/00007632-199007000-00012

4. Wang J, Zhou Y, Zhang ZF, Li CQ, Zheng WJ, Huang B. Disc herniation in the thoracolumbar junction treated by minimally invasive transforaminal interbody fusion surgery. *J Clin Neurosci*. (2014) 21(3):431–5. doi: 10.1016/j.jocn.2013.04.029

5. Sanderson SP, Houten J, Errico T, Forshaw D, Bauman J, Cooper PR. The unique characteristics of "upper" lumbar disc herniations. *Neurosurgery*. (2004) 55(2):385–9, discussion 389. doi: 10.1227/01.neu.0000129548.14898.9b

6. Kim JS, Lee SH, Moon KH, Lee HY. Surgical results of the oblique paraspinal approach in upper lumbar disc herniation and thoracolumbar junction. *Neurosurgery*. (2009) 65(1):95–9, discussion 99. doi: 10.1227/01.NEU.0000348299.89232.C2

7. Carr DA, Volkov AA, Rhoiney DL, Setty P, Barrett RJ, Claybrooks R, et al. Management of thoracic disc herniations via posterior unilateral modified transfacet pedicle-sparing decompression with segmental instrumentation and interbody fusion. *Global Spine J*. (2017) 7(6):506–13. doi: 10.1177/2192568217694140

8. Pan M, Li Q, Li S, Mao H, Meng B, Zhou F, et al. Percutaneous endoscopic lumbar discectomy: indications and complications. *Pain Physician*. (2020) 23 (1):49–56. PMID: 32013278

9. Gao S, Wei J, Li W, Zhang L, Cao C, Zhai J, et al. Full-endoscopic transforaminal ventral decompression for symptomatic thoracic disc herniation with or without calcification: technical notes and case series. *Pain Res Manag*. (2021) 2021:6454760. doi: 10.1155/2021/6454760

10. Yang FK, Li PF, Dou CT, Yu RB, Chen B. Comparison of percutaneous endoscopic thoracic decompression and posterior thoracic laminectomy for treating thoracic ossification of the ligamentum flavum: a retrospective study. *BMC Surg*. (2022) 22(1):85. doi: 10.1186/s12893-022-01532-z

11. Meng S, Xu D, Han S, Li G, Wang Y, Shen Y, et al. Fully endoscopic 360° decompression for central lumbar spinal stenosis combined with disc herniation: technical note and preliminary outcomes of 39 cases. *J Pain Res*. (2022) 15:2867–78. doi: 10.2147/JPR.S379431

12. Liu N, Chen Z, Qi Q, Li W, Guo Z. Circumspinal decompression and fusion through a posterior midline incision to treat central calcified thoracolumbar disc herniation: a minimal 2-year follow-up study with reconstruction CT. *Eur Spine J*. (2014) 23(2):373–81. doi: 10.1007/s00586-013-3054-4

13. Macnab I. Negative disc exploration. An analysis of the causes of nerve-root involvement in sixty-eight patients. *J Bone Joint Surg Am*. (1971) 53(5):891–903. doi: 10.2106/00004623-197153050-00004

14. Brotis AG, Tasiou A, Paterakis K, Tzerefos C, Fountas KN. Complications associated with surgery for thoracic disc herniation: a systematic review and network meta-analysis. *World Neurosurg*. (2019) 132:334–42. doi: 10.1016/j.wneu.2019.08.202

15. Jing Z, Li L, Song J. Percutaneous transforaminal endoscopic discectomy versus microendoscopic discectomy for upper lumbar disc herniation: a retrospective comparative study. *Am J Transl Res*. (2021) 13(4):3111–9. PMID: 34017479

16. Li Z, Zhang C, Chen W, Li S, Yu B, Zhao H, et al. Percutaneous endoscopic transforaminal discectomy versus conventional open lumbar discectomy for upper lumbar disc herniation: a comparative cohort study. *Biomed Res Int*. (2020) 2020:1852070. doi: 10.1155/2020/1852070

17. Meng SW, Peng C, Zhou CL, Tao H, Wang C, Zhu K, et al. Massively prolapsed intervertebral disc herniation with interlaminar endoscopic spine system Delta endoscope: a case series. *World J Clin Cases*. (2021) 9(1):61–70. doi: 10.12998/wjcc.v9.i1.61

18. Luo RJ, Song Y, Liao ZW, Yin HP, Zhan SF, Lu SD, et al. Keyhole foraminotomy via a percutaneous posterior full-endoscopic approach for cervical radiculopathy: an advanced procedure and clinical study. *Curr Med Sci*. (2020) 40(6):1170–6. doi: 10.1007/s11596-020-2299-5

19. Bae J, Lee SH, Wagner R, Shen J, Telfeian AE. Full endoscopic surgery for thoracic pathology: next step after mastering lumbar and cervical endoscopic spine surgery? *Biomed Res Int*. (2022) 2022:8345736. doi: 10.1155/2022/8345736

20. Bordon G, Burguet Girona S. Experience in the treatment of thoracic herniated disc using image-guided thorascopy. *Rev Esp Cir Ortop Traumatol*. (2017) 61(2):124–9. doi: 10.1016/j.recot.2015.07.003

21. Yüce İ, Kahyaoğlu O, Çavuşoğlu HA, Çavuşoğlu H, Aydın Y. Midterm outcome of thoracic disc herniations that were treated by microdiscectomy with bilateral decompression via unilateral approach. *J Clin Neurosci*. (2018) 58:94–9. doi: 10.1016/j.jocn.2018.09.033

22. Telfeian AE, Jasper GP, Oyelese AA, Gokaslan ZL. Technical considerations in transforaminal endoscopic spine surgery at the thoracolumbar junction: report of 3 cases. *Neurosurg Focus*. (2016) 40(2):E9. doi: 10.3171/2015.10.FOCUS15372

23. Gibson RDS, Wagner R, Gibson JNA. Full endoscopic surgery for thoracic pathology: an assessment of supportive evidence. *EFORT Open Rev*. (2021) 6 (1):50–60. doi: 10.1302/2058-5241.6.200080

24. Ahn Y, Lee SH, Lee JH, Kim JU, Liu WC. Transforaminal percutaneous endoscopic lumbar discectomy for upper lumbar disc herniation: clinical outcome, prognostic factors, and technical consideration. *Acta Neurochir (Wien)*. (2009) 151(3):199–206. doi: 10.1007/s00701-009-0204-x

25. Guo C, Zhu D, Kong Q, Zhang L, Wang Y, Yang J, et al. Transforaminal percutaneous endoscopic decompression for lower thoracic spinal stenosis. *World Neurosurg*. (2019) 128:e504–12. doi: 10.1016/j.wneu.2019.04.186

26. Choi KY, Eun SS, Lee SH, Lee HY. Percutaneous endoscopic thoracic discectomy; transforaminal approach. *Minim Invasive Neurosurg*. (2010) 53 (1):25–8. doi: 10.1055/s-0029-1246159

27. Ruetten S, Hahn P, Oezdemir S, Baraliakos X, Godolias G, Komp M. Operation of soft or calcified thoracic disc herniations in the full-endoscopic uniportal extraforaminal technique. *Pain Physician*. (2018) 21(4):E331–40. doi: 10.36076/ppj.2018.4.E331

28. Ye XF, Wang S, Wu AM, Xie LZ, Wang XY, Chen JX, et al. Comparison of the effects of general and local anesthesia in lumbar interlaminar endoscopic surgery. *Ann Palliat Med*. (2020) 9(3):1103–8. doi: 10.21037/apm-20-623

29. Kerimbayev T, Kenzhegulov Y, Tuigynov Z, Aleinikov V, Urunbayev Y, Makhambetov Y, et al. Transforaminal endoscopic discectomy under general and local anesthesia: a single-center study. *Front Surg*. (2022) 9:873954. doi: 10.3389/fsurg.2022.873954

frontiers | Frontiers in Surgery

TYPE Original Research
PUBLISHED 16 January 2023
DOI 10.3389/fsurg.2022.1107883

OPEN ACCESS

EDITED BY
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SPECIALTY SECTION
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

RECEIVED 25 November 2022
ACCEPTED 30 December 2022
PUBLISHED 16 January 2023

CITATION
Cheng X, Bao B, Wu Y, Cheng Y, Xu C, Ye Y, Dou C, Chen B, Yan H and Tang J (2023) Clinical comparison of percutaneous transforaminal endoscopic discectomy and unilateral biportal endoscopic discectomy for single-level lumbar disc herniation. Front. Surg. 9:1107883. doi: 10.3389/fsurg.2022.1107883

Clinical comparison of percutaneous transforaminal endoscopic discectomy and unilateral biportal endoscopic discectomy for single-level lumbar disc herniation

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Purpose: To compare the clinical outcomes of percutaneous transforaminal endoscopic discectomy (PTED) and unilateral biportal endoscopic discectomy (UBE) for the treatment of single-level lumbar disc herniation (LDH).

Materials and methods: From January 2020 to November 2021, 62 patients with single-level LDH were retrospectively reviewed. All patients underwent spinal surgeries at the Affiliated Hospital of Chengde Medical University and Beijing Tongren Hospital, Capital Medical University. Among them, 30 patients were treated with UBE, and 32 were treated with PTED. The patients were followed up for at least one year. Patient demographics and perioperative outcomes were reviewed before and after surgery. The Oswestry Disability Index (ODI), visual analog scale (VAS) for back pain and leg pain, and modified MacNab criteria were used to evaluate the clinical outcomes. x-ray examinations were performed one year after surgery to assess the stability of the lumbar spine.

Results: The mean ages in the UBE and PTED groups were 46.7 years and 48.0 years, respectively. Compared to the UBE group, the PTED group had better VAS scores for back pain at 1 and 7 days after surgery (3.06 ± 0.80 vs. 4.03 ± 0.81, $P < 0.05$; 2.81 ± 0.60 vs. 3.70 ± 0.79, $P < 0.05$). The UBE and PTED groups demonstrated significant improvements in the VAS score for leg pain and ODI score, and no significant differences were found between the groups at any time after the first month ($P > 0.05$). Although the good-to-excellent rate of the modified MacNab criteria in the UBE group was similar to that in the PTED group (86.7% vs. 87.5%, $P > 0.05$), PTED was advantageous in terms of the operation time, estimated blood loss, incision length, and length of postoperative hospital stay.

Conclusions: Both UBE and PTED have favorable outcomes in patients with single-level LDH. However, PTED is superior to UBE in terms of short-term postoperative back pain relief and perioperative quality of life.

KEYWORDS

lumbar disc herniation, percutaneous transforaminal endoscopic discectomy, unilateral biportal endoscopic discectomy, endoscopic, minimally invasive surgery

Abbreviations
LDH, lumbar disc herniation; PTED, Percutaneous transforaminal endoscopic discectomy; UBE, unilateral biportal endoscopic discectomy; DDD, Degenerative disc disease; VAS, The visual analog scale; ODI, Oswestry Disability Index.

Introduction

Lumbar disc herniation (LDH), with the disc material extruded outside the normal intervertebral space, is the main cause of low back and lower extremity pain (1). Although conservative care remains the main strategy for treatment, discectomy is required when clinical symptoms cannot be resolved *via* nonsurgical treatment (2, 3).

With advances in medical technology, open discectomy has been gradually replaced by minimally invasive spine surgery, and microdiscectomy has become an important part of the treatment of LDH (4). Facilitated by the development of endoscopic equipment and techniques, a variety of modified minimally invasive lumbar surgical techniques have been developed (5).

To protect the normal spinal structure, percutaneous transforaminal endoscopic discectomy (PTED) for LDH was developed after it was proposed by Yeung in 1997 and Hoogland in 2003 (6, 7). Based on the safety area of the lumbar posterolateral zone, PTED could remove the herniated disc effectively under local anesthesia (8). With favorable clinical results and good perioperative quality of life, PTED is appreciated by many spinal surgeons and patients (9). However, in addition to its steep learning curve, this technique requires specialized equipment, and discectomy is limited by the working channel (10).

In recent years, unilateral biportal endoscopic discectomy (UBE) with an arthroscopy system has become increasingly popular, especially in Asia (11). UBE decompression is performed on the ipsilateral side *via* two small separated surgical portals. Compared to PTED, UBE is not limited by the uniportal tube (12). The surgeons could perform discectomy and annulus fibrosus suture in a magnified surgical field with a high-definition arthroscope and a clear surgical field with saline irrigation (13). Previous reports have also shown satisfactory clinical outcomes of UBE for cervical and thoracic spinal disease (14, 15).

Few studies have directly compared PTED and UBE for the treatment of LDH (16). Therefore, to explore the differences between the two surgical techniques, this study compared the clinical efficacy of UBE and PTED for treating single level LDH.

Methods

Demographic characteristics

We performed a retrospective review in two hospitals of patients who underwent UBE and PTED from January 2020 to November 2021 after a diagnosis of single-level LDH. These surgeries were performed by two experienced surgeons. They had open lumbar surgery experience of more than 15 years, and PTED and UBE experience of more than 3 years. The baseline parameters of their demographic characteristics are given in **Table 1**. This retrospective study was approved by the Ethics Committee of the Chengde Medical University Affiliated Hospital, and written informed consent was obtained from the participants before data collection. The inclusion criteria were: (1) significant lower extremity radiating pain due to single-level LDH on x-ray, CT and MRI; (2) the absence of improvement after conservative treatment for at least three months; and (3) follow-up of at least 12 months after surgery. The exclusion criteria were: (1) mainly back pain symptoms or segmental instability on x-ray; (2) prior lumbar surgery; (3) tumor, infection, or trauma; and (4) inability to tolerate general anesthesia. The perioperative outcomes and complications were reviewed. An independent surgeon evaluated the VAS and ODI scores and modified MacNab criteria. x-ray examinations were performed one year after surgery to assess the segmental instability in both groups.

TABLE 1 Preoperative demographic characteristics.

Characteristics	UBE group ($n = 30$)	PTED group ($n = 32$)	P value
Age (years)	46.70 ± 11.62	48.03 ± 13.20	0.676
Sex (male/female)	11/19	13/19	0.749
Duration of symptoms (month)	13.53 ± 9.00	12.90 ± 9.17	0.787
Comorbidities (yes/no)	12/18	15/17	0.585
Side (right/left)	14/16	15/17	0.987
Level (L4-L5/L5-S1)	17/13	17/15	0.779
Type of disk herniation			0.769
Protrusion	10	8	
Sequestered	16	19	
Migration	4	5	

Surgical procedures

For the UBE group, the surgical procedure (based on the L4-L5 segment of LDH) was performed following methods reported in the literature (17). After successful general anesthesia with tracheal intubation, the patient was placed in a prone position with the abdomen draped, and the L4-L5 intervertebral space was marked with x-ray fluoroscopy. The initial target point is located at the junction of the inferior lamina and the spinous process of L4. The surgical bed is adjusted until the responsible intervertebral space is vertical to the floor to make the first horizontal line, and the second line is drawn along the inner edge of the pedicles of L4-L5. The observation and operation incision points on the body surface along the second line were approximately 0.5–1.0 cm from the intersection of the two lines (**Figure 1**). Two incisions were made, 0.8 cm–1.0 cm long, in the skin and subcutaneous fascia. Then, we bluntly expanded and separated the soft tissue covering the surface of the lamina to form the working and observation portals. With irrigation, the arthroscopic system was inserted into the observation portal. The soft tissue on the surface of the intervertebral space was removed by the plasma scalpel in the working portal. Next, the ipsilateral spinolaminar junction at the L4-L5 level was identified, laminotomy was performed with part of the inferior lamina of L4, and the superior lamina of L5 was removed with a drill. After the exposed ligamentum flavum was removed, the discectomy was conducted with Kerrison forceps. Finally, a drainage tube was placed after hemostasis. x-ray, CT and MRI were performed after surgery (**Figure 2**).

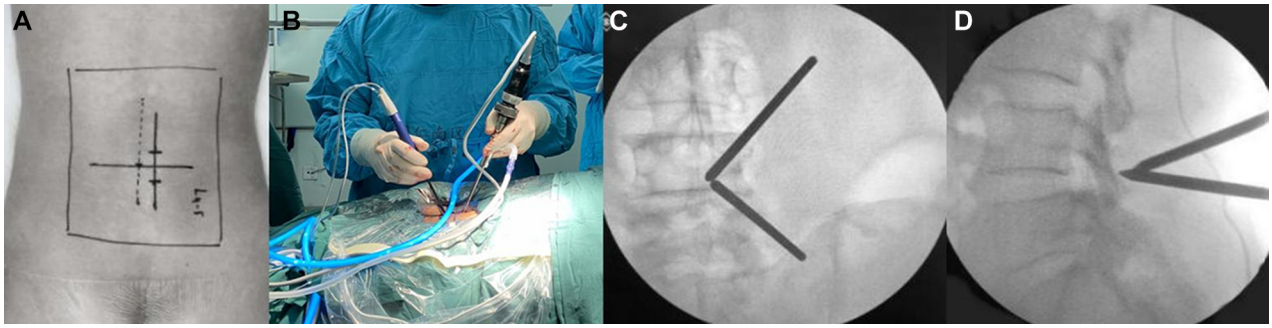

FIGURE 1
Intraoperative positioning and access establishment of UBE. (A,B) Body markers of L4/5 intervertebral space and the surgical approach. (C,D) The frontal and lateral view of the viewing and working portal.

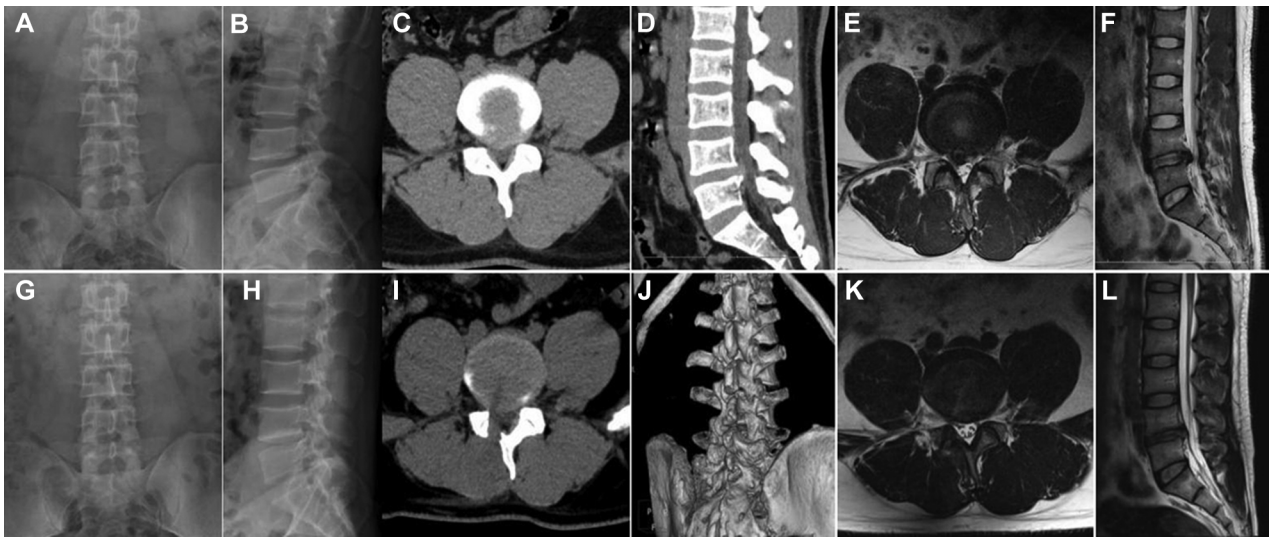

FIGURE 2
Pre- and postoperative x-ray, CT and MRI of UBE. (A,B) Preoperative x-ray. (C–F) Preoperative CT and MRI showing disc herniation. (G,H) Postoperative x-ray. (H,I) Postoperative CT and MRI showing the extruded disc was removed.

For the PTED group, the following steps (based on the L4-L5 segment of LDH) were performed following methods reported in the literature that we have published (18). A soft pillow was placed under the patient's waist while the patient was in the lateral decubitus position with their knee and hip flexed. The incision was located 8 cm–12 cm from the midline horizontally and 2 cm–4 cm above the iliac on the side with leg pain. A mixed local anesthetic, which consisted of 30 ml 1:200,000 epinephrine and 20 ml 2% lidocaine, was used. After 5 ml of the mixed anesthetic was inserted into the skin at the entry point, 20 ml was inserted into the trajectory, 15 ml was inserted into the articular process, and 10 ml was inserted into the foramen. Then, 0.8 cm–1.0 cm of skin and the subcutaneous fascia were incised. Drills were used to resect the ventral osteophytes on the superior articular process of L5. The PTED system (Hoogland Spine Products, Germany) was inserted (**Figure 3**). Parts of the ipsilateral ligamentum flavum and the extruded lumbar disc were completely resected with endoscopic forceps. The drainage tube was placed after hemostasis. X-ray, CT and MRI were performed after surgery (**Figure 4**).

Statistical analysis

The SPSS 26 program (IBM Corporation, United States) was used for statistical analysis. Repeated-measures analysis of variance was used to compare the VAS and ODI scores between the two groups. The independent-sample t test and Mann–Whitney *U* test or Fisher's exact test were used to assess the demographic characteristics and the perioperative outcomes. The level of statistical significance was set at $P < 0.05$.

Results

Perioperative outcomes

Of the 62 patients who met the study inclusion criteria, 30 underwent UBE, and 32 underwent PTED. The surgical parameters, including the operative time, estimated blood loss,

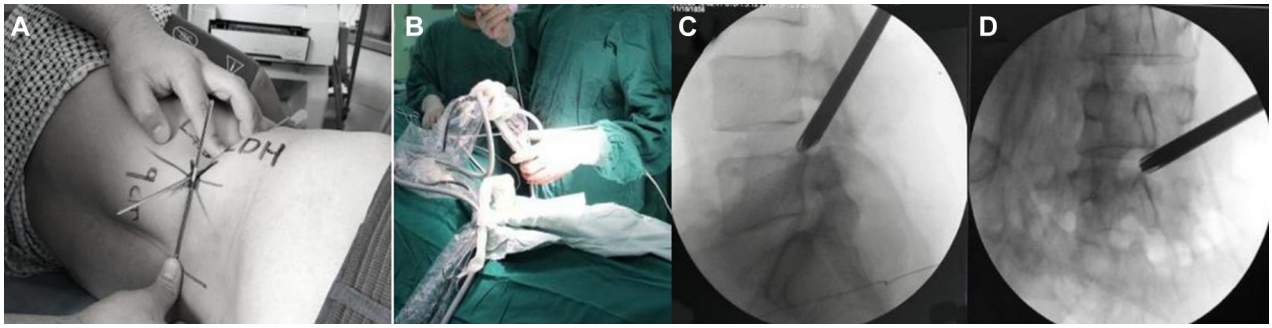

FIGURE 3
Intraoperative position and access establishment of PTED. (A,B) Body marker of L4/L5 intervertebral space and the surgical approach. (C,D) The lateral and frontal view of the working cannula.

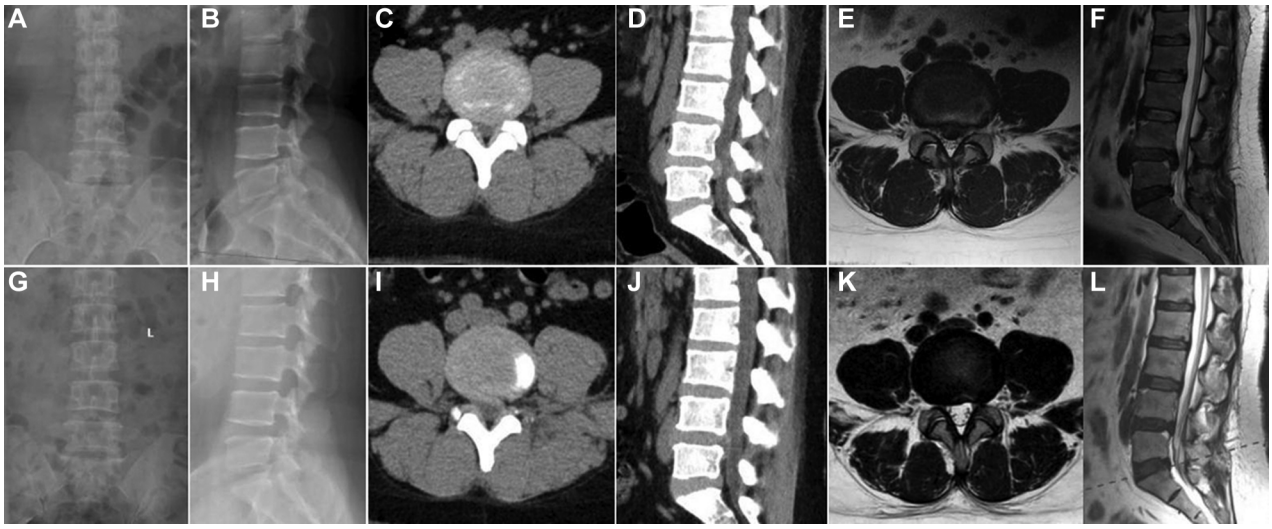

FIGURE 4
Pre- and postoperative x-ray, CT and MRI of PTED. (A,B) Preoperative x-ray. (C–F) Preoperative CT and MRI showing disc herniation. (G,H) Postoperative x-ray. (H,I) Postoperative CT and MRI showing the disc was removed.

incision length, times of x-ray, length of hospital stay and number of complications, are shown in Table 2. Except times of x-ray, the perioperative outcomes of the patients who underwent PTED were better than those of the patients who underwent UBE.

Clinical results

Preoperatively, the mean VAS and ODI scores were similar between the two groups. Compared to the UBE group, the PTED group had better VAS scores for back pain at 1 day and 7 days after surgery (3.06 ± 0.80 vs. 4.03 ± 0.81, $P < 0.05$; 2.81 ± 0.60 vs. 3.70 ± 0.79, $P < 0.05$). At 12 months, we observed similar improvements in the mean VAS scores for back and leg pain and ODI scores in the PTED and UBE groups (Figure 5). Moreover, there were no differences between the groups at any follow-up time point after the first month ($P > 0.05$). Based on the modified MacNab criteria, the good-to-excellent rate was 86.7% (26/30) in the UBE group and 87.5% (28/32) in the PTED group at the final follow-up. During the one-year follow-up in both groups, no segmental instability occurred.

Complications

Three patients in the UBE group had a dural tear, and one experienced cerebrospinal fluid leakage and headache after the operation. These symptoms were relieved by adequate rest in the hospital bed and prolonging the drainage time. In the PTED group, one patient complained of dysesthesia and weakness of the tibialis anterior, which improved after a week with neurotrophic drugs; another patient had a dural tear without cerebrospinal fluid leakage. There were no serious complications related to surgery.

Discussion

The significant improvements in the VAS score, ODI score and modified MacNab criteria revealed acceptable patient satisfaction in both groups, indicating that both PTED and UBE were effective in treating LDH. However, apartfrom times of x-ray, PTED is advantageous regarding the operative time, estimated blood loss,

TABLE 2 Perioperative outcomes.

Characteristics	UBE group ($n = 30$)	PTED group ($n = 32$)	P value
Duration of surgery (min)	84.17 ± 17.62	64.06 ± 14.73	0.00
Estimated blood loss (ml)	51.33 ± 18.33	13.13 ± 3.76	0.00
Incision length (cm)	2.27 ± 0.39	1.23 ± 0.25	0.00
Times of x-ray	6.13 ± 1.28	11.16 ± 3.71	0.00
Postoperative hospital stay (day)	4.83 ± 1.86	3.28 ± 1.08	0.00
Complications (yes/no)	3/27	2/30	0.884

incision length, length of postoperative hospital stay, and short-term postoperative back pain relief.

For the surgical treatment of LDH, the most classic decompression is open laminectomy with or without fusion (19). However, open laminectomy destroys the paraspinal muscles and the posterior stabilizing structures. Therefore, a less invasive approach is needed to reduce injury and minimize surgical wounds during the treatment of lumbar disease (20).

As a microinvasive technique, PTED is widely applied for treating LDH with faster postoperative rehabilitation and less surgical injury. Compared to conventional open discectomy, PTED has the advantage of protecting the posterior ligament structures, facet joint and lamina. It avoids the need for nerve-root retraction and has a shorter hospitalization, reduced intraoperative bleeding, and faster recovery (21).

PTED can be completed under local anesthesia (22). After lidocaine combined with epinephrine hydrochloride solution is administered, the surgical field is clearer without obvious drug-related complications. The pressure of irrigation can also be appropriately reduced, theoretically reducing the incidence of spinal hypertension reactions (23). In addition, if the surgical equipment stimulates the nerve root during the operation, the awake patient will experience an abnormal sensation, and the surgeon can stop the process in a timely manner. The patient can be asked whether they subjectively feel their symptoms being alleviated, and the straight-leg test can be performed; these responses can be used to determine whether the operation should be terminated. Local anesthesia also reduces complications related to general anesthesia in elderly patients.

However, most hospitals in developing countries cannot afford to purchase these types of equipment and cannot master the technology quickly due to its steep learning curve. In addition, it is not easy to place the tube at the target point of the lateral approach if the iliac crest is high. In addition, the working places and visual field are limited to a single rigid working cannula.

Since first reported by De Antoni in 1996, UBE with arthroscopy has achieved good clinical effects (24). However, the development of UBE was limited due to the lack of power motor drills and the radiofrequency used to remove the lamina and achieve hemostasis. In recent years, with the emergence of endoscopic surgical instruments, UBE has been widely used in the treatment of LDH and lumbar spinal stenosis (25, 26).

Soliman proposed the application of this minimally invasive technology for the treatment of LDH in 2013 (27). He concluded

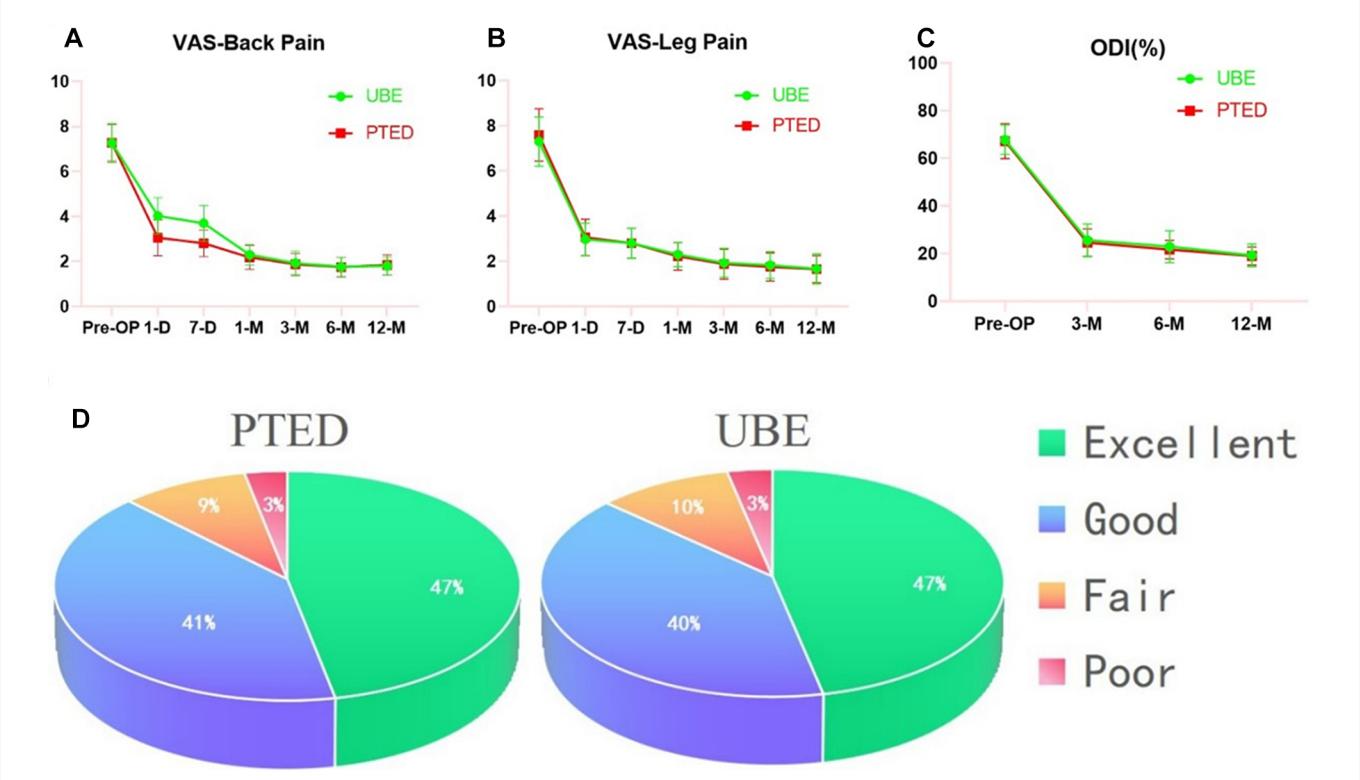

FIGURE 5
Clinical outcomes at different follow-up time points. (A) VAS score for back pain in both groups. (B) VAS score for leg pain in both groups. (C) ODI score for both groups. (D) The modified MacNab for both groups.

that the surgical field of vision was expanded with different channels, and vascular bleeding was less under irrigation. The decompression process and instruments of UBE are similar to those used for open posterior discectomy, and thus this procedure can be carried out after only a short training period (28). Therefore, the learning curve of UBE is relatively flat and short. Xu demonstrated that the learning curve for mastering UBE is 54 cases (29).

The operating instruments and observation port are in different channels. The working port does not restrict the operating instruments of UBE. The working efficiency can be greatly improved with the use of conventional, large-sized surgical instruments, such as an osteotome, rongeur, forceps, and nerve retractor (30). In addition, surgeons in developing countries can complete the procedure without purchasing specialized supporting surgical instruments and other endoscopic systems. Moreover, unlike PTED, the UBE approach is not affected by a high iliac crest (31).

In our research, the operative time of UBE is longer than PTED. For one reason, the operative time for UBE is from the beginning of general anesthesia until a drainage tube is placed after hemostasis; the operative time for PTED is from the insertion of a local anesthetic to a drainage tube placed. For another, before laminotomy, the water pressure is 35 cm–40 cm H2O (32). But when performing the discectomy, to avoid potential neurological complications caused by the increased epidural and intracranial pressure and muscle edema caused by the high pressure of irrigation fluid, we lower the water pressure to 25 cm H2O (33). The time of hemostasis may be longer. So, the total operative time of UBE is longer than PTED in our research. But this does not mean that the efficiency of UBE is inferior to PTED in the progress of discectomy.

As for times of x-ray, the UBE group is superior to PTED in this research(6.13 ± 1.28 vs. 11.16 ± 3.71). Among the procedure of PTED, the times of x-ray was higher and mainly included: the process of local anesthesia, sequential dilators and bone drills insertion to expand the soft and osseous tissues by resecting the ventral osteophytes on the superior articular process, and the working cannula placement. In the UBE, the purpose of fluoroscopy is to find the junction of the inferior lamina and the spinous process and prevent mismaking of the target lumbar segment. So in terms of times of x-ray, the UBE group is superior to PTED.

However, the trauma of UBE is relatively larger than that of PTED (34). Due to the lack of a rigid cannula to dilate the soft tissue, the longissimus pectoralis and multifidus muscle need to be bluntly dissected to create a working space before decompression. The artificial creation of the operation spaces may damage the muscle attached to the lamina and the other anatomical structures. Therefore, theoretically, UBE would result in greater blood loss and worse postoperative back pain than PTED. The probability of cerebrospinal fluid leakage caused by dural injury when retraction of the nerve root is relatively high under general anesthesia (35).

In this research, three patients in the UBE group underwent dural tears when the anatomical structure was retracted to expose the disc. One of them experienced cerebrospinal fluid leakage and postoperative headache. The first dural tear occurred during the removal of the ligament flavum by the forceps with the low water pressure and the bleeding vision. The othe two dural tears were caused when the traversing roots was pushed by the assistant in a medial direction to expose the disc. We suggest that vigorous force cannot be used while pulling on the dura and an experienced assistant is needed. Besides, thorough hemostasis is needed when bleeding occurs before the next steps.

Additionally, one patient complained of weakness of the tibialis anterior in the PTED group. The working channel compresses the nerve root when the bone drill graves the upper articular of L5, which results in radicular symptoms. Another patient had a dural tear during the procedure but without cerebrospinal fluid leakage after the surgery. To avoid these complications, the surgeon should be careful when performing the foraminoplasty with a bone drill.

This study has some limitations. First, it was a retrospective study with a relatively short follow-up period and a small sample size. Second, the operation choices were limited. To confirm the long-term outcomes, a prospective and multicenter study with different surgical procedures and a larger sample size is necessary in future research.

Conclusion

Both UBE and PTED showed favorable outcomes for the treatment of single-level LDH. With less bone and muscle damage, PTED under local anesthesia exhibited less intraoperative blood loss, a shorter operation time, and shorter postoperative hospitalization than the UBE group.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by Chengde Medical University Affiliated Hospital. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

Conception and design: XKC, BXB and JGT. Acquisition of data: XKC, YXW and CYX. Drafting of the article: XKC and BXB. Critical revision of the article: JGT and HY. Statistical analysis: XKC, CTD and YPC. Administrative, technical and material support: BC, HY and JGT. Study supervision: JGT. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Gadjradj PS, Rubinstein SM, Peul WC, Depauw PR, Vleggeert-Lankamp CL, Seiger A, et al. Full endoscopic versus open discectomy for sciatica: randomised controlled non-inferiority trial. *Br Med J*. (2022) 376:e065846.

2. Peul WC, van den Hout WB, Brand R, Thomeer RT, Koes BW. Prolonged conservative care versus early surgery in patients with sciatica caused by lumbar disc herniation: two year results of a randomised controlled trial. *Br Med J*. (2008) 336 (7657):1355–8. doi: 10.1136/bmj.a143

3. Bailey CS, Glennie A, Rasoulinejad P, Kanawati A, Taylor D, Sequeira K, et al. Discectomy compared with standardized nonoperative care for chronic sciatica due to a lumbar disc herniation: a secondary analysis of a randomized controlled trial with 2-year follow-up. *J Bone Joint Surg Am*. (2021) 103(23):2161–9. doi: 10.2106/JBJS.21.00448

4. Chen Z, Zhang L, Dong J, Xie P, Liu B, Chen R, et al. Percutaneous transforaminal endoscopic discectomy versus microendoscopic discectomy for lumbar disc herniation: 5-year long-term results of a randomized controlled trial. *Spine (Phila Pa 1976)*. (2023) 48(2):79–88. doi: 10.1097/BRS.0000000000004468

5. Wang Y, Liang Z, Wu J, Tu S, Chen C. Comparative clinical effectiveness of tubular microdiscectomy and conventional microdiscectomy for lumbar disc herniation: a systematic review and network meta-analysis. *Spine (Phila Pa 1976)*. (2019) 44 (14):1025–33. doi: 10.1097/BRS.0000000000003001

6. Yeung AT, Tsou PM. Posterolateral endoscopic excision for lumbar disc herniation: surgical technique, outcome, and complications in 307 consecutive cases. *Spine (Phila Pa 1976)*. (2002) 27(7):722–31. doi: 10.1097/00007632-200204010-00009

7. Hoogland T, Schubert M, Miklitz B, Ramirez A. Transforaminal posterolateral endoscopic discectomy with or without the combination of a low-dose chymopapain: a prospective randomized study in 280 consecutive cases. *Spine (Phila Pa 1976)*. (2006) 31(24):E890–7. doi: 10.1097/01.brs.0000245955.22358.3a

8. Ge R, Liu Z, Huang W. Percutaneous transforaminal endoscopic discectomy is a safer approach for lumbar disc herniation. *Am J Transl Res*. (2022) 14(9):6359–67.

9. Cheng XK, Chen B. Percutaneous transforaminal endoscopic decompression for geriatric patients with central spinal stenosis and degenerative lumbar spondylolisthesis: a novel surgical technique and clinical outcomes. *Clin Interv Aging*. (2020) 15:1213–9. doi: 10.2147/CIA.S258702

10. Jiang HW, Chen CD, Zhan BS, Wang YL, Tang P, Jiang XS. Unilateral biportal endoscopic discectomy versus percutaneous endoscopic lumbar discectomy in treating lumbar disc herniation: a retrospective study. *J Orthop Surg Res*. (2022) 17(1):30. doi: 10.1186/s13018-022-02929-5

11. Wang B, He P, Liu X, Wu Z, Xu B. Complications of unilateral biportal endoscopic spinal surgery for lumbar spinal stenosis: A systematic review of the literature and meta-analysis of single-arm studies. *Orthop Surg*. (2022). doi: 10.1111/os.13437. [Epub ahead of print]

12. Yuan C, Wen B, Lin H. Clinical analysis of minimally invasive percutaneous treatment of severe lumbar disc herniation with UBE two-channel endoscopy and foraminal single-channel endoscopy technique. *Oxid Med Cell Longev*. (2022) 2022:9264852.

13. Hong YH, Kim SK, Hwang J, Eum JH, Heo DH, Suh DW, et al. Water dynamics in unilateral biportal endoscopic spine surgery and its related factors: an in vivo proportional regression and proficiency-matched study. *World Neurosurg*. (2021) 149: e836–43. doi: 10.1016/j.wneu.2021.01.086

14. Park JH, Jun SG, Jung JT, Lee SJ. Posterior percutaneous endoscopic cervical foraminotomy and diskectomy with unilateral biportal endoscopy. *Orthopedics*. (2017) 40(5):e779–83.

15. Deng Y, Yang M, Xia C, Chen Y, Xie Z. Unilateral biportal endoscopic decompression for symptomatic thoracic ossification of the ligamentum flavum: a case control study. *Int Orthop*. (2022) 46(9):2071–80. doi: 10.1007/s00264-022-05484-0

16. Hao J, Cheng J, Xue H, Zhang F. Clinical comparison of unilateral biportal endoscopic discectomy with percutaneous endoscopic lumbar discectomy for single l4/5-level lumbar disk herniation. *Pain Pract*. (2022) 22(2):191–9. doi: 10.1111/papr.13078

17. Chang H, Xu J, Yang D, Sun J, Gao X, Ding W. Comparison of full-endoscopic foraminoplasty and lumbar discectomy (FEFLD), unilateral biportal endoscopic (UBE) discectomy, and microdiscectomy (MD) for symptomatic lumbar disc herniation. *Eur Spine J*. (2022) doi: 10.1007/s00586-022-07510-6. [Epub ahead of print]

18. Cheng XK, Cheng YP, Liu ZY, Bian FC, Yang FK, Yang N, et al. Percutaneous transforaminal endoscopic decompression for lumbar spinal stenosis with degenerative spondylolisthesis in the elderly. *Clin Neurol Neurosurg*. (2020) 194:105918. doi: 10.1016/j.clineuro.2020.105918

19. Hu ZX, Han J, Sun YF, Tian XL. Comparison of percutaneous endoscopic lumbar discectomy vs. Minimally invasive transforaminal lumbar interbody fusion for the treatment of single-segment lumbar disc herniation: a meta-analysis. *Eur Rev Med Pharmacol Sci*. (2022) 26:6678–90.

20. Li WS, Yan Q, Cong L. Comparison of endoscopic discectomy versus non-endoscopic discectomy for symptomatic lumbar disc herniation: a systematic review and meta-analysis. *Global Spine J*. (2022) 12(5):1012–26. doi: 10.1177/21925682211020696

21. Wei FL, Zhou CP, Zhu KL, Du MR, Liu Y, Heng W, et al. Comparison of different operative approaches for lumbar disc herniation: a network meta-analysis and systematic review. *Pain Physician*. (2021) 24(4):E381–92.

22. Youn MS, Shin JK, Goh TS, Son SM, Lee JS. Endoscopic posterior decompression under local anesthesia for degenerative lumbar spinal stenosis. *J Neurosurg Spine*. (2018) 29:661–6. doi: 10.3171/2018.5.SPINE171337

23. Cho JY, Lee SH, Lee HY. Prevention of development of postoperative dysesthesia in transforaminal percutaneous endoscopic lumbar discectomy for intracanalicular lumbar disc herniation: floating retraction technique. *Minim Invasive Neurosurg*. (2011) 54(5-6):214–8.

24. De Antoni DJ, Claro ML, Poehling GG, Hughes SS. Translaminar lumbar epidural endoscopy: anatomy, technique, and indications. *Arthroscopy*. (1996) 12:330–4. doi: 10.1016/S0749-8063(96)90069-9

25. Kwon O, Yoo SJ, Park JY. Comparison of unilateral biportal endoscopic discectomy with other surgical technics: A systemic review of indications and outcomes of unilateral biportal endoscopic discectomy from the current literature. *World Neurosurg*. (2022) 168:349–58. doi: 10.1016/j.wneu.2022.06.153

26. Aygun H, Abdulshafi K. Unilateral biportal endoscopy versus tubular microendoscopy in management of single level degenerative lumbar canal stenosis: a prospective study. *Clin Spine Surg*. (2021) 34(6):E323–8. doi: 10.1097/BSD.0000000000001122

27. Soliman HM. Irrigation endoscopic discectomy: a novel percutaneous approach for lumbar disc prolapse. *Eur Spine J*. (2013) 22(5):1037–44. doi: 10.1007/s00586-013-2701-0

28. Chen L, Zhu B, Zhong HZ, Wang YG, Sun YS, Wang QF, et al. The learning curve of unilateral biportal endoscopic (UBE) spinal surgery by CUSUM analysis. *Front Surg*. (2022) 9:873691. doi: 10.3389/fsurg.2022.873691

29. Xu J, Wang D, Liu J, Zhu C, Bao J, Gao W, et al. Learning curve and complications of unilateral biportal endoscopy: cumulative sum and risk-adjusted cumulative sum analysis. *Neurospine*. (2022) 19(3):792–804. doi: 10.14245/ns.2143116.558

30. Zheng B, Xu S, Guo C, Jin L, Liu C, Liu H. Efficacy and safety of unilateral biportal endoscopy versus other spine surgery: a systematic review and meta-analysis. *Front Surg*. (2022) 9:911914. doi: 10.3389/fsurg.2022.911914

31. Eun SS, Eum JH, Lee SH, Sabal LA. Biportal endoscopic lumbar decompression for lumbar disk herniation and spinal canal stenosis: a technical note. *J Neurol Surg A Cent Eur Neurosurg*. (2017) 78(4):390–6. doi: 10.1055/s-0036-1592157

32. Kang MS, Park HJ, Hwang JH, Kim JE, Choi DJ, Chung HJ. Safety evaluation of biportal endoscopic lumbar discectomy: assessment of cervical epidural pressure during surgery. *Spine (Phila Pa 1976)*. (2020) 45(20):E1349–1356. doi: 10.1097/BRS.0000000000003585

33. Kang T, Park SY, Lee SH, Park JH, Suh SW. Assessing changes in cervical epidural pressure during biportal endoscopic lumbar discectomy. *J Neurosurg Spine*. (2020) 30:1–7. doi: 10.3171/2020.6.SPINE20586

34. Choi KC, Shim HK, Hwang JS, Shin SH, Lee DC, Jung HH, et al. Comparison of surgical invasiveness between microdiscectomy and 3 different endoscopic discectomy techniques for lumbar disc herniation. *World Neurosurg*. (2018) 116:e750–758. doi: 10.1016/j.wneu.2018.05.085

35. Chu PL, Wang T, Zheng JL, Xu CQ, Yan YJ, Ma QS, et al. Global and current research trends of unilateral biportal endoscopy/biportal endoscopic spinal surgery in the treatment of lumbar degenerative diseases: a bibliometric and visualization study. *Orthop Surg*. (2022) 14(4):635–43. doi: 10.1111/os.13216

frontiers | Frontiers in Surgery

TYPE Original Research
PUBLISHED 06 March 2023
DOI 10.3389/fsurg.2023.1116376

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

RECEIVED 05 December 2022
ACCEPTED 14 February 2023
PUBLISHED 06 March 2023

CITATION
Xie Y, Zhou Q, Wang Y, Feng C, Fan X and Yu Y (2023) Training to be a spinal endoscopic surgeon: What matters?
Front. Surg. 10:1116376.
doi: 10.3389/fsurg.2023.1116376

Training to be a spinal endoscopic surgeon: What matters?

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Objective: Spinal endoscopic surgery has been promoted rapidly in the past decade, attracting an increasing number of young, dedicated surgeons. However, it has long been denounced for its long learning curve as a factor impeding the development of this state-of-the-art technique. The aim of the present study was to discover what really matters in the educational process of becoming a spinal endoscopic surgeon.
Methods: An online survey consisting of 14 compulsory questions was distributed in April and May 2022 through the First Chinese Spinal Endoscopic Surgeons Skills Competition. Reminders were sent to increase response rates.
Results: Of the 893 emails that were sent, we received 637 responses. A total of 375 (76.7%) surgeons most frequently used endoscopic techniques in their practices. Regardless of their different backgrounds, 284 (75.7%) surgeons thought it would be necessary for a young spinal endoscopic surgeon to perform 300 cases independently in order to become proficient, followed by 500 (n=43, 11.5%), 100 (n=40, 10.7%), and 1,000 (n=8, 2.1%) cases. According to the surgeons, the most difficult aspect of mastering the endoscopic technique is a disparate surgical view (n=255, 68%), followed by adaption to new instruments (n=86, 22.9%) and hand-eye coordination (n=34, 9.1%). The most helpful training method for helping the spinal endoscopic surgeons of younger generations improve is operating on simulation models or cadaver courses (n=216, 57.6%), followed by online or offline theoretical courses (n=67, 17.9%), acquiring opportunities during surgeries (n=51, 13.6%), and frequently participating in surgeries as an assistant (n=41, 10.9%).
Conclusion: From the perspective of surgeons, to be skilled in spinal endoscopic surgery means overcoming a steep learning curve. However, training systems should be given more attention to make them more accessible to younger surgeons so they can work on simulation models or take cadaver courses.

KEYWORDS

spine endoscopic surgery, minimally invasive spine surgery, education, spinal endoscopic surgeon of younger generations, online survey

Background

Spinal endoscopic surgery, with its unique advantages of a clearer surgical view and continuous irrigation, has been promoted worldwide to treat various forms of spinal disease, from initial degenerative pathology to spinal trauma, infection, and even deformity (1–3). Technically, in terms of the novel instruments being invented steadily with great efforts coming from peers in this field, its surgical approaches and methods have flourished in the past decade to meet the challenges of these diseases (4–6). It is for

this reason that spinal endoscopic surgery has attracted an increasing number of young, dedicated surgeons (7).

However, when it comes to this state-of-the-art technique, it is worth mentioning that its learning curve has been long considered a barrier keeping many young surgeons from mastering it (8, 9). Several studies have clarified the steep learning curve and pointed out that it was likely much steeper than any other minimally invasive spinal surgery (10–12). Yet, very few articles have disclosed the reason for this curve and what training techniques young surgeons most urgently need. The aim of the present study was to conduct an online survey in order to analyze the most difficult aspect of learning spinal endoscopic surgery and identify the most beneficial training method for the younger generation of spinal surgeons.

Methods

A questionnaire was developed using the Tencent Questionnaire Platform for spinal surgeons about the relevant educational issues of spinal endoscopic surgery (**Supplementary Material 1**). The study samples were targeted at the members of the First Chinese Spinal Endoscopic Surgeons Skills Competition, which is a national academic competition for spinal endoscopic surgery. Spinal endoscopic surgery has a predominant status in the field of minimally invasive spinal surgery in China, and this nationwide competition was held to represent surgeons and allied health professionals dedicated to advancement in this field (13, 14). As the corresponding author's institution was also the participating and reviewing institution, 2,893 members were contacted *via* email. Questionnaires were sent out in April and May 2022, with reminders after 2 weeks to increase the response rate.

Screening for surgeons

To make the study more representative, the participants involved in this survey were the surgeons who frequently utilized spinal endoscopy in their daily practice. Hence, surgeons who did not specialize in spinal surgery or who did not regularly use spinal endoscopy in their daily practice were excluded from the study.

Survey content

The survey consisted of 14 compulsory questions for surgeons. The first six questions were about basic personal information such as background, age, gender, training specialty, and title. Questions 7–11 were to acknowledge the status of their application on spinal endoscopic surgery. The last three questions collected the surgeons' attitudes toward endoscopic education.

Statistical analyses

For statistical analyses, IBM SPSS version 25.0 (IBM Corp., Armonk, NY, USA) was used. The age of the participants was represented as the mean and standard deviation ($\bar{x} \pm s$) while other indexes were expressed as a percentage [n (%)].

Results

Of the 893 emails that were sent, we received 637 responses. All respondents specialized in spinal surgery; with 489 (76.8%) considering minimally invasive spinal surgery to be their subspecialty. Among them, 375 (76.7%) surgeons used the endoscopic technique most frequently in their practice. The screening process for surgeons is shown in **Figure 1**. Of these 375 surgeons (mean age 42.5 ± 4.3 years) 323 (86.1%) were men and 52 (13.9%) were women. Of them, 263 (70.1%) were from an orthopedic background while 112 (29.9%) were from a neurosurgery background. In terms of titles, 51 (13.6%) were residents, followed by 235 (62.7%) attendings, 73 (19.5%) deputy chiefs/associated professors, and 16 (4.3%) chiefs/professors (**Figure 2**).

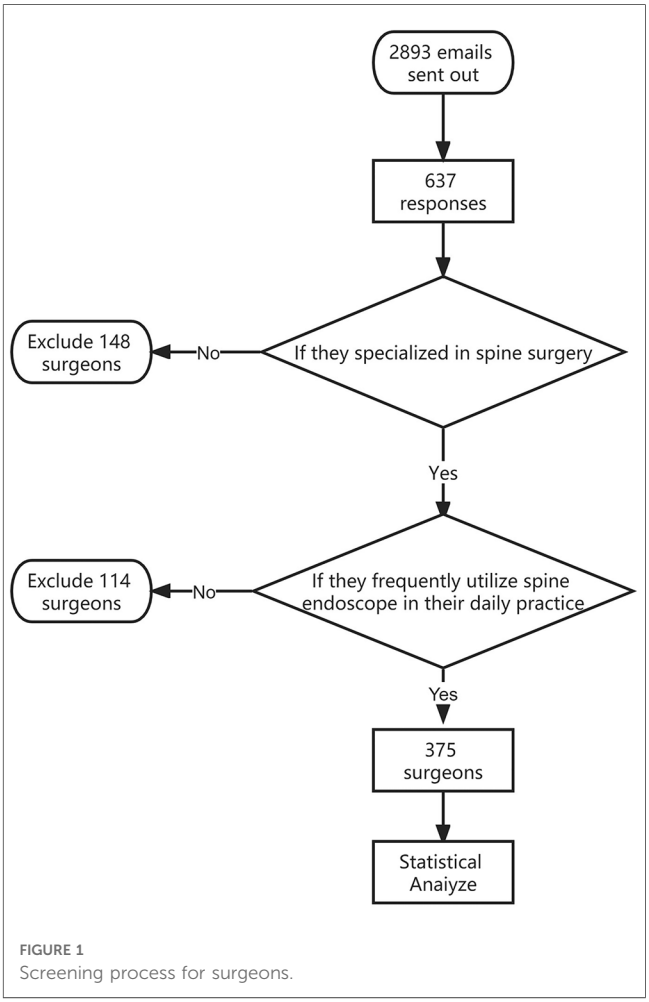

FIGURE 1
Screening process for surgeons.

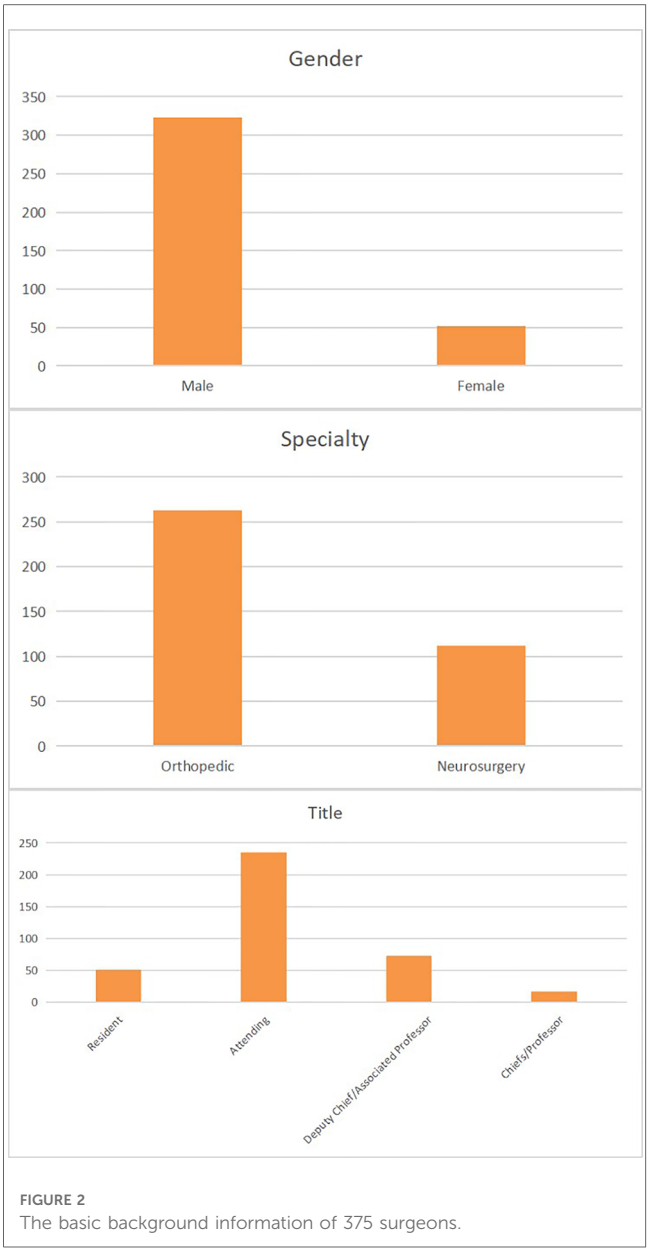

FIGURE 2
The basic background information of 375 surgeons.

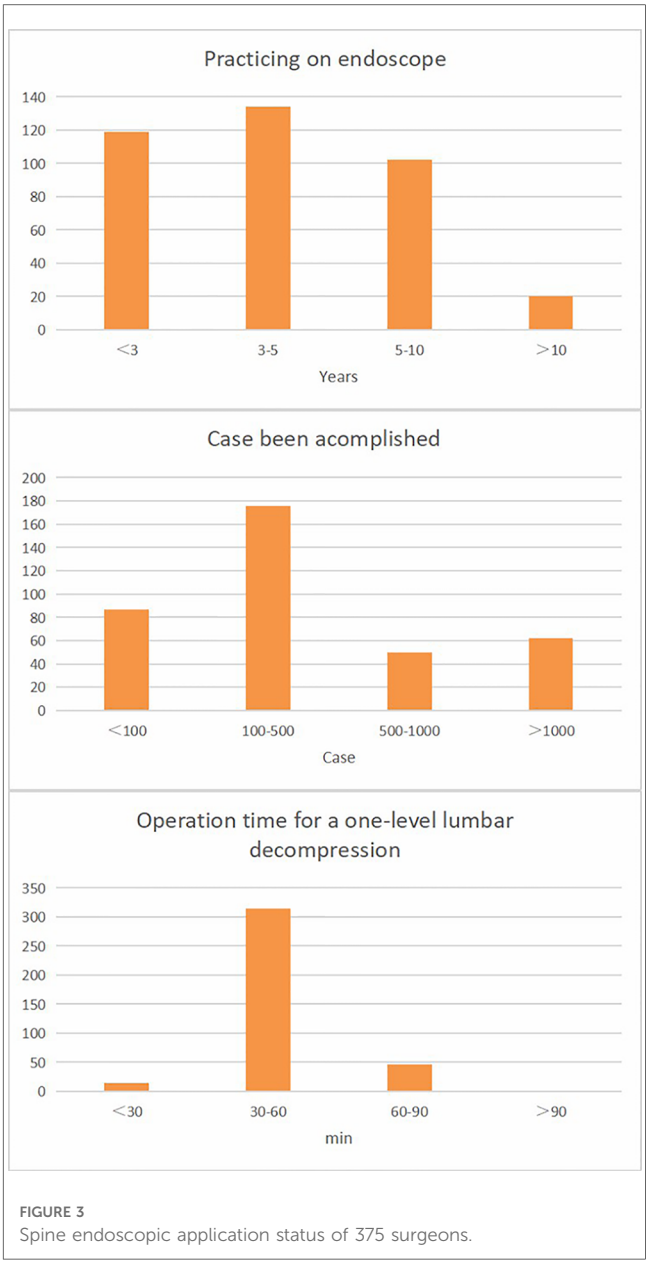

FIGURE 3
Spine endoscopic application status of 375 surgeons.

With regard to their years of experience with the endoscopic application, 119 (31.7%) surgeons had been practicing endoscopic surgery for less than 3 years, 134 (35.7%) had been practicing for 3–5 years, 102 (27.2%) had been practicing for 5–10 years, and only 20 (5.3%) surgeons had been practicing for more than 10 years. Concerning the number of cases they had already completed, 87 (23.2%) of the surgeons had worked on less than 100 cases, 176 (46.9%) had already done 100–500 cases, 50 (13.3%) had already done 500–1,000 cases, and 62 (16.5%) of them had already done more than 1,000 cases. In terms of the operating time for a one-level lumbar decompression, 15 (4%) of the surgeons could complete the procedure in less than 30 minutes, 314 (83.7%) in 30–60 minutes, 46 (12.3%) in 60–90 minutes, and none of them took more than 90 minutes (Figure 3).

Regarding the surgeons' attitudes toward the education process for spinal endoscopic surgeons, 284 (75.7%) of them thought it would be necessary for a young spinal endoscopic surgeon to perform 300 cases independently to become proficient, followed by 500 (n=43, 11.5%) cases, 100 (n=40, 10.7%) cases, and 1,000 (n=8, 2.1%) cases. According to the surgeons, the most difficult aspect of this technique to master was the disparate surgical view (n=255, 68%), followed by adapting to the novel instruments (n=86, 22.9%) and hand-eye coordination (n=34, 9.1%). The most helpful training method to help the spinal endoscopic surgeon of the younger generation improve was operating on simulation models or cadaver courses (n=216, 57.6%), followed by online or offline theoretical courses (n=67, 17.9%), acquiring opportunities during surgeries (n=51, 13.6%), and frequently participating in surgeries as an assistant (n=41, 10.9%) (Figure 4).

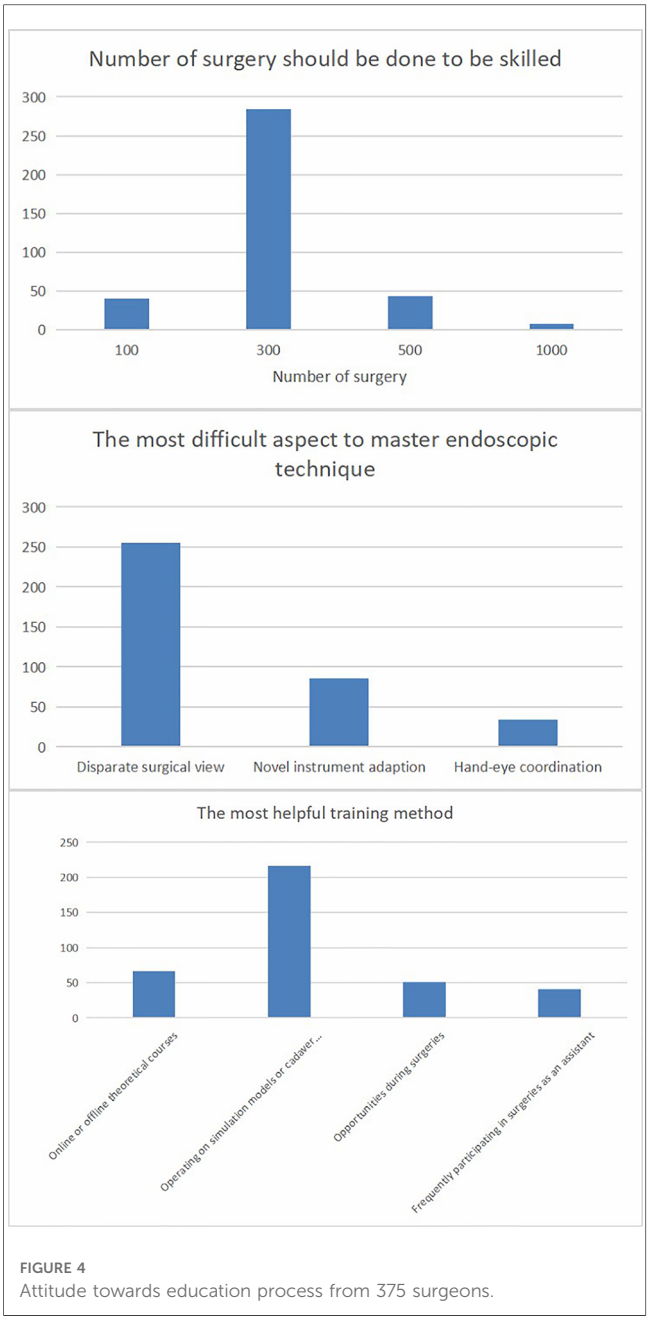

FIGURE 4
Attitude towards education process from 375 surgeons.

Discussion

The steep learning curve of this state-of-the-art technique has long been mentioned in many previous studies (10–12). Kotheeranurak et al. conducted an online survey about the learning curve, motivation, and obstacles of full-endoscopic spinal surgery in Thailand. They drew the conclusion that the trend of endoscopic spinal surgery has continued to grow and that the appropriate number of cases until one felt confident was approximately 28. The primary motivator and obstacles were personal interest and lack of support (15). Hsu et al. retrospectively evaluated the clinical presentation of 57 patients who underwent full-endoscopic lumbar discectomy and 66 patients who underwent open microdiscectomy using Spearman's coefficient of rank correlation (rho) to assess the learning curves for the transforaminal and interlaminar procedures of full-endoscopic lumbar discectomy. They believed that the transforaminal approach had a steep and easy learning curve, whereas the learning curve of the interlaminar approach was deemed flat and difficult (16). Gadjradj et al. conducted a study by observing the clinical outcomes during and after the learning curve (20 cases) presented by three surgeons new to spinal endoscopy. They later determined that spinal endoscopic surgery had a relevant steep learning curve and that young spinal surgeons should use the endoscope under the supervision of a senior surgeon (17).

In order to uncover the deeper factor for this challenging issue, the present study conducted a survey of 375 spinal endoscopic surgeons to reveal what matters to the growth of a young, medical professionals. Through the screening based on questions 3–7, it was determined that they were all peers who were dedicated specifically to this method. It was critical that the survey be representative. Despite their varied backgrounds, most of the respondents performed well in endoscopic surgery according to questions 8–10 of the survey. The study pointed out that the majority of surgeons thought the threshold for a surgeon to be skilled in spinal endoscopy was at least 300 cases. In fact, surgeons may face many challenges in the initial phase of practicing this technique, such as a lengthy operating time, a high complication rate, and even failure to finish the procedure (18–20). However, they should be patient and persevere rather than be dejected in order to add to their experiences regularly. There is also evidence that the situation will improve over time (17). According to the surgeons, the most difficult aspect of mastering this technique is the disparate surgical view (21). Unlike conventional open surgery or the cadaver specimens that medical students see regularly in medical school, the surgical view from a spinal endoscopy is entirely different because its limited view with the amplified image by the lens will make the normal-sized anatomic sites appear fairly magnified, which might confuse the beginners when recognizing the anatomic landmarks (22). Hence, great importance should be given to training. Based on the survey, the most beneficial training method for surgeons was operating on simulation models or cadaver courses. This conveyed a vital message to organizations and manufacturers who are dedicated to promoting the technique and helping less-experienced surgeons. Even though cadavers are not always available, especially in some regions, it is satisfying to see peers develop innovative alternative training programs (23, 24). This trend is in line with the survey, and it should be maintained for our efforts to be worthwhile.

Conclusion

From the perspective of surgeons, to be skilled in spinal endoscopic surgery means overcoming a steep learning curve. However, more importance should be attached to training systems so that younger generations of surgeons can operate on simulation models or take cadaver courses.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

YX and QZ contributed equally to this work and should be considered the first authors. YY and XF are jointly responsible for the project and should be considered the corresponding authors. YY and XF organized and supervised the case report. YX and QZ collected the literature and wrote the article. CF and YW performed, recorded, and audited the article. All authors contributed to the article and approved the submitted version.

Funding

This study was supported by the Chengdu Science and Technology Bureau (No. 2022-YF05-02035-SN), and China Geriatric Health Care Association (CAWA202105281637000503382-09).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsurg.2023.1116376/full#supplementary-material.

References

1. Simpson AK, Lightsey HM 4th, Xiong GX, Crawford AM, Minamide A, Schoenfeld AJ Spinal endoscopy: evidence, techniques, global trends, and future projections. *Spine J.* (2022) 22(1):64–74. doi: 10.1016/j.spinee.2021.07.004

2. Khandge AV, Sharma SB, Kim JS. The evolution of transforaminal endoscopic spine surgery. *World Neurosurg.* (2021) 145:643–56. doi: 10.1016/j.wneu.2020.08.096

3. Ahn Y. A historical review of endoscopic spinal discectomy. *World Neurosurg.* (2021) 145:591–6. doi: 10.1016/j.wneu.2020.08.008

4. Chen B, Li S, Wang Z. Clinical efficacy of percutaneous transforaminal endoscopic TESSYS technique in the treatment of senile lumbar spinal stenosis. *Am J Transl Res.* (2021) 13(8):9356–63.

5. Pan M, Li Q, Li S, Mao H, Meng B, Zhou F, et al. Percutaneous endoscopic lumbar discectomy: indications and complications. *Pain Physician.* (2020) 23 (1):49–56.

6. Meng SW, Peng C, Zhou CL, Tao H, Wang C, Zhu K, et al. Massively prolapsed intervertebral disc herniation with interlaminar endoscopic spine system delta endoscope: a case series. *World J Clin Cases.* (2021) 9(1):61–70. doi: 10.12998/wjcc.v9.i1.61

7. Lohre R, Wang JC, Lewandrowski KU, Goel DP Virtual reality in spinal endoscopy: a paradigm shift in education to support spine surgeons. *J Spine Surg.* (2020) 6(Suppl 1):S208–23. doi: 10.21037/jss.2019.11.16

8. Sclafani JA, Kim CW. Complications associated with the initial learning curve of minimally invasive spine surgery: a systematic review. *Clin Orthop Relat Res.* (2014) 472(6):1711–7. doi: 10.1007/s11999-014-3495-z

9. Lewandrowski KU, Telfeian AE, Hellinger S, Jorge Felipe RamÍrez León, Paulo Sérgio Teixeira de Carvalho Ramos MRF, et al. Difficulties, challenges, and the learning curve of avoiding complications in lumbar endoscopic spine surgery. *Int J Spine Surg.* (2021) 15(suppl 3):S21–37. doi: 10.14444/8161

10. Son S, Ahn Y, Lee SG, Kim WK, Yoo BR, Jung JM, et al. Learning curve of percutaneous endoscopic transforaminal lumbar discectomy by a single surgeon. *Medicine.* (2021) 100(4):e24346. doi: 10.1097/MD.0000000000024346

11. Kim JE, Yoo HS, Choi DJ, Hwang JH, Park EJ, Chung S. Learning curve and clinical outcome of biportal endoscopic-assisted lumbar interbody fusion. *Biomed Res Int.* (2020) 2020:8815432. doi: 10.1155/2020/8815432

12. Yang J, Guo C, Kong Q, Zhang B, Wang Y, Zhang L, et al. Learning curve and clinical outcomes of percutaneous endoscopic transforaminal decompression for lumbar spinal stenosis. *Int Orthop.* (2020) 44(2):309–17. doi: 10.1007/s00264-019-04448-1

13. Lin GX, Kotheeranurak V, Mahatthanatrakul A, Ruetten S, Yeung A, Lee SH, et al. Worldwide research productivity in the field of full-endoscopic spine surgery: a bibliometric study. *Eur Spine J.* (2020) 29(1):153–60. doi: 10.1007/s00586-019-06171-2

14. Lewandrowski KU, Soriano-Sánchez JA, Zhang X, RamÍrez León JF, Soriano Solis S, Rugeles OrtÍz JG, et al. Regional variations in acceptance, and utilization of minimally invasive spinal surgery techniques among spine surgeons: results of a global survey. *J Spine Surg.* (2020) 6(Suppl 1):S260–74. doi: 10.21037/jss.2019.09.31

15. Kotheeranurak V, Liawrungrueang W, Kuansongtham V, Sriphirom P, Bamrungthin N, Keorochana G, et al. Surgeons' perspective, learning curve, motivation, and obstacles of full-endoscopic spine surgery in Thailand: results from a nationwide survey. *Biomed Res Int.* (2022) 2022:4971844. doi: 10.1155/2022/4971844

16. Hsu HT, Chang SJ, Yang SS, Chai CL. Learning curve of full-endoscopic lumbar discectomy. *Eur Spine J.* (2013) 22(4):727–33. doi: 10.1007/s00586-012-2540-4

17. Gadjradj PS, Vreeling A, Depauw PR, Schutte PJ, Harhangi BSPTED-Study Group. Surgeons learning curve of transforaminal endoscopic discectomy for sciatica. *Neurospine.* (2022) 19(3):594–602. doi: 10.14245/ns.2244342.171

18. Zhou C, Zhang G, Panchal RR, Ren X, Xiang H, Xuexiao M, et al. Unique complications of percutaneous endoscopic lumbar discectomy and percutaneous endoscopic interlaminar discectomy. *Pain Physician.* (2018) 21(2):E105–12.

19. Lee DY, Lee SH. Learning curve for percutaneous endoscopic lumbar discectomy. *Neurol Med Chir.* (2008) 48(9):383–8; discussion 388–9. doi: 10.2176/nmc.48.383

20. Park SM, Kim HJ, Kim GU, Choi MH, Chang BS, Lee CK, et al. Learning curve for lumbar decompressive laminectomy in biportal endoscopic spinal surgery using the cumulative summation test for learning curve. *World Neurosurg.* (2019) 122: e1007–13. doi: 10.1016/j.wneu.2018.10.197

21. Hussain I, Yeung AT, Wang MY. Challenges in spinal endoscopy. *World Neurosurg.* (2022) 160:132–7. doi: 10.1016/j.wneu.2021.11.082

22. Hahn BS, Park JY. Incorporating new technologies to overcome the limitations of endoscopic spine surgery: navigation, robotics, and visualization. *World Neurosurg.* (2021) 145:712–21. doi: 10.1016/j.wneu.2020.06.188

23. Amato MCM, Aprile BC, de Oliveira CA, Carneiro VM, de Oliveira RS. Experimental model for interlaminar endoscopic spine procedures. *World Neurosurg.* (2019) 129:55–61. doi: 10.1016/j.wneu.2019.05.199

24. Kulcheski áL, Stieven-Filho E, Nunes CP, Milcent PAA, Dau L, I-Graells XS. Validation of an endoscopic flavectomy training model. *Rev Col Bras Cir.* (2021) 48: e202027910. doi: 10.1590/0100-6991e-20202901

frontiers | Frontiers in Surgery

TYPE Original Research
PUBLISHED 23 March 2023
DOI 10.3389/fsurg.2023.1137675

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

RECEIVED 04 January 2023
ACCEPTED 06 March 2023
PUBLISHED 23 March 2023

CITATION
Zhiguo Z, Fan L, Yuanxue L, Xing W, Si W and Ruichen L (2023) Minimally invasive spine surgery strategy for congenital cervicothoracic scoliosis in children: Less blood loss and shortened segmental fusions/fewer pedical screws.
Front. Surg. 10:1137675.
doi: 10.3389/fsurg.2023.1137675

Minimally invasive spine surgery strategy for congenital cervicothoracic scoliosis in children: Less blood loss and shortened segmental fusions/ fewer pedical screws

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Objective: To explore the feasibility of a minimally invasive spine surgery strategy for congenital cervicothoracic scoliosis.
Materials and methods: From April 2022 to August 2022 in the hospital, three patients with torticollis and/or shoulder imbalance due to a cervicothoracic hemivertebra were performed on by hemivertebra resection and short fusion of the adjacent vertebrae. Resection was operated by a posterior approach. The average age of three patients of surgery was 8 years 2 months and the mean follow-up period was 6 months. Radiographic assessments and cosmetic outcomes were documented on changes in measurements of segmental scoliosis, neck tilt, head shift, shoulder balance, and sagittal profiles.
Results: The mean operating time of the procedure was 283 min and the instrumentation density was 1.5 pedicle screws per vertebra. The mean estimated blood loss was 257 ml, which was 20% less than the data described in various literatures. The mean segmental Cobb angle at the cervicothoracic deformity was 35.9° before surgery, 20.7° after surgery, and 16.3° at the latest follow-up, with a correction rate of 54.59%. Neck tilt decreased from 17.3° before surgery to 14.3° after surgery, and 11.7° at the latest follow-up, with a correction rate of 32.37%. T1 tilt improved from 16.5° before surgery to 12.9° after surgery, and 7.6° at the latest follow-up, with a correction rate of 53.94%. The clavicle angle improved from 4.8° before surgery to 3.1° after surgery, and 1.9° at the latest follow-up, with a correction rate of 60.42%. Head shift improved from 21.4 mm before surgery to 9.2 mm after surgery, and 12.3 mm at the latest follow-up, with a correction rate of 42.52%. The correction of torticollis and shoulder asymmetry was achieved in all cases.
Conclusions: Minimally invasive spine surgery strategy may be an option for congenital cervicothoracic scoliosis. A good correction of cervicothoracic dissymmetry is achieved, accompanied by fewer pedicle screws and less blood loss. By deliberate operation in young kids, surgical intervention for severe compensatory curves can be prevented.

KEYWORDS

congenital scoliosis, cervicothoracic, minimally invasive spine surgery, posterior approach, hemivertebra resection

1. Introduction

Congenital cervicothoracic scoliosis (CTS) poses a perplexing spinal deformity that is relatively rare and difficult to treat in young children (1–4). It mostly results from an osseous abnormality, namely hemivertebrae, block vertebrae, or junctional bar (2–5). Located at the transition zone between the relatively stiff thoracic spine and dynamic cervical segment, adjacent to the shoulders, the spinal abnormalities in this region are often associated with an obvious decompensation in the shoulders and neck, which can develop into facial asymmetry rapidly (2–6). However, due to the limited compensation in the adjacent spine segment, conservative treatment such as spine brace treatment or serial casting, has little effect (3, 5, 7). Hence, when asymmetric growth of the neck and head is proven early, surgical intervention should be recommended early in the lives of children (1, 2, 7–9).

Surgical treatment is always accompanied by dissecting and bleeding, as well as the risk of neural injury (5, 6, 10). Of the possible osseous anomalies that can result in spinal deformities, hemivertebra(HV) is one of the most common causes (1, 2, 11, 12). To date, for congenital scoliosis caused by hemivertebrae, both posterior approach alone and combined anterior and posterior approaches have been used and reported (7, 10, 13, 14). On the one hand, combined surgery provides better correction and convenience of the manipulation, but also means more incisions, blood loss, and lengthy operation time (6, 9, 15). On the other hand, for HV resection, the posterior-only procedure is less invasive by avoiding an anterior approach and has a slightly weaker correction than combined surgery (4, 9, 13, 15, 16). To our knowledge, few studies for operating in the cervicothoracic region have been reported (3–5, 8, 9, 17).

In brief, the principle of minimally invasive spine surgery (MISS) is to perform with less damage to the body and fewer complications. Given that the weight of young children with congenital CTS is often lighter than that of adults, reducing intraoperative blood loss is conducive to a safer operation (5, 11, 18). Therefore, in order to decrease surgical incisions, and minimize surgical bleeding and the fusion of segments by the instrumentations, the authors have attempted the concept of MISS for congenital cervicothoracic spine deformities *via* a posterior-only approach. The purpose of this study was to investigate the feasibility of this procedure for congenital CTS.

2. Materials and methods

Of the three patients in the study, two were boys and one was a girl. The patients were recruited due to torticollis and/or facial asymmetry. Their mean age at the time of surgery was 8 years 2 months (range, 6 years 3 months–10 years). The mean follow-up period was 6 months (range, 4 months–8 months). The congenital cervicothoracic scoliosis patients involved the lower thoracic region in one case and the middle and lower cervical region in one case (**Table 1**).

All of the patients with a cervicothoracic hemivertebra exhibited regional scoliosis and without significant kyphosis. To evaluate operative invasiveness, the volume of blood loss was reviewed from the clinical records along with transfusion and operative time. Similarly, the number of hemivertebra resection and pedicle screws was documented in our study (**Table 1**). The instrumentation density was also calculated using [the total pedicle screws inserted/the total instrumented vertebrae in the procedure] to assess invasiveness.

The correction ratios of both the main structural curve in the whole standing anteroposterior film and the kyphosis in the lateral standing film were evaluated. To evaluate the cosmetic parameter, the correction ratio of the T1 angle, neck tilt, and clavicle angle was investigated. For cases of head shift, a perpendicular line was drawn from the center of the mandibular, and the distance from this line to the center of the sacrum was measured to examine pre- and postoperative head balance.

Careful neurologic examination was included in the preoperative evaluation. Cervical CT angiography (CTA) and a 3-dimensional CT scan of the entire spine were performed to detect details of the vertebra and vertebral artery anomalies (3, 9, 19). A MRI was also mandatory to explore intraspinal anomalies that may also need to be addressed before surgery. Urogenital and cardiovascular examinations were performed to screen abnormalities of the renal system and congenital heart diseases.

Ethical approval was warranted by the local Ethics Committee of our institution and all the processes being performed were routine care. All subjects' guardians signed informed consent.

3. Radiographic assessment

Whole standing spine anteroposterior (AP) and lateral radiographs were reviewed to assess spinal correction preoperatively, postoperatively, and at the latest follow-up. The parameters in the coronal plane included both local scoliosis and the distal compensatory curve. Following Chen's method (9), four parameters were also measured to determine the cosmetic effect on each radiograph (**Table 2**) as follows: (1) T1 tilt, the angle between the line through the upper endplate of T1 and the horizontal line; (2) clavicle angle, the angle between the tangential line connecting the highest two points of each clavicle and the horizontal line; (3) neck tilt, the angle between the longitudinal axis of the cervical spine (the line connect the center of C7 with the center of C2 odontoid process) and the vertical line of the center of C2; and (4) head shift, the distance between the central sacral vertical line and midline of the mandibular body. For the cases of multiple hemivertebrae, the scoliosis formed by the proximal HV was defined as the proximal segmental scoliosis, compared with the curve formed by the distal HV, which was called the distal segmental scoliosis.

In the sagittal plane, segmental kyphosis, lumbar lordosis, and thoracic kyphosis were measured. The cobb angle of the segmental scoliosis curve was measured between the inferior endplate of the caudal vertebrae and the superior endplate of the cranial vertebra adjacent to the HV. The segmental lordosis or kyphosis was

TABLE 1 Demographic anatomical and surgical characteristics.

	Age (year + month)	Gender	Resected HV	Associated congenital abnormalities	Estimated blood loss (ml)	Operating-time (min)	Fused segment	Pedicle screws
Case 1	8y + 4m	Female	C7-R	C3.T5-HV-R; C4-C6-BV; Synostosis: C2-C3-R; T4-T6-L;	450	310	2 (C6-T1)	4
Case 2	6y + 3m	Male	T2-L	C7,T1-BFV; T10 -HV-R	150	210	3 (T1-T4)	5
Case 3	10y	Male	T1-L T4-R	T2-Butterfly vertebra	170	330	5 (T1-T6)	6
Average					257	283		1.5/fusion segment

Note: HV, hemivertebra; BV, block vertebra; BFV, butterfly vertebra; R, right; L, left.

investigated in the sagittal plane, in the same way as was segmental scoliosis in the coronal plane. Lumbar lordosis (L1–S1) and thoracic kyphosis (T5–T12) were also assessed and documented. The distance between the posterior superior corner of the S1and C7 plumb line was obtained to assess sagittal trunk shift.

Radiographic data were assessed and collected from a picture archiving and communication system (PACS) software of our hospital, with an accuracy of 0.1°or 0.1 mm. The correction rate was calculated using [(preoperation parameter–latest follow-up parameter)/preoperation parameter] × 100%. To minimize measurement error of interobserver, all radiographs were evaluated by 2 authors who did not anticipate the surgery, and the mean measurements were collected for analysis.

4. Operative procedure

After general anesthesia and neuromonitoring installation, the patient was placed in the prone position with the neck slightly flexed position on the polyurethane gelatum pads of the head. The HV was checked by fluoroscopy and the back was prepared in a routine fashion. A midline skin incision was made on the back at the center of the spinal deformity. The posterior elements of the spine were carefully revealed at the level of the HV and the adjacent vertebrae. The lamina and attached transverse process of the HV was identified and pedicle screws were inserted in the adjacent vertebrae. In this study, we preferred all-pedicle-screw instrumentation based on data from the computed tomography three-dimensional (3D) reconstruction. Meanwhile, laminar hook or hybrid instrumentation should also be prepared as a good alternative. For the anomalous pedicles of the adjacent vertebrae, normal pedicle screws were shortened appropriately by a rod-cutter before insertion, consisting of a limited length of the abnormality. For the pedicles with enough diameter and length, normal pedicle screws were routinely inserted. The lamina and attached transverse process of the HV were removed to expose the pedicle after the screw implantation.

Bleeding during HV resection was well controlled by pre-cauterizing the intraspinal venous plexus down the medial wall of the pedicle to the posterior wall of the body of the HV with a bipolar coagulation. Thereafter, the pedicle was removed and the vertebral body and its discs of the HV were visualized easily. After the dura sac and nerve roots above and below the HV were carefully exposed and protected, a sharp dissection was made with a scalpel between the edge of the disc of the HV and the bony endplate of the adjacent vertebrae.Sequently, an osteotome was inserted into the gap carefully along with the bony endplate of the adjacent vertebrae. The vertebral body of the HV and the upper and lower disks were gently pried up by the osteotome and the residual anterior wall of the HV was done with a nucleus pulposus forceps and/or a curette. After the removal of the HV, a temporary rod was then placed on the concave side and the endplate of the adjacent vertebrae were completely decorticated to prepare for fusion. The temporary rod was removed and two rods were mounted on the convex and concave sides respectively. Thereafter, the gap was closed by gradually compressing the convex side and extending the concave side along the rods. Meanwhile, the upper and lower vertebrae of the

TABLE 2 Demographic: changes in the coronal and sagittal planes.

		T1 Tilt (°)	Clavical Angle (°)	Neck Tilt (°)	Head Shift (mm)	Segmental Scoliosis (°)
Case 1	Pre-operative	18.2	5.3	18.4	16.3	32.3
	Post-operative	14.3	4.3	10.4	10.3	16.8
	Latest follow-up	13.4	3.2	9.7	7.8	14.5
	Correction ratio %	26.37	39.63	47.53	52.15	55.11
Case 2	Pre-operative	13.6	4.5	20.5	16.3	P:34.2 D:34.6
	Post-operative	20.5	2.6	25.2	7.9	P:37.6 D:4.0
	Latest follow-up	6.5	0.5	18.7	13.3	P:10.5 D:13.4
	Correction ratio %	52.21	88.89	8.78	18.40	P:69.29 D:61.27
Case 3	Pre-operative	17.7	4.7	13.0	31.5	P:38.3 D: 39.9
	Post-operative	4.1	2.4	7.3	9.5	P:26.1 D:18.6
	Latest follow-up	3.0	2.0	6.8	15.9	P:22.5 D:20.8
	Correction ratio %	83.05	57.45	47.69	49.52	P:41.25 D:47.87

Notes: P, proximal segmental curve; D, distal segmental curve.

HV should be horizontalized as much as possible under fluoroscopy. All the bones removed during the hemivertebrectomy were operated as graft material throughout the residual defect. Decortication of the posterolateral elements of vertebrae and fusion was then performed. Neuromonitoring was mandatory throughout the procedure.

All patients attempted to stand and walk with the drainage tube on the second day after surgery. Afterward, a cranial-cervical-thoracic brace was worn for three to six months.

5. Results

5.1. Surgical outcomes of all patients

Osteotomy and pedicle screw insertion were operated free-hand in all cases. Three young patients with congenital CTS were included in this study, and underwent posterior-only approach correction and fusion. The median operating time of the procedure was 283 min (range, 210–330 min), and the mean estimated blood loss was 257 ml (range, 150–450 ml), which was 20% less than in previous literature. The instrumentation density was 1.5 pedicle screws per vertebra, suggesting this method is less invasive. All cases achieved good shoulder balance and improved facial cosmetics.

5.2. Correction of the coronal plane

5.2.1. Segmental correction

The mean segmental Cobb angle between the vertebrae adjacent to the HV was 35.9° before surgery, 20.7° after surgery, and 16.3° at the latest follow-up, with a correction rate of 54.59% (Table 2).

5.2.2. Neck tilt

The angle between the vertical line of C2 and the longitudinal axis of the cervical spine (the line connecting the center of the C2 odontoid process with the center of C7) improved from 17.3° before surgery to 14.3° after surgery, and 11.7° at the latest follow-up, with a correction rate of 32.37%.

5.2.3. T1 tilt

The angle between the line through the upper endplate of T1 and the horizontal line improved from 16.5° before surgery to 12.9° after surgery, and 7.6° at the latest follow-up, with a correction rate of 53.94%.

5.2.4. Clavical tilt

The angle between the tangential line connecting the highest two points of each clavicle and the horizontal line improved from 4.8° before surgery to 3.1° after surgery, and 1.9° at the latest follow-up, with a correction rate of 60.42%.

5.2.5. Head shift

The distance between a vertical line drawn from the middle line of the mandibular body to the middle of the sacrum improved from 21.4 mm before surgery to 9.2 mm after surgery, and 12.3 mm at the latest follow-up, with a correction rate of 42.52%.

5.3. Sagittal plane

Only subtle changes in the sagittal plane were observed. The segmental angles between the adjacent vertebrae averaged 0.9° before surgery, 1.5° after surgery, and 1.1° at the last follow-up. The mean value of LL was 32.8° before surgery, 26.5° after surgery, and 29.8° at the latest follow-up, and the mean value of TK was 25.3° before surgery, 21.3° after surgery, and 22.3° at the latest follow-up. The spinal sagittal balance was maintained perioperatively and at the final follow-up.

5.3.1. Case description

Case 1: A 8-year-4-month-old girl who was recognized as torticollis since the age of 6 months, and had undergone physiotherapy treatment without success. She had been unable to gaze horizontally since birth but had no pain or neurologic deficits. The preoperative computed tomography revealed a Klipple-Feil syndrome with multiple abnormalities in the cervical and upper thoracic spine: a segmented C7 HV at the right side in a synostosed bony mass from C3 to T6, two semi-segmented HV C3 and T5 at the right side, synostosed partially with the C2 to C3, and T4 to T6 conglomerate, and a blocked vertebrae C4 to C6. Meanwhile, conventional tomography showed a perplexing synostosis of the lamina of C3 to T6. The Cobb angle between C6 and T1 was 32.3°, neck tilt was 18.4° and a compensatory convex of the lumbar spine to the left was 29.3° on the standing anteroposterior x-ray (Figure 1). An MRI excluded deformities of the spinal cord. The C7 HV was removed by a posterior approach with the fusion of C6 to T1 vertebrae. C7 HV was resected with a drill and the gap between C6 and T1 was instrumented with 4 pedicle screws, with 450 ml blood loss. The dura sac and nerve roots adjacent to the C7 HV were carefully identified and protected by a retractor and the neuromonitoring did not reveal any changes intraoperatively. However, the patient underwent a transient C7 nerve injury, complaining of right shoulder pain, and inability to straighten the right upper limb and fingers, and fully recovered without treatment 3 months postoperatively. At the latest follow-up (4 months postoperative), the patient achieved horizontal gaze and her neck position was neutral (Figure 1). The Cobb angle C6 to T1 improved to 14.5° (correction ratio 55.11%) at the latest follow-up, and neck tilt was 9.7° (correction ratio 47.53%), meanwhile, her compensatory lumbar scoliosis was completely straightened.

Case 2: A 6-year-3-month-old boy presented stiff torticollis since the age of 1 year, treated by a brace without success. His torticollis worsened significantly, but there was no neck pain or neurologic deficits. Conventional tomography showed an HV between T1 and T3 on the left side and an HV between T9 and

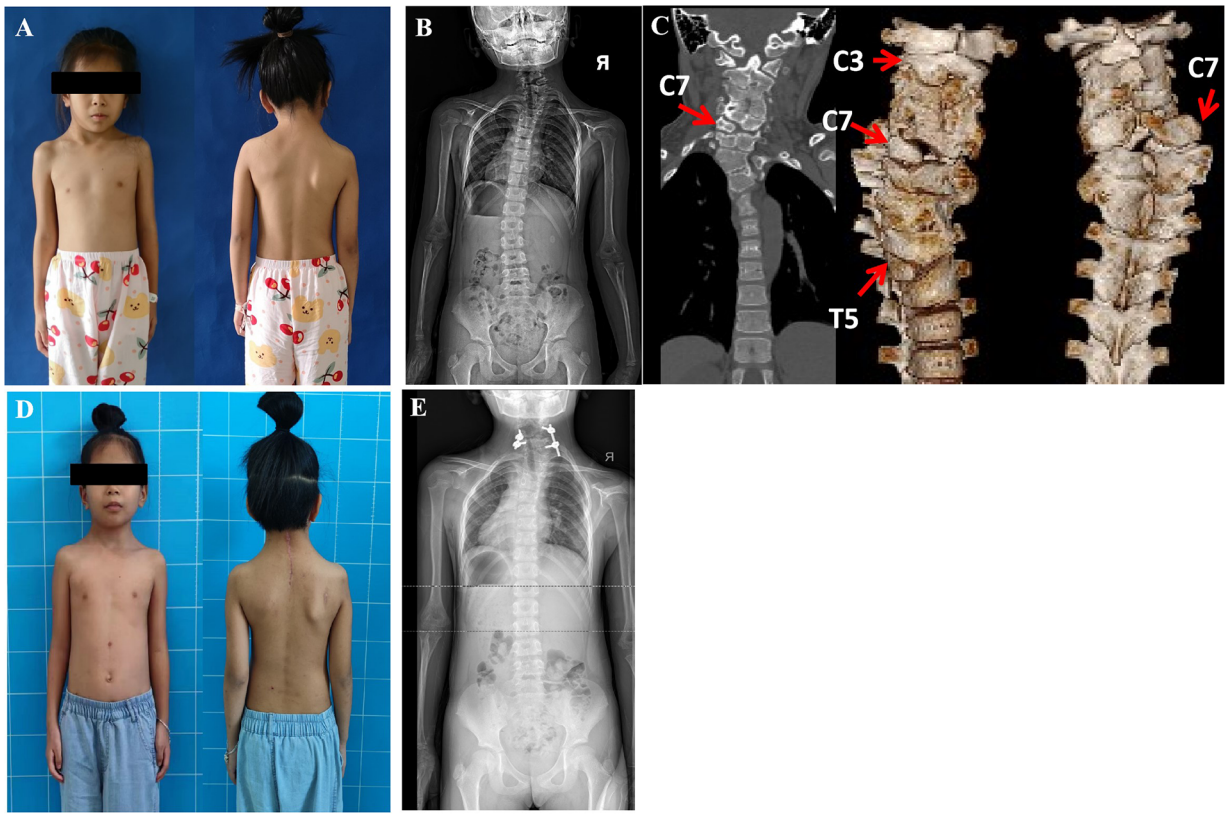

FIGURE 1
An 8 years 4 months old girl could not gaze horizontally with rigid torticollis (**A**). 3D CT showed a complexed deformitu of Klippel-Feil syndrome: C3.C7.T5-HV-R,C7 segmented HV,C3,T5 semi-segmented HV; C4-C6-BV; synostosis: C2-C3-R; T4-T6-L (**C**). She underwent C7 HVR with bilateral short fusion and could gaze horizontally three months postoperatively (**D**). Radiographs images demonstrated that there was a congenital cervicothoracic scoliosis with a compensatory lumbar curve preoperatively (**B**), thereafter, the neck tilt was significantly improved and the compensatory lumbar curve became 0° straight postoperatively at the latest follow-up 4 months later (**E**).

T11 on the right side of the thoracic spine. Therefore, the proximal scoliosis created by T2 HV was 34.2° and the distal thoracic curve created by T10 HV was 34.6°, compensating for each other. At the first surgery, the T10 HV was removed by a posterior approach with instrumentation T9 to T12 vertebrae, with 150 ml blood loss. Three months later, the shoulder asymmetry was corrected completely due to the correction of the distal segmental scoliosis from 34.6° to 4.0° (correction ratio 88.6%). However, without any compensation at T10 HV in the thoracic spine, a considerable neck tilt (proximal segmental scoliosis) deteriorated from 34.2°to 37.6° (Figure 2), and head shift improved from 1.62 cm to 0.79 cm. The resection of T2 HV was performed with fusion T1 to T3 vertebrae, five pedicle screws, and 150 ml blood loss. Staged HV excisions resulted in a perfect correction of neck and shoulder imbalance in general view and on radiographic assessment. At the latest follow-up (3 months post-second operation), the patient was without complaints and his neck position was neutral (Figure 2). Meanwhile, the Cobb angle at T2 HV improved from 37.6° to 10.5°, the distal curve at T10 HV from 34.6° to 13.4°, and the head shift from 0.79 cm to 1.33 cm at the last follow-up.

Case 3: A 10-year-old boy complained of neck pain with mild torticollis and right shoulder height since the age of 9 years, without physiotherapy treatment. The radiologic examinations revealed a right clavicle height with an HV between C7 and T2 vertebrae on the left side and an HV between T3 and T5 vertebrae on the right side. T4 HV was removed first and the initial plan for T1 HV was resection of T1 HV and short fusion between C7 and T2 vertebrae. Due to the difficulty of screw insertion free hand in the C7 vertebra, our strategy was adjusted to preserve the pedicle and upper part of T1. A wedge osteotomy was performed between the lower part of the T1 HV and the upper part of the T2 vertebra, then the deficits were closed using screws at T1 HV and T3 vertebra. After the osteotomy at T4 and partial T1 HV, six pedicle screws were done to fix five spinal segments (T1-T6) and 170 ml of bleeding was documented. At the latest follow-up, the patient was pain-free and his shoulder balance was restored effectively. The neck tilt was 6.8° to the right and the head shift 1.59 cm to the left at the latest follow-up (Figure 3).

5.3.2. Complications

Although there was no abnormal change from the neuromonitoring intraoperatively, case 1 presented a transient C7 nerve injury, complaining of right shoulder pain, inability to straighten the right upper limb and fingers, and fully recovered 3

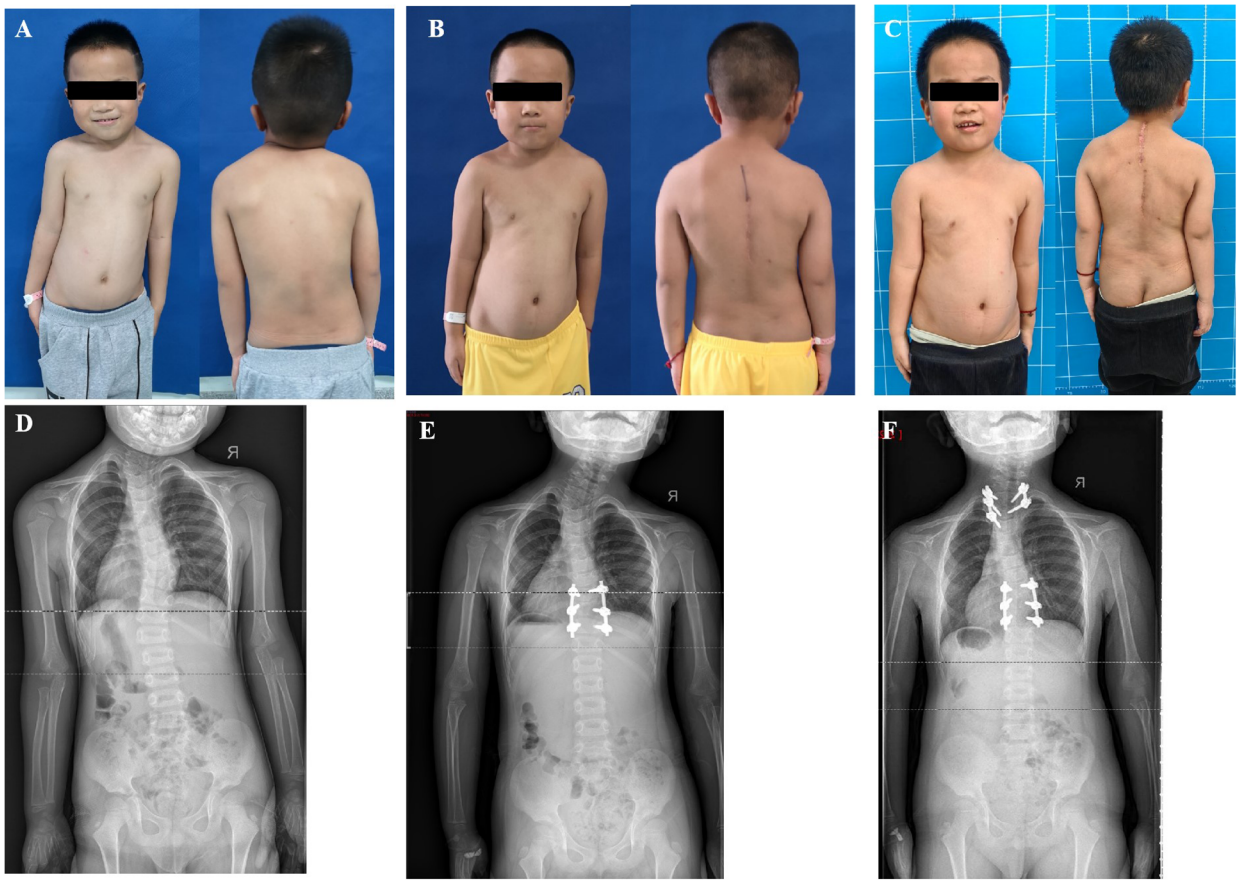

FIGURE 2
A 6 years 3 months old boy presented shoulder imbalance and facial asymmetry. Radiographs indicated that T2 and T10 were both hemivertebra and they compensated each other before the operation (**A**,**D**). He underwent a staged operation. The T10 HV was removed at the first surgery and he gained good shoulder balance and worsening torticollis due to the lack of compensatory T10 HV 3 months post the first operation (**B**,**E**). T2 HV was resected a second time, and his facial cosmesis and torticollis improved significantly 3 months post the second surgery (**C**,**F**).

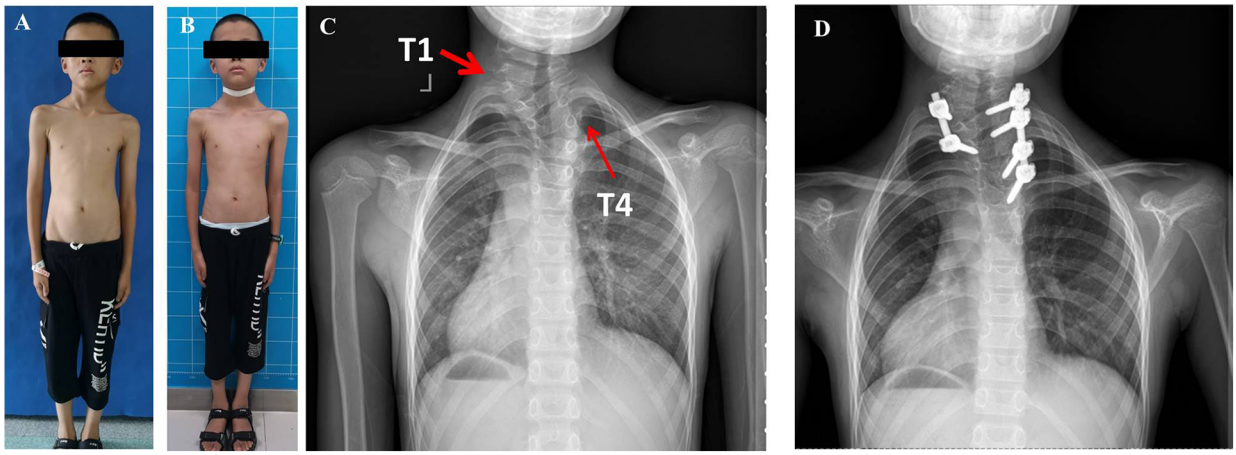

FIGURE 3
A 10 years old boy complained of neck pain and shoulder imbalance and was revealed to have two HVs at T1 and T4 (**A**,**C**). For the distal segment scoliosis, the T4 HV was removed and T2 to T6 vertebrae were instrumented on the convex side. For the proximal segment scoliosis, due to the difficulty of screw placement free hand in C7, a wedge osteotomy was performed between the lower part of the T1 hemivertebra and the upper part of the T2 vertebra, then the deficits were closed using screws at T1 and T3 vertebra. He achieved good shoulder balance and no neck pain 3 months postoperatively (**B**,**D**) Ji lilili oFIIFA.

months without treatment after surgery. No surgical site infection occurred in all cases.

6. Discussion

The average amount of blood loss in this study was 257 ml, about 20% less than the median blood loss of 313 ml in previous literatures (3, 5, 7, 9, 16, 17). In this study, 1.5 pedicle screws were instrumented per vertebral body, a reduction of 0.5 screws per vertebral body compared to the usual 2 pedicle screws per vertebral body (3, 16, 17). For CTS, the fusion length could be reduced by early intervention and the pedicle screws could be cut down by appropriate screw density, which was to reduce body damage. For multiple hemivertebra of CTS, priority treatment to the distal hemivertebra and staged surgery is an appropriate option to employ the principle of MISS strategy. Following the above measures, the fixed segment could be reduced and the amount of bleeding could be controlled efficiently.

Whereas there were relatively few cases of congenital scoliosis in the cervicothoracic segment, current surgical treatments vary widely in previous literature. Current posterior-only surgery and combined surgery have their own pros and cons, respectively (13–21). Therefore, to provide satisfactory scoliosis correction and less damage to the body of children, surgical timing, surgical plan-making, and surgical techniques are important foundations for MISS strategy.

First, surgical timing is a priority principle of MISS to treat congenital CTS. Timing the operation properly means shorter fusion segments and fewer pedicle screws. Case 1 presented a perplexing cervicothoracic spinal deformity and compensatory lumbar scoliosis on radiographic imaging (**Figure 1**). After excision of the C7 HV that was the apex, a simplified bifusion of the upper and lower vertebrae was performed. The patient's torticollis was efficiently improved with the compensatory lumbar curve spontaneously corrected to 0° (**Figure 1**). This result suggested that HV excision at an early age may arrest the secondary curve progression of trunk shift. A similar conclusion was obtained that early operation to congenital CTS could meliorate overall spine coronal balance significantly after surgery (2, 5, 9, 10, 15). Conversely, the untreated compensatory curves tend to progress to structural deformity, which requires extended correction and fusions (2, 7, 17). Hence, in the cases of congenital scoliosis at the cervicothoracic region in children, shoulder imbalance and cosmetic deficit rather than the angle of curvature is a critical indications for operative treatment (2, 3, 5, 15–17).

Second, for multiple hemivertebrae in congenital CTS, it was an optimal option that the flexible distal HV segment should be treated first, sequentially followed by the proximal HV region with poor mobility. This surgical procedure could indicate neck and shoulder balance as good as possible with fewer fusions (9, 20). Case 2 was treated with staged hemivertebrae resection (**Figure 2**). The thoracic HV at T10 was resected at the first time, and the shoulder balance was significantly improved while the deterioration of his torticollis was noted at the follow-up post first surgery. The second surgery was performed to remove the cervicothoracic HV at T1 three months after the first operation, and the torticollis was significantly improved both immediately after surgery and at the latest follow-up. In case 3, the two hemivertebrae at T1 and T4 were adjacent to each other, and a one-stage surgery was performed. The caudal HV at T4 was firstly removed and instrumented first. Consequently, a wedge osteotomy was performed between T1 HV and T2 vertebra, then, the gap was closed using internal fixation at T1 HV and T3 vertebra a one-stage operation. Thereafter, four pedicle screws were used to fix the distal convex side and two screws instrumented the proximal convex side (**Figure 3**). The purpose of this asymmetrical screw formation was to warrant a solid stabilization of the pedicle screws on the convex side and reduce the number of instrumentations (21). Eventually, both patients achieved good shoulder balance and facial cosmetics. Therefore, for a complex congenital CTS, more attention should be paid to reasonable surgical plan-making (13, 19–21).

Third, the surgical technique of meticulous pre-cautery of the intraspinal venous plexus adjacent to the hemivertebrae can effectively decrease the amount of intraoperative bleeding, consistent with the MISS strategy. After the intraspinal venous plexus pre-hemostasis was completed, there was little bleeding in the surgical field during HV resection. Moreover, in case of massive bleeding during the resection of the hemivertebra, effective hemostasis could be achieved by cauterization of the venous plexus down the posterior wall of the vertebral body. The average amount of blood loss was about 257 ml in our study, which was 20% less than the procedures as being described in the previous literatures. For young children, lower operation time and blood loss can ensure safer operations and faster recovery (5, 19, 21). Hence, the effective maneuver of intraspinal pre-hemostasis is more conducive to the practice of MISS strategy (19, 21).

There were several limitations in our study. First, it had a limited sample size since this circumstance is relatively rare. However, to the best of our knowledge, this is an earlier study to treat congenital CTS with MISS strategy. The second limitation of this study is that the follow-up duration is still relatively short considering the immature nature of the spines in question. Thus, a long-term follow-up study should be further carried out.

In conclusion, our short-term study achieved excellent correction results using the one-stage strategy with MISS, which hopefully could provide an option for the treatment of congenital CTS. Future well-designed prospective studies with longer follow-up times are required to further validate our study.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by the local Ethics Committee of Wuhan Children's

Hospital. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

Conceptualization: ZZ, LF; Data curation: LF, LR, WS; Formal analysis: WX, LY, WS; Methodology: ZZ; Project administration: ZZ; Visualization: LY, LR, WS; Writing—original draft: ZZ; Writing—review; editing: WX, LF. All authors contributed to the article and approved the submitted version.

Acknowledgments

The authors thank Lili for the English language editing of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

1. Pahys JM, Guille JT. What's new in congenital scoliosis? *J Pediatr Orthop*. (2018) 38(3):e172–9. doi: 10.1097/BPO.0000000000000922

2. Smith MD. Congenital scoliosis of the cervical or cervicothoracic spine. *Orthop Clin North Am*. (1994) 25(2):301–10. doi: 10.1016/S0030-5898(20)31911-8

3. Zhang HQ, Du YX, Liu JY, Deng A, Wu JH, Wang YX, et al. Strategy and efficacy of surgery for congenital cervicothoracic scoliosis with or without hemivertebra osteotomy. *Orthop Surg*. (2022) 14(9):2050–8. doi: 10.1111/os.13480

4. Balestrino A, Gondar R, Jannelli G, Zona G, Tessitore E. Surgical challenges in posterior cervicothoracic junction instrumentation. *Neurosurg Rev*. (2021) 44 (6):3447–58. doi: 10.1007/s10143-021-01520-6

5. Cao S, Chen X, Pan SF, Diao YZ, Zhao YB, Xia T, et al. Evaluation and comparation of a novel surgical technique and hemivertebra resection to the correction of congenital cervical scoliosis in lower cervical and cervicothoracic spine. *Neurospine*. (2022) 19 (4):1071–83. doi: 10.14245/ns.2244554.277 [published online ahead of print, 2022 Nov 18].

6. Bayoumi AB, Efe IE, Berk S, Kasper EM, Toktas ZO, Konya D. Posterior rigid instrumentation of C7: surgical considerations and biomechanics at the cervicothoracic junction. A review of the literature. *World Neurosurg*. (2018) 111:216–26. doi: 10.1016/j.wneu.2017.12.026

7. Ruf M, Jensen R, Harms J. Hemivertebra resection in the cervical spine. *Spine (Phila Pa 1976)*. (2005) 30(4):380–5. doi: 10.1097/01.brs.0000153398.78661.2b

8. Yang JH, Chang DG, Suh SW, Kim W, Park J. Clinical and radiological outcomes of hemivertebra resection for congenital scoliosis in children under age 10 years: more than 5-year follow-up. *Medicine (Baltimore)*. (2020) 99(32):e21720. doi: 10.1097/MD.0000000000021720

9. Chen ZH, Qiu Y, Zhu ZZ, Li S, Chen X, Xu L, et al. Posterior-only hemivertebra resection for congenital cervicothoracic scoliosis: correcting neck tilt and balancing the shoulders. *Spine (Phila Pa 1976)*. (2018) 43(6):394–401. doi: 10.1097/BRS.0000000000002325

10. Toll BJ, Samdani AF, Amanullah A, Pahys JM, Janjua MB, Hwang SW. Congenital scoliosis of the pediatric cervical spine: characterization of a 17-patient operative cohort. *J Pediatr Orthop*. (2021) 41(3):e211–6. doi: 10.1097/BPO.0000000000001718

11. Basu PS, Elsebaie H, Noordeen MH. Congenital spinal deformity: a comprehensive assessment at presentation. *Spine (Phila Pa 1976)*. (2002) 27 (20):2255–9. doi: 10.1097/00007632-200210150-00014

12. McMaster MJ. Spinal growth and congenital deformity of the spine. *Spine (Phila Pa 1976)*. (2006) 31(20):2284–7. doi: 10.1097/01.brs.0000238975.90422.c4

13. Lyu QN, Zhou CG, Song YM, Liu LM, Hu BW, Feng GJ, et al. The efficacy of hemivertebra resection for hemimetameric segmental shift. *World Neurosurg*. (2019) 121:e528–34. doi: 10.1016/j.wneu.2018.09.158

14. Yaszay B, Brien O, Shufflebarger HL, Betz R, Lonner B, Shah SA. Efficacy of hemivertebra resection for congenital scoliosis: a multicenter retrospective comparison of three surgical techniques. *Spine (Phila Pa 1976)*. (2011) 36 (24):2052–60. doi: 10.1097/BRS.0b013e318233f4bb

15. Nakamura H, Matsuda H, Konishi S, Yamano Y. Single-stage excision of hemivertebrae via the posterior approach alone for congenital spine deformity: follow-up period longer than ten years. *Spine (Phila Pa 1976)*. (2002) 27(1):110–5. doi: 10.1097/00007632-200201010-00026

16. Chang DG, Kim JH, Ha KY, Lee JS, Jang JS, Suk SI. Posterior hemivertebra resection and short segment fusion with pedicle screw fixation for congenital scoliosis in children younger than 10 years: greater than 7-year follow-up. *Spine (Phila Pa 1976)*. (2015) 40(8):E484–91. doi: 10.1097/BRS.0000000000000809

17. Zhu X, Wei X, Chen J, Li C, Li M, Qiao Y, Ran B. Posterior hemivertebra resection and monosegmental fusion in the treatment of congenital scoliosis. *Ann R Coll Surg Engl*. (2014) 96(1):41–4. doi: 10.1308/003588414X13824511650173

18. Zhuang Q, Zhang J, Li S, Wang S, Guo J, Qiu G. One-stage posterior-only lumbosacral hemivertebra resection with short segmental fusion: a more than 2-year follow-up. *Eur Spine J*. (2016) 25(5):1567–74. doi: 10.1007/s00586-015-3995-x

19. Zhuang Q, Zhang J, Wang S, Guo J, Qiu G. Multiple cervical hemivertebra resection and staged thoracic pedicle subtraction osteotomy in the treatment of complicated congenital scoliosis. *Eur Spine J*. (2016) 25(Suppl 1):188–93. doi: 10.1007/s00586-015-4352-9

20. Zhou CG, Liu LM, Song YM, Liu H, Li T, Gong Q. Hemivertebrae resection for unbalanced multiple hemivertebrae: is it worth it? *Eur Spine J*. (2014) 23(3):536–42. doi: 10.1007/s00586-013-3065-1

21. Zhao S, Xue X, Li K, Miao F, Zhao B. Two-staged posterior osteotomy surgery in complex and rigid congenital scoliosis in younger than 10 years old children. *BMC Musculoskelet Disord*. (2021) 22(1):788. doi: 10.1186/s12891-021-04682-y (Published 2021 Sep 13).

frontiers | Frontiers in Surgery

TYPE Case Report
PUBLISHED 27 April 2023
DOI 10.3389/fsurg.2023.1142679

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

RECEIVED 12 January 2023
ACCEPTED 20 March 2023
PUBLISHED 27 April 2023

CITATION
Moura DL and Cavaca AR (2023) Internal replacement of a vertebral body in pseudarthrosis—Armed kyphoplasty with bone graft-filled stents: Case report.
Front. Surg. 10:1142679.
doi: 10.3389/fsurg.2023.1142679

Internal replacement of a vertebral body in pseudarthrosis—Armed kyphoplasty with bone graft-filled stents: Case report

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Background: Post-traumatic vertebral necrosis and pseudarthrosis represents one of the most concerning and unpredictable challenges in spinal traumatology. The evolution of this disease at the thoracolumbar transition usually courses with progressive bone resorption and necrosis, leading to vertebral collapse, retropulsion of the posterior wall and neurological injury. As such, the therapeutic goal is the interruption of this cascade, seeking to stabilize the vertebral body and avoid the negative consequences of its collapse.
Case description: We present a clinical case of a pseudarthrosis of T12 vertebral body with severe posterior wall collapse, treated with removal of intravertebral pseudarthrosis focus by transpedicular access, T12 armed kyphoplasty with VBS® stents filled with cancellous bone autograft, laminectomy and stabilization with T10-T11-L1-L2 pedicle screws. We present clinical and imaging detailed results at 2-year follow-up and discuss our option for this biological minimally invasive treatment for vertebral pseudarthrosis that mimics the general principles of atrophic pseudarthrosis therapeutic and allows to perform an internal replacement of the necrotic vertebral body, avoiding the aggression of a total corpectomy.
Conclusions: This clinical case demonstrates a successful outcome of the surgical treatment of pseudarthrosis of vertebral body (mobile nonunion vertebral body) in which expandable intravertebral stents allow to perform an internal replacement of the necrotic vertebral body by creating intrasomatic cavities and filling them with bone graft, obtaining a totally bony vertebra with a metallic endoskeleton, which is biomechanically and physiologically more similar to the original one. This biological internal replacement of the necrotic vertebral body technique can be a safe and effective alternative over cementoplasty procedures or total vertebral body corpectomy and replacement for vertebral pseudarthrosis and may have several advantages over them, however long-term prospective studies are needed in order to prove the effectiveness and advantages of this surgical option in this rare and difficult pathological entity.

KEYWORDS
vertebral necrosis, pseudarthrosis, armed kyphoplasty, stents, bone graft

Introduction

Avascular necrosis of the vertebral body diagnosis in post-traumatic context has been increasing, probably due to population aging, being more commonly found in the thoracolumbar transition and in elderlies with osteoporosis (1–7). It is estimated that posttraumatic vertebral necrosis is underdiagnosed and that its real incidence is

significant, with studies indicating its occurrence in 7 to 37% of vertebral compression fractures, affecting more frequently the more comminuted fractures, those with greater flattening and the ones that reach the less vascularized regions of the vertebral body. All of these are risk factors known for the development of pseudarthrosis in general. Post-traumatic vertebral necrosis represents a failure in vertebral bone healing and, thus, it makes sense that the treatment aims to interrupt this disease's evolution and negative consequences, which represents one of the most concerning and unpredictable challenges in spinal traumatology. This way, patients with symptomatic vertebral necrosis (axial pain and functional limitation), with or without neurological compression symptoms, are candidates for surgical intervention, ranging from vertebroplasty, kyphoplasty, posterolateral arthrodesis to corporectomy and application of an intersomatic spacer. The indications for each type of surgical intervention depend on the integrity of the vertebral body, spinal stability, the patient's previous functional condition and the degree of future solicitation of the spine for each patient, which can justify only a percutaneous cementoplasty or a more invasive intervention like a total vertebral body replacement. The risks-benefits of each surgical solution must be weighed taking into account the level of functional demand of each patient and the type of vertebral necrosis, however the exact indications remain poorly defined in the literature (1, 2, 8–11). Expandable intravertebral implants are self-expanding devices applied percutaneously with posterior transpedicular access. They are introduced inside the vertebral body (armed kyphoplasty) and their expansion allows for restoration of their height, integrity and stability, when filled with bone cement or graft (12–22). The evolution of indications for these recent devices has also shown promising results in vertebral fractures evolving symptomatically and chronically to non-union situations (23, 24).

Case presentation

We present a 71-year-old male patient, previously autonomous in daily living activities, with a history of type II diabetes mellitus, arterial hypertension and dyslipidemia, who came to our center emergency department bedridden with complaints of thoracolumbar axial pain. This pain was severe (grade 7/10 on *Visual Analog Pain Scale*—VAS) and had progressively worsened over 2 weeks, leading to the patient being currently unable to sit or walk (25). The patient had no radiculalgia or neurological deficits and the assessed *Oswestry score* (ODI) was 96% (26). The patient reported that 4 months before he had been diagnosed in another hospital with a fracture of T12 following a fall from standing height and he started conservative treatment with Jewett-type brace and analgesia. After 2 months of treatment, the pain disappeared, so the patient stopped using the Jewett-type brace and did not return to hospital. The patient brought the initial radiography and computed tomography (CT) performed at another hospital, which demonstrated an acute compression fracture of T12 vertebral body, with marked destruction of the intrasomatic trabeculae, especially in the anterior half of the vertebral body, as well as an old fracture of the L1 lower body endplate (**Figure 1** Sag-Li, Sag-I and **Figure 2**—Rad-APi, Cor-I, Ax-I). A CT scan was performed in the context of the current episode and a pseudarthrosis of T12 vertebral body was identified, with almost total somatic collapse, the presence of a large anterior intrasomatic cleft and marked retropulsion of the posterior wall (**Figure 1** Sag-P and **Figure 2**—Color-P, Ax-P). Average Hounsfield units at T11 and L1 and L2 vertebral body on this CT was 180, so patient demonstrated normal bone mineral density. Once this was a previously autonomous patient with current inability to verticalize the trunk due to severe axial pain in the context of T12 vertebral body pseudarthrosis and collapse, we proceeded to the following surgical intervention: laminectomy of T12 for spinal cord decompression, cleaning and removal of intravertebral pseudarthrosis focus with curettes and tweezers by bilateral transpedicular access, T12 armed kyphoplasty with VBS® stents filled with cancellous bone autograft (after the maximum expansion of the stents, we applied and impacted the bone autograft through transpedicular cannulas inside both stents until they were completely filled; autologous bone graft removed from the spinous and laminae after decompression and iliac bone) and stabilization with T10-T11-L1-L2 pedicle screws. In **Figure 3** we show an illustration of the armed kyphoplasty with VBS® stents. We only performed the open median posterior lumbar approach centered on T12, strictly necessary for the T12 laminectomy and cruentation of the adjacent lamina and zygapophysis, in order to promote posterolateral arthrodesis of the T11-T12-L1 segment, while all the remaining pedicle instrumentation was performed by percutaneous approach. The patient walked on the first postoperative day and was discharged 1 week after. At the 2-month follow-up visit, he already had no relevant pain complaints and no limitations in activities of daily living, with evaluated VAS of 1 and an ODI of 12% at this time. We performed a control CT at the end of the first year after the surgery, in which we could verify the complete healing of the pseudarthrosis, with no signs of migration or failure of intrasomatic stents or pedicle screws, as well as of bone graft resorption, which indicates its osseointegration and healing (**Figure 1** Sag-Fm, Sag-Fr and Sag-Fl; **Figure 2** Cor-F and Ax-F). At 2-year follow-up, the patient was satisfied, pain free (VAS 0) and without relevant limitations in activities of daily living, with an assessed ODI of 4%. We present the final radiographic control at 2 years postoperatively, which demonstrates maintenance of the integrity of the vertebral body and implants (**Figure 1** Rad-Lf and **Figure 2** Rad-APf).

Discussion

In the present clinical case, the marked destruction of the intrasomatic trabeculae in the initial fracture associated with its location in the thoracolumbar transition, a region of important mobility, would, in our opinion, be a criterion for performing an *ad inicium* T12 armed kyphoplasty in order to guarantee the anterior column support, stabilize it and thus precisely prevent

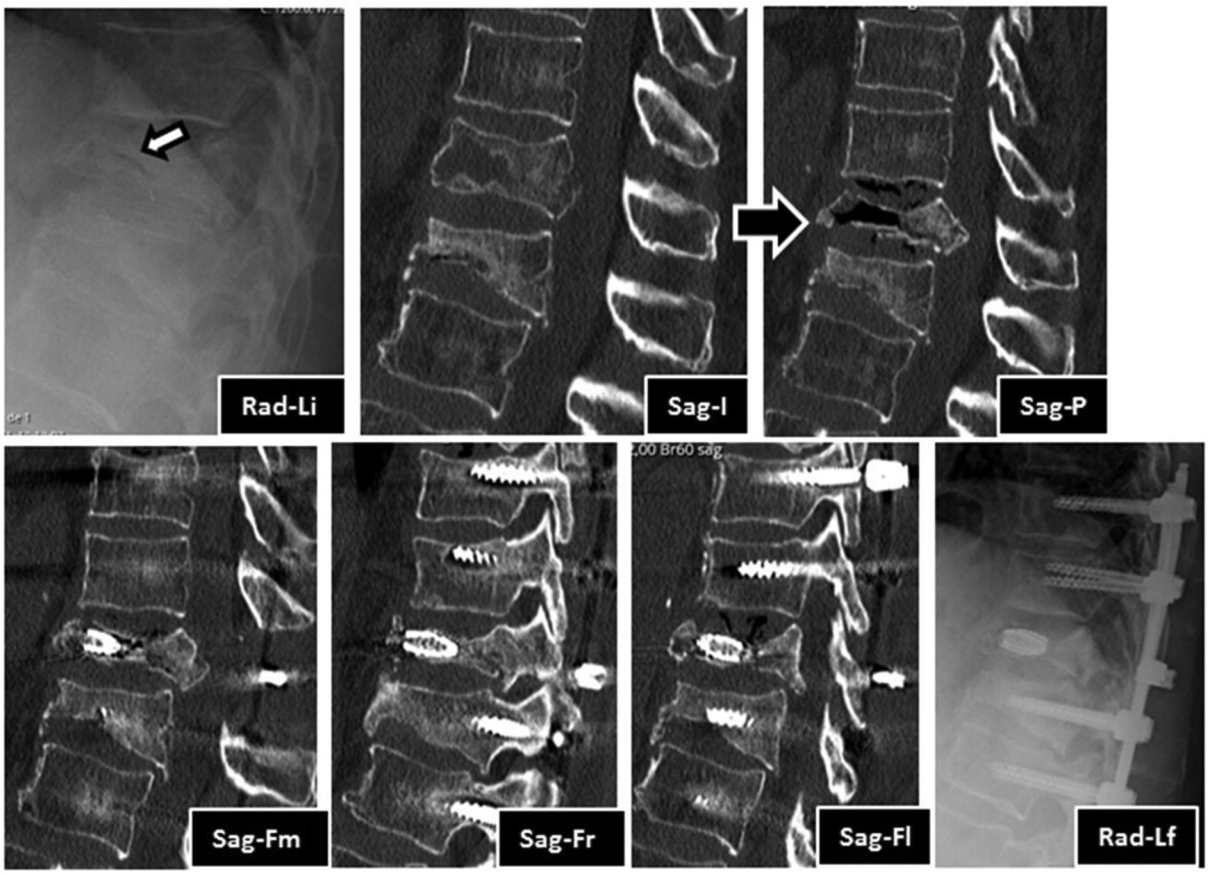


FIGURE 1
Imaging evolution of the clinical case in lateral view radiography images and sagittal CT sections: Rad-Li—initial radiograph in lateral view, showing T12 and L1 vertebral body flatenning and extensive bone destruction at T12 (arrow); Sag-I—initial median sagittal view of computed tomography, showing acute T12 fracture and old L1 fracture. Note the extensive bone trabeculae destruction at anterior half of the vertebral body; Sag-*P*—Median sagittal view of tomography, showing T12 vertebral body pseudarthrosis with a large anterior intravertebral cleft and marked posterior wall retropulsion; Sag-Fm—Median sagittal view of CT at 1 year after surgery, showing T12 vertebral body pseudarthrosis filled with stent and signs of T12 laminectomy; Sag-Fr—Right parasagittal view of CT at 1 year after surgery, showing the right stent filled with bone graft and the right pedicular screws, note the pseudarthrosis healing; Sag-Fl—Left parasagittal view of CT at 1 year after surgery, showing the left stent filled with bone graft and the right pedicular screws. Note the pseudarthrosis healing; Rad-Lf—Final radiograph in lateral view at 2 years after surgery, showing T12 stents, adjacent pedicle screws, rods and crosslink.

vertebral collapse due to non-union. The repeated excessive loads on the mobile thoracolumbar transition, in view of the weakened fractured T12 vertebral body with marked destruction of the anterior column, led to insufficient stability to provide bone healing, which led to progressive bone reabsorption and necrosis, with consequent loss of its structural integrity and support function, following vertebral flattening and collapse with retropulsion of the posterior wall and neurological risk (1, 2, 8–11). During the first two months of conservative treatment, the use of Jewett brace ensured some stability to the thoracolumbar transition and, together with analgesia, attenuated the symptoms; however, the non-union and progression to pseudarthrosis led to worsening pain mainly due to intravertebral instability. Vertebral lack of stability led to progressive bone resorption and the appearance of an intrasomatic cavity or focus of pseudarthrosis, which means pathological intravertebral mobility clinically characterized by axial mechanical pain. The non-interruption of the natural course of this case of vertebral pseudarthrosis, which presents several risk factors for unfavorable evolution, such as being located at the mobile thoracolumbar transition, reaching the posterior wall and with the presence of a large intravertebral cleft, would certainly lead to progressive vertebral collapse, accentuation of posterior wall retropulsion and severe neurologic damage (1, 2, 4, 5, 8, 27, 28).

Based on the scarce scientific literature available, the authors propose post-traumatic vertebral necrosis evolution stages (**Figure 4**) built on the grounds of parameters that directly influence the surgical therapeutic guidance based on the possibility or not to preserve the vertebral body, namely the morphology and dynamics of the necrotic vertebra (29–34). We distinguish, therefore, two types of vertebral morphology, the situations of vertebra non-plana and vertebra plana (defined as height inferior than one third of the height of the original body along its entire length), as well as two types of mobility, vertebrae with mobile deformity or pseudarthrosis (1–10, 28).

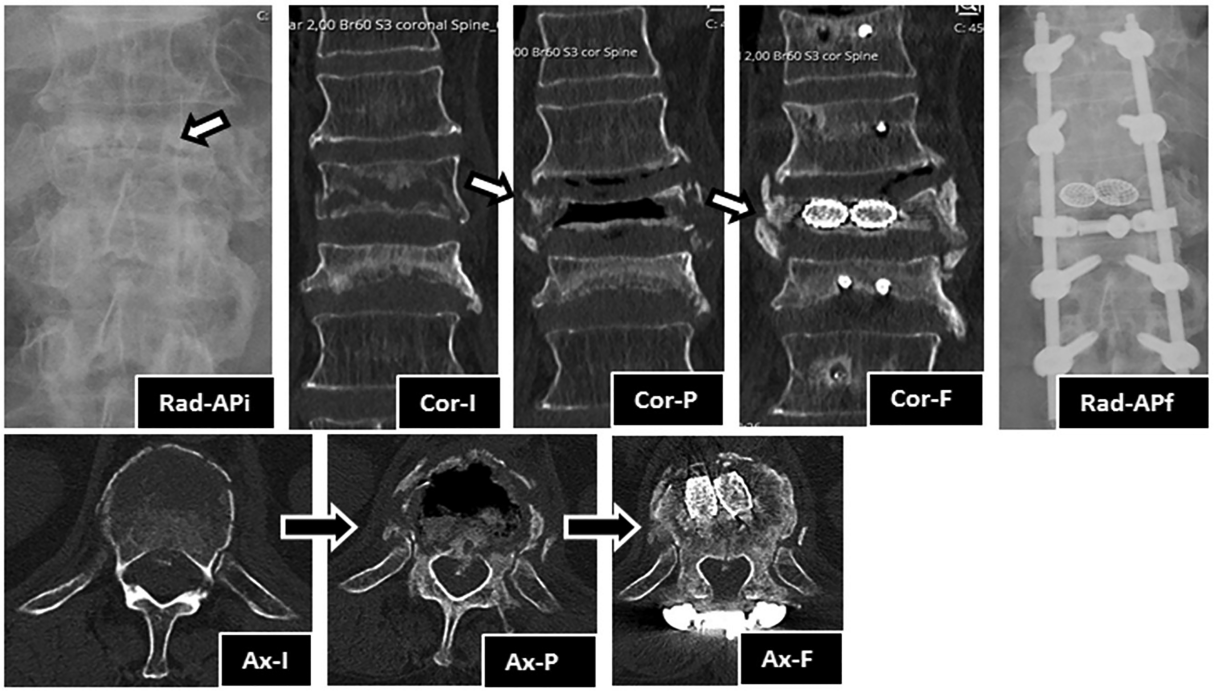


FIGURE 2
Imaging evolution of the clinical case in anteroposterior view radiography and coronal and axial CT sections: Rad-APi—initial radiograph in anteroposterior view, showing T12 and L1 vertebral body flattening and extensive bone destruction (arrow) at T12; Cor-I—initial coronal view of CT, showing acute T12 fracture and old L1 fracture. Note the extensive bone trabeculae destruction across the entire width of the vertebral body; Cor-*P*—Coronal view of CT, showing T12 vertebral body pseudarthrosis with a large intravertebral cleft across the entire width and height of the vertebral body; Cor-F—Coronal view of CT at 1 year after surgery, showing T12 vertebral body pseudarthrosis cleft filled with stents with bone graft inside, which demonstrates signs of bone healing and osteointegration. Also note the development of lateral osteophytes that help to stabilize the vertebral body to the adjacent ones; Rad-APf—Final radiograph in anteroposterior view at 2 years after surgery, showing T12 stents, adjacent pedicle screws, rods and crosslink; Ax-I—Initial axial view of CT, showing acute T12 fracture. Note the extensive bone trabeculae destruction across the entire width of the anterior half of the vertebral body; Ax-*P*—Axial view of CT, showing T12 vertebral body pseudarthrosis with a large intravertebral cleft across the entire width of the anterior half of the vertebral body; Ax-F—Axial view of CT at 1 year after surgery, showing T12 vertebral body pseudarthrosis cleft filled with two stents with bone graft inside, which demonstrates signs of bone healing and osteointegration. Also note T12 laminectomy procedure, the crosslink applied at that level and the remodeling of posterior wall retropulsion with reabsorption of intracanalar bone.

In mobile vertebrae (pseudarthrosis, that is, with intravertebral clefts—Figure 4), such as the present clinical case, regardless of their non-plana or plana morphology, it is possible to restore at least a part of vertebral body height through the positioning of the spine in hyperextension, which causes the separation of the upper and lower halves of the pseudarthrosis, increasing the size of the cleft and restoring the vertebral body height, which is filled internally (Figure 4). Thus, in these cases, a vertebral body still with sufficient bone tissue, namely with preserved bone cover (cortical ring and endplates), allows for containing the application of expandable intravertebral implants, permitting a vertebral body interior reconstruction instead of its total replacement. As such, in the face of necrosis with this vertebral dynamics, we recommend an armed kyphoplasty, in which expandable intravertebral implants will fill the empty cavity within the vertebral body surrounded by bone trabeculae impacted by the devices, and the body is then filled with bone cement or graft, which provides it with interior consistency and stability. The complete filling of the intrasomatic cleft is essential to stabilize the vertebral body, eliminating pathological and symptomatic intravertebral mobility (1–10, 28). Our clinical case was a mobile necrotic vertebra plana, which corresponds to Stage 2 m in Figure 4.

Authors usually choose VBS® stent implants in vertebrae with mobile deformity (Figure 3 and Table 1), an implant with a high capacity for space occupation, allowing the creation of large intrasomatic cavities with a cover made of the metallic mesh of the devices and impacted bone trabeculae, which allows for the application of a greater amount of bone cement or graft (12–18, 20, 21). The application of bone cement aims to fill and stabilize the interior of the vertebral body in an inert way, not expecting bone healing, solving the problem of bone regeneration inability. However, the authors defend, in post-traumatic vertebral necrosis in active patients with non-osteoporotic bone, instead of bone cement, the intrasomatic application of cancellous bone graft associated with expandable implants, seeking to obtain bone matrix colonization by osteoprogenitor cells, its vascular invasion and osseointegration, with the objective of achieving a vertebra that is biomechanically and physiologically more similar to the original in terms of loads distribution towards an active patient with a high functional demand in the future. We use autologous cancellous graft extracted regionally after laminectomy or from the patient's iliac bone for intrasomatic filling, and, if necessary, to obtain more quantity, we mix the autograft with cancellous allograft from bone bank. In the same way of the treatment concerning general bone pseudarthrosis,

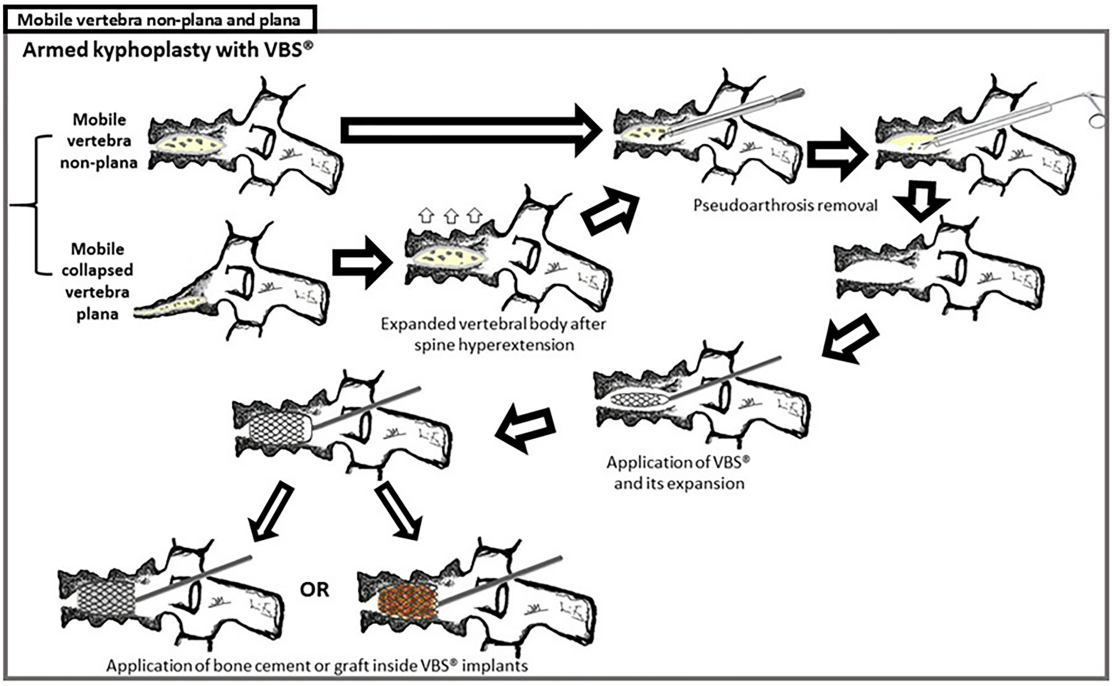


FIGURE 3
Armed kyphoplasty with VBS® in treatment of posttraumatic vertebral necrosis with mobile vertebrae non-plana and plana. The present clinical case was a mobile vertebra plana; however, the treatment of armed kyphoplasty is similar to the one of plana or non-plana mobile necrotic vertebrae, as is illustrated in this figure. After removal of pseudarthrosis region (the same as the intravertebral cleft) and proper intravertebral cleaning, the implants are expanded and then filled with bone cement or graft (in this clinical case, we chose bone graft).

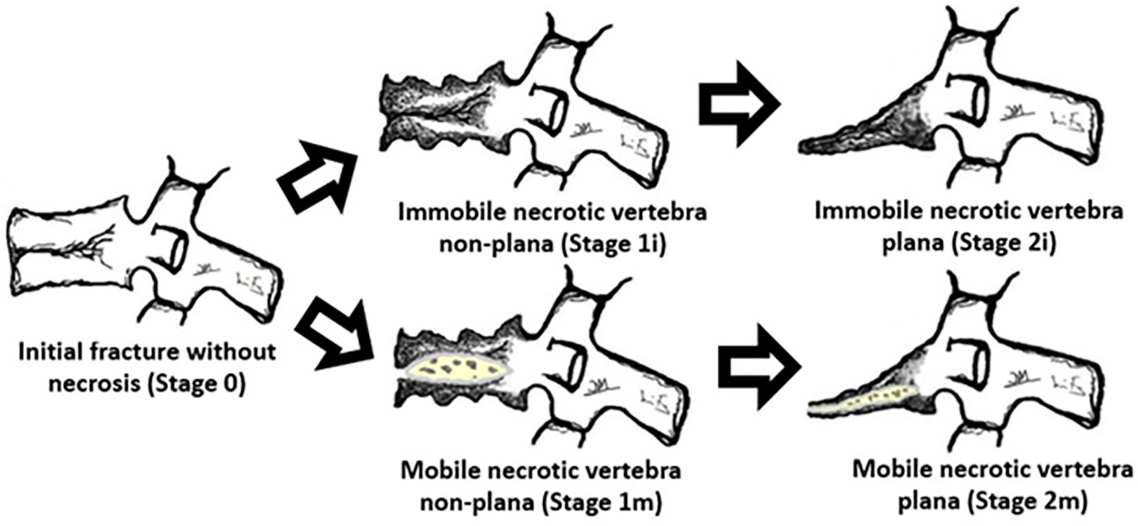
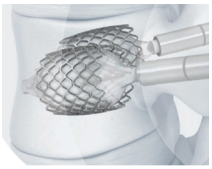


FIGURE 4
Suggested post-traumatic vertebral necrosis evolution stages: stage 0—initial fracture without necrosis; stage 1i—Immobile necrotic vertebra non-plana; stage 1 m—Mobile necrotic vertebra non-plana; stage 2i—Immobile necrotic vertebra plana; stage 2 m—Mobile necrotic vertebra plana; highlighting the presence of intravertebral cleft only in the mobile vertebrae marked with m(obile). Immobile vertebrae do not present intravertebral cleft and are marked with (i)mmobile. The drawings on the right side demonstrate vertebral body pseudarthrosis or mobile necrotic vertebra morphology and biomechanics. The determination of vertebral morphology and mobility in the context of post-traumatic necrosis must be performed through the combination of radiographs, including dynamic radiographs in hyperextension and orthostatism, CT and magnetic resonance imaging, also allowing to evaluate the amount of the remaining bone tissue.

in vertebral necrosis we sought to use a type of bone graft combining all the properties of osteoconduction, osteoinduction, osteointegration and osteogenesis that are favorable to bone healing, which is the autologous one (27, 35–42). The application of the bone graft combined with expandable intravertebral implants not only ensures the maintenance of vertebral height in time but also protects the

TABLE 1 Biomechanical characteristics of the expansive intravertebral implants VBS® (*vertebral body stenting*) (12–22).

Implant name	VBS® *(Vertebral Body Stenting)*
Illustration	
Morphology	Cylindrical shape network (stent). Two implants by bipedicular access
Material	Chromium-cobalt
Expansion direction	Circumferential and centrifugal in the coronal plane (craniocaudal + lateral)
Expansion mechanism	Hydraulic mechanism, through a kyphoplasty balloon (controlled pressure and volume)
Expansion force	Maximum pressure of 30 Atm; Maximum expansion volumes: #Small stent = 4 ml; #Medium stent = 4.5 ml; #Large stent = 5 ml
Goal	Vertebra reduction and space occupation
Rationale	The application of expandable intravertebral implants, also known as armed kyphoplasty, in addition to allowing the immediate analgesia and stabilization benefits of vertebroplasty and kyphoplasty, also theoretically guarantees, through a metallic endoskeleton, a greater strength of the vertebral body and a long-term maintenance of restored vertebral height. This happens because vertebral endplates, after reduction, are mechanically supported by the expanded devices, decreasing or preventing vertebral flattening after its expansion and also lowering the risk of post-traumatic local and segmental kyphosis, while ensuring very stable anterior support at the vertebral body. VBS® is a reduction and space-filling implant system since it can multidirectionally expand (vertically and laterally). It is indicated for internal replacement/reconstruction of the vertebral body, preserving its bone cover, which must be enough to contain the expansive implants and the bone cement or graft. Stents are implants that by its expansion form two big cavities within the vertebral body, coated by a casing of surrounding impacted trabeculae. These implants form cavities that, after being filled with bone cement or graft, replace much of the vertebral body interior, filling and stabilizing it. Moreover, they minimize cement extravasation by recreating the walls of the vertebral body by impaction of bony trabeculae containing the cement.

bone graft from excessive loads, minimizing its damage and resorption until its osseointegration is achieved, allowing to obtain a totally bony vertebra with a metallic endoskeleton. The limited histological evidence carried out in cases without the use of intravertebral implants demonstrated, in some patients, the absence of intrasomatic graft integration, with frequent microscopic findings of partial graft necrosis even in the presence of clinical and imaging signs of bone healing. This suggests a likely excessive load on the not yet osseointegrated graft (not protected by the intravertebral implant) and a weak histology-clinical correlation. Other studies have demonstrated the efficacy and revascularization of bone grafts applied in the context of vertebral pseudarthrosis (27, 42–49). The use of cancellous autograft as a method of intrasomatic filling inside the stents makes it possible to guarantee a completely bony vertebra with a metallic endoskeleton, which constitutes a more biological treatment of vertebral pseudarthrosis compared to the application of intravertebral bone cement, which, in addition to having a risk high level of extravasation in vertebral necrosis situations, cannot mimic the biology of bone healing, remaining as inert substance, biologically inactive and with excessive rigidity compared to adjacent levels, which in theory can favor fractures of adjacent vertebral bodies. Nevertheless, in spine, cementoplasty techniques (vertebroplasty and kyphoplasty) have been used to treat this disease, immediately stabilizing the vertebral body without waiting for bone healing (5–9). The option of not applying bone cement in this clinical case was based on the high risk of posterior leakage, given the morphology of the vertebra plana and the severe destruction and collapse of the posterior wall, but also because this was an active patient, with a non-osteoporotic resistant bone still with healing potential. Even in a 71-year-old patient with a severe vertebra plana stage pseudarthrosis, the combination of a proper pseudarthrosis cleaning, intrasomatic stents application and filling with bone graft allowed a sucessful internal replacement of the vertebral body, demonstrated by clear signs of bone healing and osteointegration (**Figures 1**, **2**), which guaranteed symptoms relief. In situations of vertebral necrosis with pseudarthrosis already with marked bone resorption and vertebral collapse (vertebra plana), as in this clinical case, it is frequent, even with the positioning of the column in hyperextension and the expansion of the intravertebral implants, that only a partial height restoration is achieved and not its entirety. In this clinical case, the possible vertebral body height gain was about half of its original height; nonetheless, the stabilization and healing of the vertebral body with this morphology was enough to stop the progression of pseudarthrosis and vertebral collapse, allowing for the resolution of patient´s complaints. A proper cleaning of the pseudarthrosis region, keeping only the bone cover of the vertebral body, is essential when applying bone graft inside the stents, seeking to bring blood inside the vertebra and, as such, the necessary mediators to provide invasion by vessels of the bone graft matrix, and guarantee its desired osseointegration, without interference from interposed necrotic tissues and the fibrocartilaginous membrane that characterizes the false joint and that internally lines the intravertebral cleft, making local blood access difficult (**Figure 3**) (1–10, 13–18, 27, 50). In this clinical case, given the accentuated posterior wall retropulsion with compression of the medullary cord and even in the absence of neurological deficits, we initially chose to perform local prophylactic laminectomy in order to obtain the greatest possible neurological decompression. Also, this act helps to easily identify with direct visualization the pedicle entry points, which can be difficult by anteroposterior fluoroscopy because of the severe vertebral body destruction. Besides that, laminectomy allows to obtain regional bone autograft with excellent properties for intrasomatic application to seek consolidation of pseudarthrosis. The decompression performed and the extensive vertebral body bone destruction, as well as the total collapse of the posterior wall,

determined the option for posterolateral arthrodesis of the T11-T12-L1 segment and percutaneous pedicle instrumentation two levels above and below, seeking to stabilize the vertebra as much as possible, reducing the loads on the posterior wall in order to minimize the risk of worsening its intracanalar retropulsion.

In this way, we consider this surgical technique a useful minimally invasive biological option that preserves the vertebral body in vertebral pseudarthrosis, avoiding corpectomy, which is thus only reserved for situations of non-union with immobile vertebra plana characteristics (**Figure 4**), that is, without pseudarthrosis, without intravertebral cleft, therefore without the possibility of increasing the vertebral height and of applying any support inside it (38, 41, 43, 50–55).

In view of this suggested post-traumatic vertebral necrosis evolution stages, it is easily understood that we should early intervene in situations of post-traumatic vertebral necrosis, ideally in vertebrae non-plana stages (stages 1i and 1 m—**Figure 2**), so that there is still enough bone tissue in the vertebral body to allow for the less invasive treatment, with percutaneous access and faster convalescence, which is the armed kyphoplasty. A late diagnosis or an unnecessary postponement of surgical intervention causes bone necrosis and resorption to progress, leading to situations of vertebra plana (stages 2) and increasing the risk of developing neurological damage due to retropulsion of the posterior wall and collapse of the vertebral body, which requires more aggressive surgical solutions. However, even the percutaneous current vertebral body reconstruction technique is not risk-free, and there may be migration or failure of intrasomatic stents or pedicle screws, as well as of bone graft resorption, which indicates failure to obtain osseointegration and healing of pseudarthrosis. It is also possible that the stents don't expand and as such it is not possible to put any bone inside them filling the vertebral body, which leads us to reinforce the indication of armed kyphoplasty only in the mobile vertebra plana (pseudarthrosis) and not in the rigid vertebra plana. Attempting to place expandable intravertebral implants in this type last of vertebrae involves high risks and may have serious consequences, from migration of the implants, because they are not stable within bone tissue, with damage to major neurological and vascular tissues. Also this technique requires some experience and a learning curve both in transpedicular access to the vertebral body and in percutaneous techniques with fluoroscopy.

In conclusion, this clinical case demonstrates that the treatment of pseudarthrosis of vertebral body, even in vertebra plana stage, can be carried out as an internal replacement of the necrotic vertebral body performed by posterior transpedicular access in which expandable intravertebral stents allow to create intrasomatic cavities, which are filled with bone graft, obtaining a totally bony vertebra with a metallic endoskeleton. This biological internal replacement of the necrotic vertebral body technique can be a safe and effective alternative over cementoplasty procedures or total vertebral body corpectomy and replacement for vertebral pseudarthrosis and may have several advantages over them, like allowing by a less invasive posterior technique to obtain a totally bony vertebra biomechanically and physiologically more similar to the original one and avoiding the risks of bone cement leakage. Our clinical case shows quite satisfactory clinical and radiographic results regarding this technique in a vertebra plana pseudarthrosis; however, long-term prospective studies are needed in order to prove the effectiveness and advantages of this surgical option in a rare and difficult pathological entity.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Materials, further inquiries can be directed to the corresponding author/s.

Ethics statement

The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

Both authors did equally the following steps: substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work, drafting the work or revising it critically for important intellectual content, provide approval for publication of the content, agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Young WF, Brown D, Kendler A, Clements D. Delayed post-traumatic osteonecrosis of a vertebral body (Kummell's Disease). *Acta Orthop Belg*. (2002) 68 (1):13–9. PMID: 11915453

2. Benedek TG, Nicholas JJ. Delayed traumatic vertebral body compression fracture; part II: pathologic features. *Semin Arthritis Rheum*. (1981) 10(4):271–7. doi: 10.1016/0049-0172(81)90004-4

3. Osterhouse MD, Kettner NW. Delayed posttraumatic vertebral collapse with intravertebral vacuum cleft. *J Manipulative Physiol Ther*. (2002) 25(4):270–5. doi: 10.1067/mmt.2002.123164

4. Maldague BE, Noel HM, Malghem JJ. The intravertebral vacuum cleft: a sign of ischemic vertebral collapse. *Radiology*. (1978) 129:23–9. doi: 10.1148/129.1.23

5. Lane JI, Maus TP, Wald JT, Thielen KR, Bobra S, Luetmer PH. Intravertebral clefts opacified during vertebroplasty: pathogenesis, technical implications, and prognostic significance. *AJNR Am J Neuroradiol*. (2002) 23:1642–6. PMID: 12427615

6. Hasegawa K, Homma T, Uchiyama S, Takahashi H. Vertebral pseudarthrosis in the osteonecrotic spine. *Spine*. (1998) 23:2201–6. doi: 10.1097/00007632-199810150-00011

7. Nicholas J, Benedek T, Reece G. Delayed traumatic vertebral body compression fracture. Part 1: clinical features. *Semin Arthritis Rheum*. (1981) 10:264–70. doi: 10.1016/0049-0172(81)90003-2

8. McKiernan F, Faciszewski T. Intravertebral clefts in osteoporotic vertebral compression fractures. *Arthritis Rheum*. (2003) 48(5):1414–9. doi: 10.1002/art.10984

9. Mirovsky Y, Anekstein Y, Shalmon E, Peer A. Vacuum clefts of the vertebral bodies. *AJNR Am J Neuroradiol*. (2005) 26(7):1634–40. PMID: 16091506

10. Kim YC, Kim YH, Ha KY. Pathomechanism of intravertebral clefts in osteoporotic compression fractures of the spine. *Spine J*. (2014) 14:659–66. doi: 10.1016/j.spinee.2013.06.106

11. McCormack T, Karaikovic E, Gaines RW. The load sharing classification of spine fractures. *Spine (Phila Pa 1976)*. (1994) 19(15):1741–4. doi: 10.1097/00007632-199408000-00014

12. Vanni D, Galzio R, Kazakova A, Pantalone A, Grillea G, Bartolo M, et al. Third-generation percutaneous vertebral augmentation systems. *J Spine Surg*. (2016) 2 (1):13–20. doi: 10.21037/jss.2016.02.01

13. Muto M, Greco B, Setola F, Vassallo P, Ambrosanio G, Guarnieri G. Vertebral body stenting system for the treatment of osteoporotic vertebral compression fracture: follow-up at 12 months in 20 cases. *Neuroradiol J*. (2011) 24:610–9. doi: 10.1177/197140091102400418

14. Diel P, Röder C, Perler G, Vordemvenne T, Scholz M, Kandziora F, et al. Radiographic and safety details of vertebral body stenting: results from a multicenter chart review. *BMC Musculoskelet Disord*. (2013) 14:233. doi: 10.1186/1471-2474-14-233

15. Hartmann F, Griese M, Dietz SO, Kuhn S, Rommens PM, Gercek E. Two-year results of vertebral body stenting for the treatment of traumatic incomplete burst fractures. *Minim Invasive Ther Allied Technol*. (2015) 24:161–6. doi: 10.3109/13645706.2014.962546

16. Schützenberger S, Schwarz SM, Greiner L, Holub O, Grabner S, Huf W, et al. Is vertebral body stenting in combination with CaP cement superior to kyphoplasty? *Eur Spine J*. (2018) 27:2602–8. doi: 10.1007/s00586-018-5717-7

17. Garnon J, Doré B, Auloge P, Caudrelier J, Dalili D, Ramamurthy N, et al. Efficacy of the vertebral body stenting system for the restoration of vertebral height in acute traumatic compression fractures in a non-osteoporotic population. *Cardiovasc Intervent Radiol*. (2019) 42:1579–87. doi: 10.1007/s00270-019-02265-y

18. Cianfoni A, Distefano D, Isalberti M, Reinert M, Scarone P, Kuhlen D, et al. Stent-screw-assisted internal fixation: the SAIF technique to augment severe osteoporotic and neoplastic vertebral body fractures. *J Neurointerv Surg*. (2019) 11 (6):603–9. doi: 10.1136/neurintsurg-2018-014481

19. Vanni D, Pantalone A, Bigossi F, Pineto F, Lucantoni D, Salini V. New perspective for third generation percutaneous vertebral augmentation procedures: preliminary results at 12 months. *J Craniovertebr Junction Spine*. (2012) 3:47–51. doi: 10.4103/0974-8237.116537

20. Moura DL, Gabriel JP. Expandable intravertebral implants: a narrative review on the concept, biomechanics, and outcomes in traumatology. *Cureus*. (2021) 13(9): e17795. doi: 10.7759/cureus.17795

21. Moura DFL, Gabriel JP. Intravertebral expandable implants in thoracolumbar vertebral compression fractures. *Acta Ortop Bras*. (2022) 30(3):e245117. doi: 10.1590/1413-785220223003e245117

22. Moura DFL, Gabriel JP. Evolution of vertebral posttraumatic necrosis to bone healing after self-stabilizing osteophytosis development-case report. *J Spine Surg*. (2021) 7(4):524–31. doi: 10.21037/jss-21-58

23. Premat K, Vande Perre S, Cormier É, Shotar E, Degos V, Morardet L, et al. Vertebral augmentation with the SpineJack® in chronic vertebral compression fractures with major kyphosis. *Eur Radiol*. (2018) 28(12):4985–91. doi: 10.1007/s00330-018-5544-6

24. Distefano D, Scarone P, Isalberti M, La Barbera L, Villa T, Bonaldi G, et al. The "armed concrete" approach: stent-screw-assisted internal fixation (SAIF) reconstructs and internally fixates the most severe osteoporotic vertebral fractures. *J Neurointerv Surg*. (2021) 13(1):63–8. doi: 10.1136/neurintsurg-2020-016597

25. Freyd M. The graphic rating scale. *J Educ Psychol*. (1923) 43:83–102. doi: 10.1037/h0074329

26. Fairbank JC, Pynsent PB. The oswestry disability Index. *Spine (Phila Pa 1976)*. (2000) 25:2940–52.; discussion 2952. doi: 10.1097/00007632-200011150-00017

27. Hasegawa K, Homma T, Uchiyama S, Takahashi HE. Osteosynthesis without instrumentation for vertebral pseudarthrosis in the osteoporotic spine. *J Bone Joint Surg Br*. (1997) 79(3):452–6. doi: 10.1302/0301-620X.79B3.0790452

28. McKiernan F, Jensen R, Faciszewski T. The dynamic mobility of vertebral compression fractures. *J Bone Miner Res*. (2003) 18:24–9. doi: 10.1359/jbmr.2003.18.1.24

29. Li KC, Wong TU, Kung FC, Li A, Hsieh CH. Staging of Kummel's Disease. *J Musculoskeletal Res*. (2004) 8:43–55. doi: 10.1142/S0218957704001181

30. Ito Y, Hasegawa Y, Toda K, Nakahara S. Pathogenesis and diagnosis of delayed vertebral collapse resulting from osteoporotic spinal fracture. *Spine J*. (2002) 2 (2):101–6. doi: 10.1016/S1529-9430(01)00165-6

31. Formica M, Zanirato A, Cavagnaro L, Basso M, Divano S, Formica C, et al. What is the current evidence on vertebral body osteonecrosis?: a systematic review of the literature. *Asian Spine J*. (2018) 12(3):586–99. doi: 10.4184/asj.2018.12.3.586

32. Mochida J, Toh E, Chiba M, Nishimura K. Treatment of osteoporotic late collapse of a vertebral body of thoracic and lumbar spine. *J Spinal Disord*. (2001) 14(5):393–8. doi: 10.1097/00002517-200110000-00004

33. Patil S, Rawall S, Singh D, Mohan K, Nagad P, Shial B, et al. Surgical patterns in osteoporotic vertebral compression fractures. *Eur Spine J*. (2013) 22(4):883–91. doi: 10.1007/s00586-012-2508-4

34. Hao DJ, Yang JS, Tuo Y, Ge CY, He BR, Liu TJ, et al. Reliability and application of the new morphological classification system for chronic symptomatic osteoporotic thoracolumbar fracture. *J Orthop Surg Res*. (2020) 15(1):348. doi: 10.1186/s13018-020-01882-5

35. Verlaan JJ, Oner FC, Slootweg PJ, Verbout AJ, Dhert WJ. Histologic changes after vertebroplasty. *J Bone Joint Surg Am*. (2004) 86(6):1230–8. doi: 10.2106/00004623-200406000-00016

36. Libicher M, Hillmeier J, Liegibel U, Sommer U, Pyerin W, Vetter M, et al. Osseous integration of calcium phosphate in osteoporotic vertebral fractures after kyphoplasty: initial results from a clinical and experimental pilot study. *Osteoporos Int*. (2006) 17(8):1208–15. doi: 10.1007/s00198-006-0128-8

37. Korovessis P, Hadjipavlou A, Repantis T. Minimal invasive short posterior instrumentation plus balloon kyphoplasty with calcium phosphate for burst and severe compression lumbar fractures. *Spine (Phila Pa 1976)*. (2008) 33(6):658–67. doi: 10.1097/BRS.0b013e318166e0bb

38. Korovessis P, Repantis T, Petsinis G, Iliopoulos P, Hadjipavlou A. Direct reduction of thoracolumbar burst fractures by means of balloon kyphoplasty with calcium phosphate and stabilization with pedicle-screw instrumentation and fusion. *Spine (Phila Pa 1976)*. (2008) 33(4):E100–8. doi: 10.1097/BRS.0b013e3181646b07

39. Chiu JC, Stechison MT. Percutaneous vertebral augmentation and reconstruction with an intravertebral mesh and morcelized bone graft. *Surg Technol Int*. (2005) 14:287–96. PMID: 16525985

40. Chiu JC, Maziad AM. Post-traumatic vertebral compression fracture treated with minimally invasive biologic vertebral augmentation for reconstruction. *Surg Technol Int*. (2011) 21:268–77. PMID: 22505001

41. Verlaan JJ, Somers I, Dhert WJ, Oner FC. Clinical and radiological results 6 years after treatment of traumatic thoracolumbar burst fractures with pedicle screw instrumentation and balloon assisted endplate reduction. *Spine J*. (2015) 15 (6):1172–8. doi: 10.1016/j.spinee.2013.11.044

42. Chen LH, Lai PL, Niu CC, Chen CH, Chen WJ, Fu TS. Intracorporal bone grafting for vertebral compression fractures with intraosseous vacuum phenomenon. *Int Orthop*. (2004) 28:52–5. doi: 10.1007/s00264-003-0504-3

43. Daniaux H. Transpedicular repositioning and spongioplasty in fractures of the vertebral bodies of the lower thoracic and lumbar spine. *Unfallchirurg*. (1986) 89:197–213. PMID: 3523761

44. Van Herck B, Leirs G, Van Loon J. Transpedicular bone grafting as a supplement to posterior pedicle screw instrumentation in thoracolumbar burst fractures. *Acta Orthop Belg*. (2009) 75(6):815–21. PMID: 20166365

45. Lam S, Khooa LT. A novel percutaneous system for bone graft delivery and containment for elevation and stabilization of vertebral compression fractures technical note. *Neurosurg Focus*. (2005) 18(3):E10. doi: 10.3171/foc.2005.18.3.11

46. Alanay A, Acaroglu E, Yazici M, Oznur A, Surat A. Short-segment pedicle instrumentation of thoracolumbar burst fractures: does transpedicular intracorporeal grafting prevent early failure? *Spine (Phila Pa 1976)*. (2001) 26(2):213–7. doi: 10.1097/00007632-200101150-00017

47. Knop C, Fabian HF, Bastian L, Blauth M. Late results of thoracolumbar fractures after posterior instrumentation and transpedicular bone grafting. *Spine (Phila Pa 1976)*. (2001) 26(1):88–99. doi: 10.1097/00007632-200101010-00016

48. Tägil M, Johnsson R, Strömqvist B, Aspenberg P. Incomplete incorporation of morselized and impacted autologous bone graft: a histological study in 4 intracorporally grafted lumbar fractures. *Acta Orthop Scand*. (1999) 70:555–8. doi: 10.3109/17453679908997841

49. Crawford RJ, Askin GN. Fixation of thoracolumbar fractures with the dick fixator: the influence of transpedicular bone grafting. *Eur Spine J*. (1994) 3 (1):45–51. doi: 10.1007/BF02428316

50. Kim KT, Suk KS, Kim JM, Lee SH. Delayed vertebral collapse with neurological deficits secondary to osteoporosis. *Int Orthop*. (2003) 27:65–9. doi: 10.1007/s00264-002-0418-5

51. Krüger A, Schmuck M, Noriega DC, Ruchholtz S, Baroud G, Oberkircher L. Percutaneous dorsal instrumentation of vertebral burst fractures: value of additional percutaneous intravertebral reposition-cadaver study. *Biomed Res Int*. (2015) 2015:434873. doi: 10.1155/2015/434873

52. Jang JS, Kim DY, Lee SH. Efficacy of percutaneous vertebroplasty in the treatment of intravertebral pseudarthrosis associated with noninfected avascular necrosis of the vertebral body. *Spine*. (2003) 28(14):1588–92. PMID: 12865850

53. Raman T, Miller E, Martin CT, Kebaish KM. The effect of prophylactic vertebroplasty on the incidence of proximal junctional kyphosis and proximal junctional failure following posterior spinal fusion in adult spinal deformity: a 5-year follow-up study. *Spine J*. (2017) 17(10):1489–98. doi: 10.1016/j.spinee.2017.05.017

54. Nardi A, Tarantino U, Ventura L, Armotti P, Resmini G, Cozzi L, et al. Domino efect: mechanic factors role. *Clin Cases Miner Bone Metab*. (2011) 8(2):38–42. PMID: 22461815

55. Cheung JPY. The importance of sagittal balance in adult scoliosis surgery. *Ann Transl Med*. (2020) 8(2):35. doi: 10.21037/atm.2019.10.19

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