frontiers | Research Topics

Advancing the understanding of surgical management for degenerative spine conditions

Edited by
Lingxiao Chen, Shiqing Feng, Wei Zeng and Hengxing Zhou

Published in
Frontiers in Surgery

ISSN 1664-8714
ISBN 978-2-83251-396-5
DOI 10.3389/978-2-83251-396-5

About Frontiers

Frontiers is more than just an open access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

Frontiers journal series

The Frontiers journal series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the *Frontiers journal series* operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

Dedication to quality

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews. Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view. By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the *Frontiers journals series*: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area.

Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers editorial office: frontiersin.org/about/contact

Advancing the understanding of surgical management for degenerative spine conditions

Topic editors

Lingxiao Chen — The University of Sydney, Australia
Shiqing Feng — Tianjin Medical University General Hospital, China
Wei Zeng — Longyan University, China
Hengxing Zhou — Tianjin Medical University General Hospital, China

Citation

Chen, L., Feng, S., Zeng, W., Zhou, H., eds. (2023). *Advancing the understanding of surgical management for degenerative spine conditions*. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-83251-396-5

Table of contents

frontiers | Frontiers in Surgery

TYPE Editorial
PUBLISHED 09 January 2023
DOI 10.3389/fsurg.2022.1099978

OPEN ACCESS

EDITED AND REVIEWD BY
Sean D. Rundell,
University of Washington, United States

*CORRESPONDENCE
Hengxing Zhou
zhouhengxing@sdu.edu.cn
Shiqing Feng
shiqingfeng@sdu.edu.cn
Lingxiao Chen
lche4036@uni.sydney.edu.au

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

RECEIVED 16 November 2022
ACCEPTED 13 December 2022
PUBLISHED 09 January 2023

CITATION
Fu R, Zhang C, Wang W, Zeng W, Zhou H, Feng S and Chen L (2023) Editorial: Advancing the understanding of surgical management for degenerative spine conditions.
Front. Surg. 9:1099978.
doi: 10.3389/fsurg.2022.1099978

Editorial: Advancing the understanding of surgical management for degenerative spine conditions

Runhan Fu[1], Chi Zhang[1], Wei Wang[1], Wei Zeng[2], Hengxing Zhou[1]*, Shiqing Feng[1,3]* and Lingxiao Chen[1,4]*

[1]Department of Orthopaedics, Qilu Hospital of Shandong University, Shandong University Centre for Orthopaedics, Advanced Medical Research Institute, Cheeloo College of Medicine, Shandong University, Jinan, China, [2]School of Physics and Mechanical and Electrical Engineering, Longyan University, Longyan, China, [3]The Second Hospital of Shandong University, Cheeloo College of Medicine, Shandong University, Jinan, China, [4]Faculty of Medicine and Health, The Back Pain Research Team, Sydney Musculoskeletal Health, The Kolling Institute, University of Sydney, Sydney, Australia

KEYWORDS

degenerative spine conditions, spine surgery, evidence-based, surgical techniques, prognosis

Editorial on the Research Topic
Advancing the understanding of surgical management for degenerative spine conditions

Degenerative spine conditions are common in adults, especially among the elderly. In parallel with the aged tendency of population worldwide, the prevalence of degenerative spine diseases has been increasing. There has also been an increasing trend in spine surgery worldwide (1–3). However, current understanding of surgical treatment for degenerative spine conditions is insufficient: on the one hand, the results of some studies indicated that surgery might not be better than nonsurgical treatment for some patients (4, 5); on the other hand, advancements in surgical techniques during recent years provide surgeons diverse options to perform the operations, however, evidence is lacking for which one should be preferred. In this Research Topic, a number of valuable articles involving basic knowledge, treatment (comparison of surgical procedures and learning curve of surgical technique) and prognosis (prediction model, prognostic factors and complications after surgery) of degenerative spine disorders have been published.

Learning the basic knowledge of spinal disorders helps to give us an overall understanding of surgical treatment. Several papers in this Research Topic gave us their understandings of pathogenesis of some spine diseases. The reason why cervical sagittal curvature of certain patients will be lordotic after laminoplasty is unclear. As

pointed out by *Qian* et al. that may because the laminoplasty releases dorsal spinal cord from compression in pinching cervical spondylotic myelopathy (PCSM). *Yang* et al. took advantage of finite element analysis of CT images and found the maximum stress in involved segments of cervical spondylotic myelopathy (CSM) was higher compared with the control group. Two papers summarized theoretical knowledge of certain spine diseases. *Xu* et al. gave a detailed and authoritative review for ponticulus posticus, including the epidemiology, pathology, anatomy, clinical presentation, radiographic examination and surgical significance of ponticulus posticus. *Mei* et al. gave us a rare case of camptocormia related to Parkinson's disease and reviewed the literature on camptocormia.

A number of papers in the current Research Topic focused on comparing different surgical procedures used in spine surgery. *Wasinpongwanich* et al. in their systematic review and meta-analysis, summarized fusion rate, operative time, clinical outcomes, complications (e.g., total adverse events and revision rate) for transforaminal lumbar interbody fusion (TLIF) vs. other techniques used in lumbar spine diseases. Focusing on elderly patients with single-level thoracolumbar severe osteoporotic vertebral compression fracture (sOVCF), *Zhou* et al. provided evidence for the effects of percutaneous kyphoplasty (PKP) with vs. without posterior pedicle screw fixation (PPSF) on long-term spinal sagittal balance. Due to limited guideline information on whether indirect decompression is sufficient after oblique lumbar interbody fusion (OLIF), *Tseng* et al. compared the effectiveness of the indirect decompression by OLIF with direct posterior decompression among lumbar foraminal stenosis patients. Radiofrequency denervation, as a common interventional treatment for chronic low back pain, has different emerging types such as pulsed radiofrequency denervation. In their systematic review, *Li* et al. comprehensively reviewed literature on radiofrequency denervation therapy in treating facet joint-derived chronic low back pain and compared efficacy of different radiofrequency denervation interventions using network meta-analysis.

Understanding the learning process of surgical techniques is beneficial to surgeons who hope to master one surgical technique. For the past few years, unilateral biportal endoscopic (UBE) has become a popular technique for spinal surgery. However, even for skilled spinal surgeons, there may be obstacles in the learning process of UBE technology. To this end, *Chen* et al. evaluated the learning curve of UBE using the cumulative summation (CUSUM) method analysis.

Prognosis research is of great importance in the context of current spine surgery. Several papers published in this Research Topic developed prediction model and investigated prognostic factors in different kinds of spine surgery. Clinical prediction models have plenty of applications in clinical practice. For instance, clinical prediction models help us to decide whether we need further testing, whether we need to start a treatment and which treatment need to be performed (6). *Briguglio* et al. tried to develop a hemoglobin-based prediction model to predict long-term recovery after spine surgery but regrettably, this model may not be reliable due to the low specificity. Nevertheless, as indicated by *Briguglio* et al. preoperative hemoglobin, interestingly, is one of the key laboratory biomarkers to predict long-term recovery after spine surgery. Identifying prognostic factors for patients who received spine surgery is also of great importance. By finding out factors which could provide prognostic information for patients, we may forecast the future outcomes in patients with a particular health condition and thus choose more suitable treatment under a specific situation. The risk factors for postoperative shoulder imbalance are rarely reported in adult scoliosis (AS). Hence, *Ke* et al. performed a detailed assessment of risk factors related to radiography in AS patients who underwent correction surgery. *Deng* et al. gave a comparison of sagittal balance and functional outcomes in lumbar fracture surgery patients using different intermediate pedicle screws with different insertion depth. *Wei* et al. examined risk factors of bone graft nonfusion for spinal tuberculosis patients who underwent lesion removal, bone graft fusion and internal fixation.

Complications after surgery also deserve more attention. Focusing on postoperative cage subsidence, a common complication after spine surgery, *Jin* et al. compared the subsidence rate in zero profile anchored spacer (ROI-C) and conventional cage and plate construct (CPC) in patients undergoing anterior cervical decompression and fusion (ACDF). Cases series by *Florence* et al. provided eight cases who had hardware complications after placement of interspinous process devices (IPDs) and gave us experience in management of high risk IPD patients.

This Research Topic also included papers related to other orthopedic surgery, which give an additional view for spine surgery. For instance, *Xu* et al. developed a new surgical plan for adults with tibial-eminence fracture (TEF) and assessed the clinical effectiveness of day case arthroscopic-surgery treatment. Interestingly, thromboelastography (TEG) markers could forecast the occurrence of ecchymosis after total knee arthroplasty (TKA), as found by *Chen* et al.

We sincerely thank all authors who contributed to the current Research Topic "Advancing the Understanding of Surgical Management for Degenerative Spine Conditions". We

appreciate the reviewers' valuable comments and constructive suggestions. Also, we express our gratitude to the editorial team for their support.

We unfeignedly hope that articles in this Research Topic will help surgeons make the right decisions and inspire researchers to give a further exploration of surgical management for degenerative spine conditions.

Author contributions

All authors contributed to the article and approved it for publication. 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. Oglesby M, Fineberg SJ, Patel AA, Pelton MA, Singh K. Epidemiological trends in cervical spine surgery for degenerative diseases between 2002 and 2009. *Spine*. (2013) 38(14):1226–32. doi: 10.1097/BRS.0b013e31828be75d

2. Grotle M, Småstuen MC, Fjeld O, Grøvle L, Helgeland J, Storheim K, et al. Lumbar spine surgery across 15 years: trends, complications and reoperations in a longitudinal observational study from Norway. *BMJ open*. (2019) 9(8): e028743. doi: 10.1136/bmjopen-2018-028743

3. Ponkilainen VT, Huttunen TT, Neva MH, Pekkanen L, Repo JP, Mattila VM. National trends in lumbar spine decompression and fusion surgery in Finland, 1997–2018. *Acta Orthop*. (2021) 92(2):199–203. doi: 10.1080/17453674.2020.1839244

4. Brox JI, Sørensen R, Friis A, Nygaard Ø, Indahl A, Keller A, et al. Randomized clinical trial of lumbar instrumented fusion and cognitive intervention and exercises in patients with chronic low back pain and disc degeneration. *Spine*. (2003) 28(17):1913–21. doi: 10.1097/01.BRS.0000083234.62751.7A

5. Fairbank J, Frost H, Wilson-MacDonald J, Yu LM, Barker K, Collins R. Randomised controlled trial to compare surgical stabilisation of the lumbar spine with an intensive rehabilitation programme for patients with chronic low back pain: the MRC spine stabilisation trial. *Br Med J (Clin Res Ed)*. (2005) 330 (7502):1233. doi: 10.1136/bmj.38441.620417.8F

6. Chen L. Overview of clinical prediction models. *Ann Transl Med*. (2020) 8 (4):71. doi: 10.21037/atm.2019.11.121

frontiers in Surgery

ORIGINAL RESEARCH
published: 27 October 2021
doi: 10.3389/fsurg.2021.736680

Comparative Analysis of Cage Subsidence in Anterior Cervical Decompression and Fusion: Zero Profile Anchored Spacer (ROI-C) vs. Conventional Cage and Plate Construct

Zhe-yu Jin†, Yun Teng†, Hua-zheng Wang, Hui-lin Yang‡, Ying-jie Lu*‡ and Min-feng Gan*‡*

Department of Orthopedics, First Affiliated Hospital of Soochow University, Suzhou, China

OPEN ACCESS

Edited by:
Hengxing Zhou,
Tianjin Medical University General Hospital, China

Reviewed by:
Haipeng Si,
Shandong University, China
Dexiang Ban,
Tianjin Medical University General Hospital, China

***Correspondence:**
Hui-lin Yang
suzhouspine@163.com
Ying-jie Lu
yingjie06@126.com
Min-feng Gan
ganmf0408@163.com;
spineganmf@126.com

†*These authors have contributed equally to this work and share first authorship*

‡*These authors share last authorship*

Specialty section:
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

Received: *05 July 2021*
Accepted: *27 September 2021*
Published: *27 October 2021*

Citation:
Jin ZY, Teng Y, Wang HZ, Yang HL, Lu YJ and Gan MF (2021) Comparative Analysis of Cage Subsidence in Anterior Cervical Decompression and Fusion: Zero Profile Anchored Spacer (ROI-C) vs. Conventional Cage and Plate Construct. Front. Surg. 8:736680. doi: 10.3389/fsurg.2021.736680

Background: Anterior cervical discectomy and fusion (ACDF) has been widely performed to treat cervical generative diseases. Cage subsidence is a complication after ACDF. Although it is known that segmental kyphosis, acceleration of adjacent segmental disease, and restenosis may occur due to cages subsidence; however detailed research comparing zero-profile cages (ROI-C) and conventional plate and cage construct (CPC) on cage subsidence has been lacking.

Objective: The objectives of this study was to compare the rate of postoperative cage subsidence between zero profile anchored spacer (ROI-C) and conventional cage and plate construct (CPC) and investigate the risk factors associated with cage subsidence following ACDF.

Methods: Seventy-four patients with ACDF who received either ROI-C or CPC treatment from October 2013 to August 2018 were included in this retrospective cohort study. Clinical and radiological outcomes and the incidence of cage subsidence at final follow up-were compared between groups. All patients were further categorized into the cage subsidence (CS) and non-cage subsidence (NCS) groups for subgroup analysis.

Results: The overall subsidence rate was higher in the ROI-C group than in the CPC group (66.67 vs. 38.46%, $P = 0.006$). The incidence of cage subsidence was significantly different between groups for multiple-segment surgeries (75 vs. 34.6%, $P = 0.003$),but not for single-segment surgeries (54.55 vs. 42.30%, $P = 0.563$). Male sex, operation in multiple segments, using an ROI-C, and over-distraction increased the risk of subsidence. Clinical outcomes and fusion rates were not affected by cage subsidence.

Conclusion: ROI-C use resulted in a higher subsidence rate than CPC use in multi-segment ACDF procedures. The male sex, the use of ROI-C, operation in multiple segments, and over-distraction were the most significant factors associated with an increase in the risk of cage subsidence.

Keywords: cage subsidence, anterior cervical decompression and fusion, over-distraction, multiple segments, zero-profile cages

INTRODUCTION

Anterior cervical decompression and fusion (ACDF) has been widely used as a surgical treatment method for cervical disc degenerative diseases since it was first developed by Smith and Robinson in 1958 (1). Augmentation through the use of anterior cervical plating provides immediate stabilization and the preservation of cervical alignment, preventing graft dislodgment and enhancing fusion rates. However, the implantation of anterior plating has also been associated with complications, including postoperative dysphagia, soft tissue damage, and hardware failure (2–4). Zero-profile anchored spacers (ROI-Cs) have become popular due to reduced damage to soft-tissues, lower blood loss, and the avoidance of hardware-related complications compared with traditional cage and plate constructs (CPCs) (5–7). Moreover, after the insertion of the anchors, ROI-Cs provide immediate stability, facilitating fusion (8). Cage subsidence is a common complication following ACDF and can result in the loss of disc height, disrupting the sagittal alignment of the spine, preventing solid fusion, and introducing restenosis of the foramina (9, 10). However, the impacts of cage subsidence on clinical outcomes remain controversial for the cervical spine (11). Several factors have been proposed to contribute to cage subsidence, including aggressive endplate preparation, osteoporosis, differences in treatment levels, cage size, and cage material (11–13). However, data comparing ROI-C cages and CPCs regarding cage subsidence are scarce.

Thus, the purposes of this study were (1) to retrospectively evaluate the clinical and radiological outcomes of ACDF treatments for cervical disc degenerative disease (CDDD) using ROI-Cs compared with CPC fixation, with a focus on cage subsidence; and (2) to identify the preoperative and perioperative risk factors associated with cage subsidence and determine the impact of subsidence on clinical and radiological outcomes.

MATERIALS AND METHODS

Patient Population

This study was conducted as a retrospective analysis of 85 patients with one to three levels of CDDD who underwent ACDF from October 2013 to August 2018. The study was approved by the Medical Ethics Committee of the First Affiliated Hospital of Soochow University. Informed written consent was obtained from all included patients prior to surgery. The study inclusion criteria were as follows: (1) the clinical presentation of myelopathy or radiculopathy; (2) spinal cord or nerve root compression observed on recent magnetic resonance imaging (MRI); and (3) the failure of conservative treatment after a minimum of 6 months. The exclusion criteria were: (1) operations at the C2–3 or C7–T1 disc levels; (2) severe cervical instability, developmental stenosis, or the ossification of the posterior longitudinal ligament; (3) previous medical records of cervical surgery, trauma, metabolic diseases, infection, or tumor; and (4) follow-up less than 12 months. The following data were collected from patients' perioperative, surgical, and discharge records: demographic characteristics, surgical procedure, intraoperative blood loss, length of hospital stay. Follow-up clinical notes (postoperatively at 1 month and final follow-up) were reviewed to evaluate postoperative changes in clinical and radiographical outcomes.

Surgical Method

All surgeries were performed by the same surgeon in this study. All surgical procedures were performed as previously described by our orthopedic center (3, 4). After general anesthesia, with the patient placed in supine position, the classic Robinson and Cloward anterior cervical approach and technique were used. Extensive decompression was performed, including the removal of osteophytes, herniated discs and posterior longitudinal ligament as indicated to achieve sufficient decompression of the spinal cords and nerve roots. The cartilage endplates were abraded carefully, and the bony endplates were preserved to prevent possible subsidence. No allograft was used. The choice of implant was according to surgeon's preference. Stand-alone PEEK cages were inserted into the disc space along with anterior cervical plates immobilized by self- tapping screws in the CPC group. For ROI-C group (ROI-C, LDR, Troyes, France), after insertion of a trial cage to confirm intraoperative stability, a ROI-C cage sized properly, and packed with autologs cancellous bone was then placed in the disc space using an impactor. Two anchoring chips were placed into the upper and lower vertebra under fluoroscopic guidance. Postoperatively, all patients were encouraged to exercise around their bedsides with the assistance of a semi-rigid neck collar 24 hours after surgery. Patients were strongly advised to refrain from excessive cervical movements for a minimum of 3 months after surgery.

Clinical Evaluation

The modified Japanese Orthopedic Association (JOA) scoring system was used to assess preoperative and postoperative functional status. The Neck Disability Index (NDI) scoring system was used to determine disability caused by neck pain during daily life.

Radiologic Assessment

The radiographic outcome was evaluated preoperatively and at each follow up time point. The Cobb angle of the cervical C2–C7 (CA) vertebrae was defined as the angle between the tangent lines of the lower C2 vertebral body endplates and the upper C7 vertebral body endplates. The T1 slope was measured as the angle formed between a horizontal line and the T1 upper endplate. If the T1 slope was not visible due to anatomical interference, the upper C7 slope was used instead (14) (**Figure 1A**). The fused segment Cobb angle (FSC) was defined as the Cobb angle that was formed by the fusion levels, as measured from the upper endplate of the upper vertebral body and the lower endplate of the lower vertebral body. The mean disc height (mDH) was evaluated as the mean value of the anterior disc height (ADH), the midline disc height (MDH), and the posterior disc height (PDH). The fusion segment height (FSH) was assessed as the distance from the midpoint of the upper endplate of the upper vertebral body of the fused segment to the midpoint of the lower endplate of the lower vertebral body

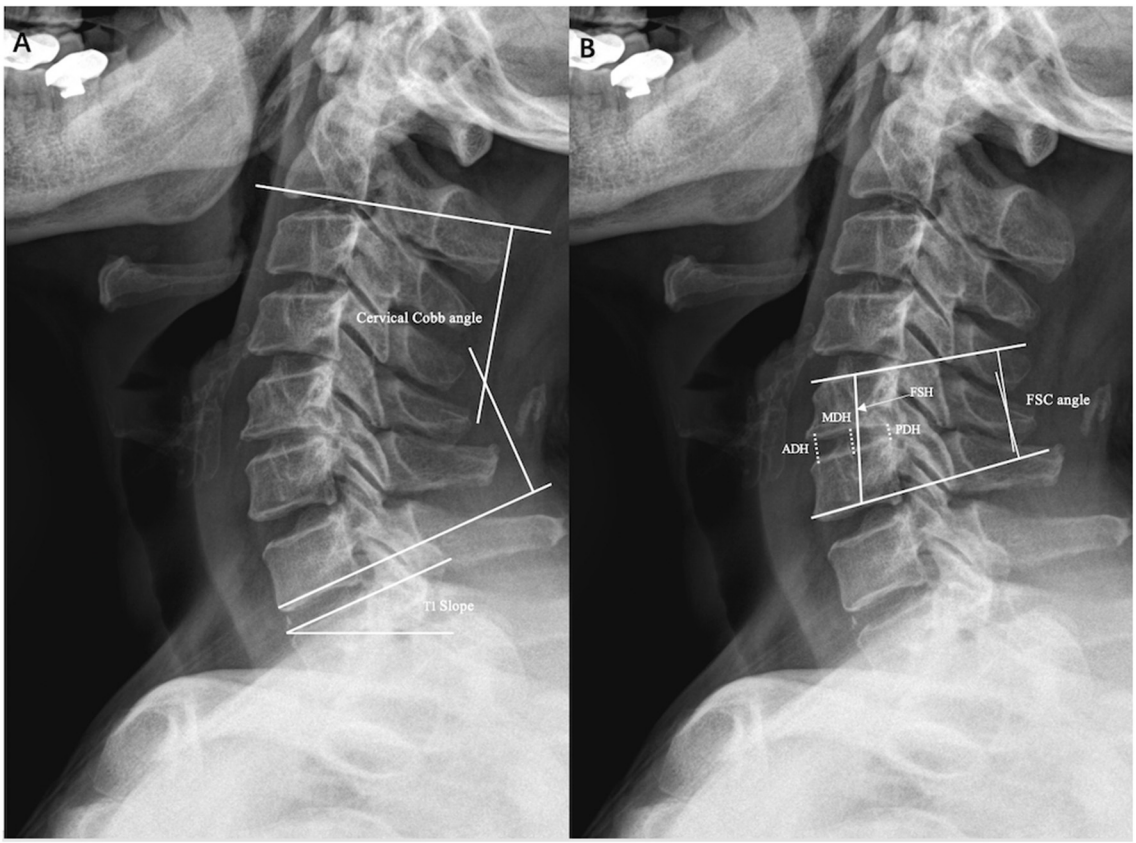


FIGURE 1 | Illustrations of radiographic measurements. **(A)** Cervical cobb angle, T1 slope. **(B)** Fused segment cobb angle (FSC), anterior disc height (ADH), midline disc height (MDH), posterior disc height (PDH), and fused segment height (FSH).

(**Figure 1B**). Adjacent segment degeneration (ASD) was defined as new osteophyte formations or the enlargement of existing osteophytes, new disc space narrowing, or segmental instability visible on plain film radiographs, or any decrease in disc signal intensity or intervertebral herniation at adjacent segments observed on T2-weighted MRI (15, 16). The postoperative fusion was defined based on the assessment of the following features: (1) trabecular bridging across the bone-graft interface, (2) the absence of radiolucent gaps between the graft and the vertebral endplate, and (3) changes of less than 2 mm in the interspinous distance of the fused segments, assessed on lateral flexion-extension radiographs (17). Subsidence was defined as a greater than 2 mm reduction in mDH at the final follow-up compared with measurements taken at 1 month postoperatively.

All patients were further divided into a cage subsidence group (CS group) and a non-cage subsidence group (NCS group) to examine the risk factors associated with the incidence of postoperative cage subsidence. The factors assessed in this analysis included age, sex, the use of ROI-C cage, the number of operated levels (single vs. multiple), the affected levels (C3–C5 vs. C5–C7), preoperative cervical Cobb angle (CA), postoperative CA, change in CA (ΔCA = postoperative CA-preoperative CA), and change in mDH (ΔmDH = postoperative mDH-preoperative mDH).

Statistical Analysis

All statistical analyses were performed using SPSS 24.0 software (SPSS Inc., Chicago, IL). All continuous variables were compared between groups using the independent *t*-test. All categorical variables are expressed as the number and percentage and were compared using the Chi-square or Fisher's exact test. To adjust for confounding variables, we performed a multivariate logistic regression analysis of the risk factors associated with subsidence that exhibited significance. A $P < 0.05$ was considered significant.

RESULTS

Study Population

Ultimately, 74 patients (36 men and 38 women) were considered eligible for enrollment in this study. The cohort was first divided into two subgroups based on the types of implants received. The CPC group included 36 patients that received conventional polyetheretherketone (PEEK) cages and an anterior titanium plate, whereas the ROI-C group included 38 patients who underwent fusion utilizing zero-profile anchored spacers.

In the CPC group, the mean age and follow-up time were 49.7 $\pm$ 10.9 years (range: 32–73 years) and 28.06 $\pm$ 13.09 months

TABLE 1 | Summary of preoperative and operative details.

Variables	CPC	ROI-C	*P*-value
Patients (n)	38	36	
Gender (male/female)	19/19	17/19	0.821
Age (yr)	49.7 ± 10.9	53.7 ± 9.98	0.110
Height (cm)	164.7 ± 7.57	164.6 ± 7.27	0.955
BMI	24.44 ± 3.149	24.22 ± 3.163	0.772
Diagnosis (n)			
Radiculopathy	9	15	0.815
Myelopathy	22	19	0.137
Combined symptoms	7	2	0.153
Number of operated levels	52	54	0.623
One-level	26	22	
Two-level	10	10	
Three-level	2	4	
Operation time (min)	149.29 ± 47.80	144.78 ± 60.84	0.727
Estimated blood loss (mL)	107.37 ± 46.97	57.64 ± 36.10	< 0.001*
Hospital stay, days	8.68 ± 5.57	7.69 ± 3.96	0.390
Follow-up period, months	28.06 ± 13.09	24.64 ± 9.79	0.209

Statistically significant difference (P < 0.05).

(range: 12.07–56.83 months), respectively. In the ROI-C group, the mean age and follow-up time were 53.7 ± 9.98 years (range: 44–72 years) and 24.64 ± 9.786 (range: 13.57–23.80) months, respectively. The patient groups that received ROI-C and CPC spacers were closely matched in terms of patient number, age, sex, height, BMI, indications for surgery, and the number of operated levels, with no significant differences in any of these variables ($P > 0.05$). The use of ROI-C spacers was associated with less estimated blood loss compared with the use of the CPC. The length of hospital stays was slightly longer for the CPC group than for the ROI-C group, but this difference was not significant ($P > 0.05$). **Table 1** summarizes the perioperative and postoperative data.

Clinical and Radiological Outcomes

The JOA and NDI scores improved significantly compared with baseline data for both groups ($P < 0.01$). No significant differences were observed in the JOA and NDI scores between the two groups at the final follow up ($P > 0.05$, **Table 2**). The T1 slope values showed no significant differences between two groups at each follow-up time point ($P > 0.05$). The mDH and FSH values after surgery for both groups increased significantly ($P < 0.01$), with no significant differences between the two groups at each follow-up time point, indicating the restoration of disc height ($P > 0.05$). At the final follow-up, reductions in cervical Cobb angle, mDH, and FSH value were observed compared with the postoperative values for both groups. These values for both groups were well maintained postoperatively at the final follow-up. **Table 3** shows the radiologial outcomes.

Radiological evidence of ASD was identified in nine cases (23.7%) in the ROI-C group and 5 cases (13.9%) in the CPC group. The fusion rates at the final follow-up for the CPC group and the ROI-C group were 92.1 and 97%, respectively. No significant difference was observed between either the ASD rates or the fusion rates between the two groups ($P > 0.05$).

TABLE 2 | Clinical outcomes between ROI-C and CPC group.

Variables	ROI-C	CPC	*P*-value
JOA Scores			
Preop	11 ± 0.93	11.2 ± 0.8	0.500
Postop 1 M	15.58 ± 0.63	15.67 ± 0.67	0.569
Final FU	16.8 ± 0.43	16.9 ± 0.35	0.290
NDI scores			
Preop	40.88 ± 6.57	37.76 ± 6.011	0.039*
Postop 1 M	16 ± 4.34	16.4 ± 4.82	0.740
Final FU	8.95 ± 4.44	7.5 ± 3.69	0.140

Statistically significant difference (P < 0.05).

TABLE 3 | Radiographic outcomes between ROI-C group and CPC group.

Variable	Roi-C (36)	CPC (38)	*P*-value
C2-C7 CA			
Preop	13 ± 8.7	12 ± 9.2	0.700
Postop 1 M	15 ± 8.1	14 ± 8.4	0.700
Final FU	13.6 ± 9.07	13.2 ± 8.72	0.86
T1 Slope			
Preop	21.62 ± 7.12	21.45 ± 8.59	0.929
Postop 1 M	22.83 ± 7.49	22.18 ± 6.92	0.705
Final FU	21.5 ± 7.76	22.8 ± 7.07	0.470
mDH (mm)			
Preop	5.26 ± 0.81	5.43 ± 1.06	0.360
Postop 1 M	8.62 ± 1.51	8.41 ± 1.48	0.460
Final FU	6.8 ± 4.05	6.57 ± 1.25	0.703
FSH			
Preop	31.35 ± 4.53	30.74 ± 3.65	0.452
Postop 1 M	37.41 ± 6.30	37.27 ± 5.745	0.907
Final FU	33.77 ± 10.37	33.10 ± 9.00	0.728
Subsidence, n (%)			
2 mm	36/54 (66.67%)	20/52 (38.46%)	0.006*
Single level	12/22 (54.55%)	11/26 (42.30%)	0.563
Multiple level	24/32 (75.00%)	9/26 (34.62%)	0.003*
Fusion rate			
Postop 3 M	31/36 (86.1%)	30/38 (78.95%)	0.545
Final FU	35/36 (97.2)	35/38 (92.1%)	0.615
ASD	5/36 (13.9%)	9/38 (23.7%)	0.377

Statistically significant difference (P < 0.05).

Cage Subsidence

Subsidence was more frequently observed in the ROI-C group (66.7%) than in the CPC group (38.5%, $P = 0.037$). Cage subsidence was not observed at immediate postoperatvie radiographs in both groups.At the final follow-up, the overall rate of cage subsidence was 62.26% (66/106 levels), occurring in 42 patients (55.26%, **Table 3**). Among single-level ACDFs, the occurrence of subsidence was not significantly different between

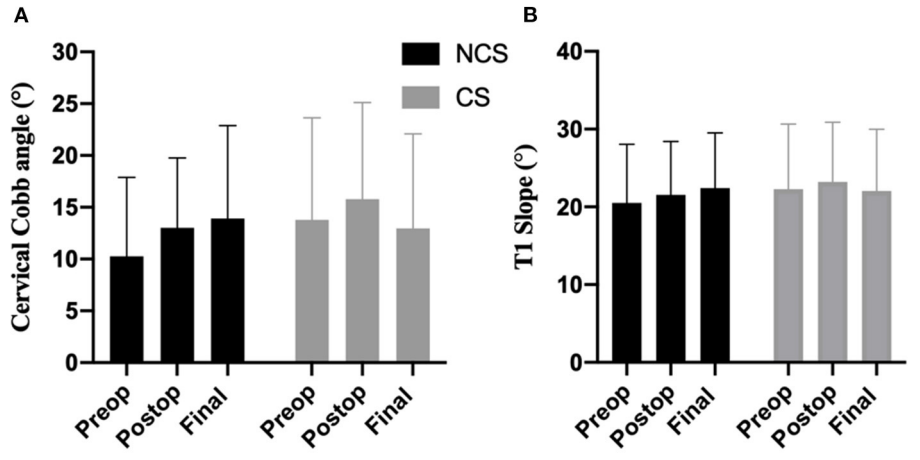


FIGURE 2 | The mean cervical Cobb angle **(A)** and T1 slope **(B)** values in CS (cage subsidence) and NCS (non-cage subsidence) groups.

the two groups. However, among multiple-level ACDFs, the subsidence rate was higher for the ROI-C group than for the CPC group (75.00 vs. 34.62%, $P = 0.003$).

Subgroup Analysis

Clinical and Radiological Outcomes

At the final follow-up, the JOA scores for the NCS group and the CS group were 16.219 ± 1.157 and 16.381 ± 1.103, respectively. The NDI scores were 8.938 ± 4.250 and 7.143 ± 4.194, respectively. No significant difference was observed for either value between the two groups ($P > 0.05$). In the CS group, 73 levels (96.05%) achieved fusion. In the NCS group, 29 levels (96.67%) achieved fusion, with no significant difference between groups ($P > 0.05$). ASD rates also showed no significant difference between groups ($P > 0.05$).

No significant difference was found in the mean Cobb angle and T1 slope values between the CS and NCS groups at any time follow up point. In the CS group, the mean Cobb angle decreased at the final follow-up compared with postoperative value (15.79 ± 9.33 vs. 12.95 ± 9.14); whereas a small increase in the mean Cobb angle after surgery was observed for the NCS group (13.00 ± 6.77 vs. 13.91 ± 8.98); however, these differences were not significant for either group ($P > 0.05$, **Figure 2**). The ΔmDH in the CS group was significantly higher than that of the NCS group (3.849 ± 1.586 mm vs. 0.422 ± 1.311 mm, $P < 0.001$). The ΔFSH in the CS group (11.57 ± 8.827) was also higher than that of the NCS group (4.61 ± 4.392, $P < 0.001$). These results indicated that the cervical disc spaces were excessively distracted after the insertion of cages in the CS group compared with that of the NCS group.

To compare the effect of cage subsidence on local and general curvature, groups were further divided into single level and multiple levels (**Figure 3**). The loss of both FSC angle (6.68 ± 10.95 vs. 0.52 ± 7.8) and cervical Cobb angle (3.82 ± 7.67 vs. −1.24 ± 7.07) were more pronounced in multiple levels with cage subsidence, but not in single level ACDFs. However, both values failed to reach statistically significant difference ($P > 0.05$).

Risk Factors of Subsidence

After univariate analysis, we identified the following factors as being associated with an increase in the risk of cage subsidence: male sex ($P < 0.001$), the use of ROI-C cage ($P = 0.007$), operation at multiple levels ($P = 0.024$), and ΔmDH ($P < 0.001$, **Table 4**). Multiple logistic regression was performed by analyzing these variables. The results revealed that the risk of cage subsidence was significantly associated with the male sex (OR = 16.767; $P < 0.001$) and the use of ROI-C cage (OR = 5.389; $P < 0.001$, **Table 5**).

DISCUSSION

The patient-reported outcomes in our current study results were consistent with those that have previously been published in the literature for ACDF when comparing zero-profile stand-alone locking screws and CPC (5–7). All neurological symptoms were relieved due to sufficient decompression, and no significant differences were observed in either the JOA or NDI scores between the groups at the final follow-up. However, in this study, we found that the occurrence of cage subsidence in patients using the ROI-C cage (19/26, 73.08%) was significantly higher than that for the CPC group (7/26, 26.92%) when the treatment involved multiple-level discectomies, although no significant difference was found for single-level surgeries.

After surgery, the occurrence of cage subsidence was frequently observed in ACDF surgeries, with a mean incidence of 21.1%, ranging from 0 to 83% (18). Earlier studies also reported a higher rate of cage subsidence when using ROI-C compared with CPC for the treatment of multiple-level ACDFs. In a meta-analysis conducted by Lu et al. (19) no significant differences were found between the zero-profile self-locking standalone cages (SLSA) and CPC group after performing single-segment ACDF, whereas increased subsidence was demonstrated in the zero-profile group for multi-segment ACDFs. According to Chen

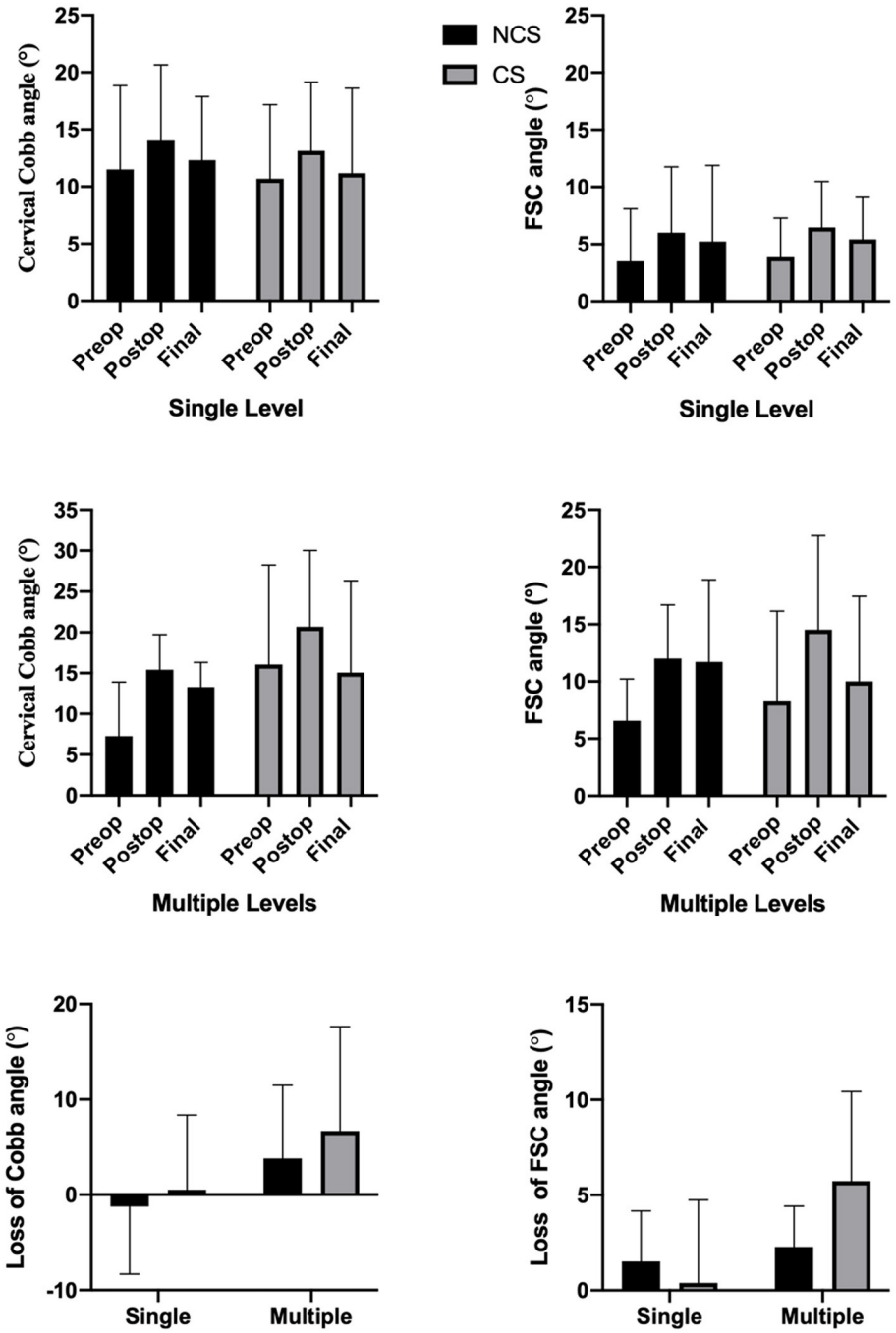


FIGURE 3 | The mean cervical Cobb angle, FSC angle, the loss of mean Cobb angle, and FSC angle in single level and multiple levels between CS and NCS groups.

et al. (20) for the treatment of three-level cervical degenerative spondylopathy, cage subsidence of greater than 3 mm was observed in 14/28 patients in the SLSA group compared with 5/26 patients cage and plate fixation group at the final follow-up ($P = 0.043$). Similarly, Zhu et al. (21) reported 17/90 (18.8%) patients in the SLSA group experienced subsidence compared with 8/96 (8.3%) patients in the CPC group for three-level ACDF ($P > 0.05$). From a biomechanical view, the loading pressure that is directly delivered to endplate/cage interfaces can be shared by anterior metal plating. In multi-segment ACDFs, this effect can be more pronounced relative to that in single-level discectomies, which can attenuate the risk of cage subsidence, resulting in a higher incidence of cage subsidence when using anchored cages.

TABLE 4 | Univariate analysis of clinical and radiological factors between groups.

Variables (n)	CS (42 patients,56 cages)	NCS (32 patients, 50 cages)	*P-value*
Age, years	53.60 ± 11.19	49.03 ± 9.707	0.070
Gender (male/female)	30/12	6/26	<0.001*
BMI	24.43 ± 2.93	24.20 ± 3.53	0.764
Surgical methods			
CPC	17 (44.74%)	21(55.26%)	0.038*
ROI-C	25 (69.44%)	11(30.56%)	
Number of operated levels			0.037*
1	23 (47.92%)	25 (52.08%)	
≥2	19 (73.08%)	7 (26.92%)	
Subsidence levels			0.222
C3-5	28	12	
C5-7	38	28	
Pre-op CA	13.79 ± 9.84	10.25 ± 7.65	0.097
Post-op CA	15.79 ± 9.33	13.00 ± 6.77	0.158
ΔCA	2.000 ± 10.44	2.750 ± 7.348	0.730
ΔmDH	3.849 ± 1.586	2.422 ± 1.311	<0.001*

**Statistically significant difference (P < 0.05).*

TABLE 5 | Multivariate analysis of the risk factors.

Variables	Odds Ratio (95%CI)	*P*-value
Gender (Male vs. Female)	16.767	< 0.001
Operation method (CPC vs. ROI-C)	5.389	0.012
Number of discectomies (1 vs. ≥2)	3.183	0.084

Surprisingly, we noticed a sex difference in the occurrence of cage subsidence, with significantly higher rates observed in men than in women. At our spine center, patients are recommended to wear cervical collars for at least 1 month postoperatively and to refrain from excessive movements. One possible explanation is the early removal of the cervical collar after surgery and a more aggressive range of motion among men compared with women. Indeed, aggressive cervical movement in the early postoperative period can cause larger axial and rotational stress upon the interbody/cage interface, which can result in cage subsidence before solid fusion. However, this study did not aim to collect data regarding the timing of cervical collar removal or the impact of cervical collar removal on the clinical and radiological outcomes after surgery; therefore, additional research is necessary.

Cages are inserted to maintain the clinical efficacy of decompression. However, overly distracted disc space can increase the risk of cage subsidence. Yang et al. (22) confirmed that a larger anterior intraoperative distraction increased the risk of cage subsidence and recommended that interbody distraction be performed before anterior longitudinal ligament resection. Similarly, Yamagata et al. (23) demonstrated that using a titanium cage for ACDF with a size of 6.5 or 7.5 mm had a higher rate of subsidence than when using a titanium cage for an ACDF with a size of 4.5 or 5.5 mm. According to an *in vitro* biomechanical study performed by Truumees et al. (24) the insertion of larger grafts results in higher distractive forces and increases the subsequent compressive forces delivered to the endplate-cage interface. These authors further proved that distractive force and the subsequent compressive forces were strongly correlated in an *in vivo* ACDF model (25). After the restoration of disc height via cage insertion, the increase in disc height causes the surrounding ligaments and muscles to absorb and resist distraction forces, contributing to the immediate compression of the graft. In the present study, the ΔmDH and ΔFSH in the CS group were significantly higher than those in the NCS group. The results of our study, combined with those of other studies, suggested that excessive distraction should be avoided to reduce the risk of potential cage subsidence in ACDF surgery.

Cage subsidence has been reported to cause loss of fused segment height, further leading to disruption of cervical stability (13, 20). Similarly, we found that the loss of cervical lordosis and fusion segment cobb angle were more pronounced in CS group (**Figure 4**). However, the impact of subsidence on loss of general and local lordosis was mainly observed in the treatment of multiple segments. Whereas, in single level surgeries, cage subsidence had little or no effect (**Figure 3**). This suggests that the increase in the number of fused segments would increase the effect of subsidence upon both local and general curvature. However, the overall clinical outcomes, fusion rates, and ASD rates were not associated with cage subsidence in our study. Previous studies have proposed that cage subsidence may represent an inherent process that occurs during the fusion of the bony endplates with the interbody cage, which includes the resorption and remodeling of the bone until rigid arthrodesis occurs (26, 27). Fujibayashi et al. (9) further divided cage subsidence into two types: a transient subsidence type demonstrates 1–3 mm subsidence without further change, whereas a progressive subsidence type results in nonunion. A systemic review by Noordhoek et al. (18) was unable to conclude that subsidence impacts clinical outcomes and fusion. Wu et al. (28) reported that cervical lordosis, rather than cage subsidence, had the most effect on long-term clinical and radiological outcomes. However, from a biomechanical standpoint, progressive subsidence is likely to result in the recompression of nerves after initial decompression. Surgeons should be highly aware of the risk factors for subsidence to avoid its occurrence. Previously reported risk factors and those identified in the present study include and are not limited to age, sex, bone density, endplate preparation, cage material and position, over-distraction, and multi-segment fusion (22, 29–31).

The limitations of the present study include its retrospective nature and the lack of randomization between procedures. Second, this study did not include osteoporosis as a risk factor that may influence cage subsidence. Third, although postoperative CT (93.2%) were taken for most patients, an inconsistency among the imaging techniques used

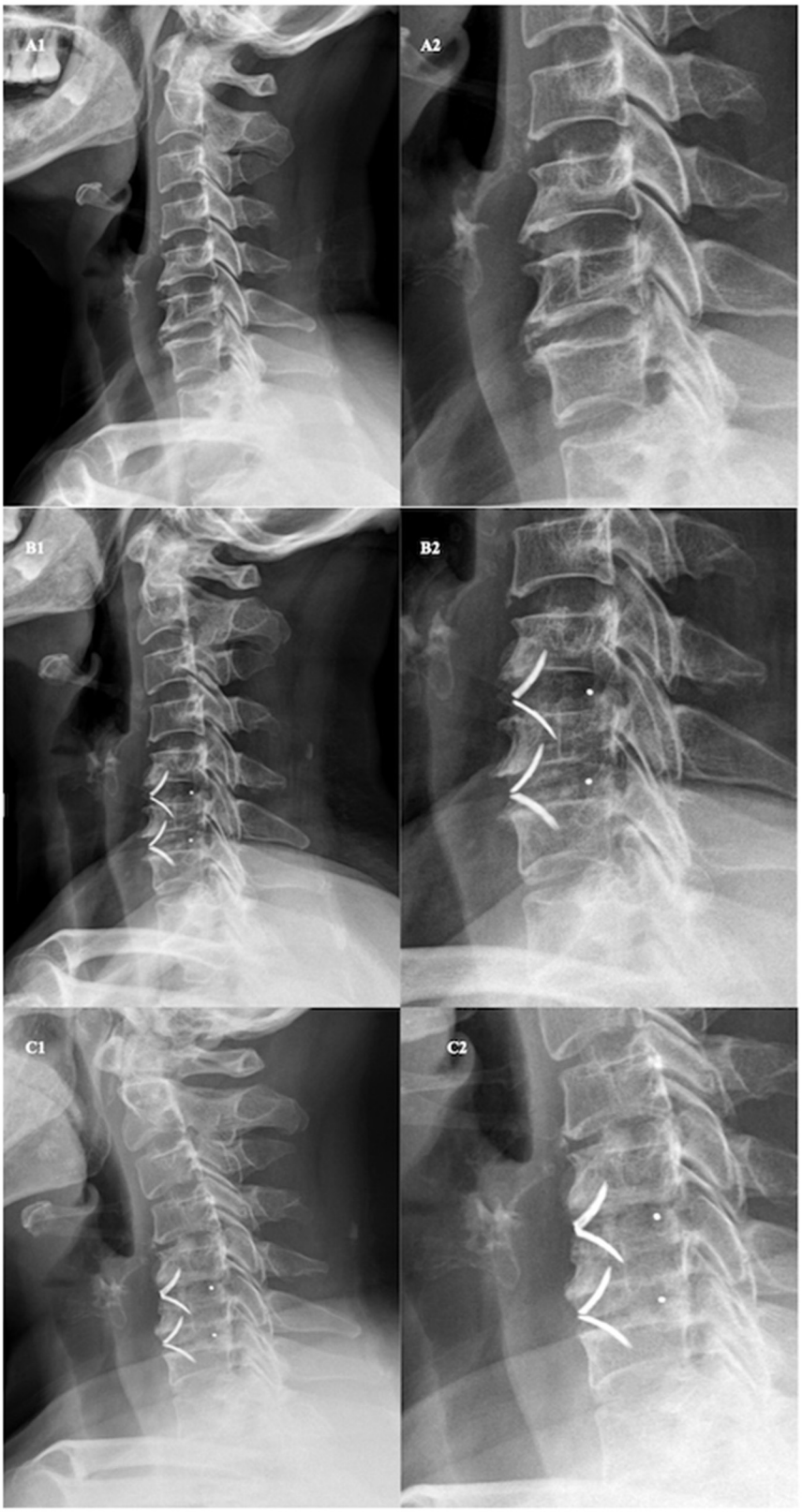


FIGURE 4 | Demonstration of cage subsidence after ACDF and its influence on local and general cervical lordosis. Lateral radiograph **(A1)** and enhanced view **(A2)** before anterior cervical discectomy and fusion with ROI-C cage. Lateral radiograph **(B1)** and enhanced view **(B2)** one month after ACDF with ROI-C cage. Lateral radiograph **(C1)** and enhanced view **(C2)** one year after ACDF with ROI-C cage. Fused segment cobb angle were 0°, 10°, and, 0° and Cervical cobb angle were 2°, 5°, and −15° before operation, 1-month post-op, and 1-year post-op respectively.

for evaluation was present during follow-up, which may cause variations in radiographic measurements. Longer follow-up period and larger number of patients remains necessary to evaluate changes in subsidence over time and to determine its impact on clinical outcomes and cervical alignments.

CONCLUSION

In our study, ACDF with ROI-C cage achieved comparable clinical outcomes and cervical stability compared with the use of a CPC. However, our study demonstrated that the occurrence of cage subsidence was considerably higher in the ROI-C group when multiple-level surgeries were performed compared with that in the CPC group. We further identified that male sex, the use of a ROI-C cage, multiple-level discectomies, and over-distraction were significant risk factors for cage subsidence. Despite no correlation between cage subsidence and clinical outcomes was observed in our study, the potential drawbacks of cage subsidence should be considered when using the ROI-C cage in multiple-level ACDFs.

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 Medical Ethics Committee of the First Affiliated Hospital of Soochow University (IRB#2021-119). 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

M-fG, Y-jL, and H-lY contributed to the study concept and design. Z-yJ, YT, and H-zW contributed to the acquisition of data and analysis and interpretation of data. Z-yJ contributed to the drafting of the manuscript. All authors have read and approved the final manuscript.

REFERENCES

1. 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) 40:607–24. doi: 10.2106/00004623-195840030-00009
2. Fountas KN, Kapsalaki EZ, Nikolakakos LG, Smisson HF, Johnston KW, Grigorian AA, et al. Anterior cervical discectomy and fusion associated complications. *Spine (Phila Pa 1976).* (2007) 32:2310–7. doi: 10.1097/BRS.0b013e318154c57e
3. Gazzeri R, Tamorri M, Faiola A, Gazzeri G. Delayed migration of a screw into the gastrointestinal tract after anterior cervical spine plating. *Spine (Phila Pa 1976).* (2008) 33: E268–271. doi: 10.1097/BRS.0b013e31816b8831
4. Amelot A, Bouazza S, George B, Orabi M, Bresson D. Anterior extrusion of fusion cage in posttraumatic cervical disk disease. *J Neurol Surg A Cent Eur Neurosurg.* (2015) 76:168–71. doi: 10.1055/s-0034-1389095
5. Grasso G, Giambartino F, Tomasello G, Iacopino G. Anterior cervical discectomy and fusion with ROI-C peek cage: cervical alignment and patient outcomes. *Eur Spine J.* (2014) 23 (Suppl. 6):650–7. doi: 10.1007/s00586-014-3553-y
6. Wang Z, Jiang W, Li X, Wang H, Shi J, Chen J, et al. The application of zero-profile anchored spacer in anterior cervical discectomy and fusion. *Eur Spine J.* (2015) 24:148–54. doi: 10.1007/s00586-014-3628-9
7. Lu Y, Bao W, Wang Z, Zhou F, Zou J, Jiang W, et al. Comparison of the clinical effects of zero-profile anchored spacer (ROI-C) and conventional cage-plate construct for the treatment of noncontiguous bilevel of cervical degenerative disc disease (CDDD): a minimum 2-year follow-up. *Medicine (Baltimore).* (2018) 97:e9808. doi: 10.1097/MD.0000000000009808
8. Bucci MN, Oh D, Cowan RS, Davis RJ, Jackson RJ, Tyndall DS, et al. The ROI-C zero-profile anchored spacer for anterior cervical discectomy and fusion: biomechanical profile and clinical outcomes. *Med Devices.* (2017) 10:61–9. doi: 10.2147/MDER.S127133
9. Fujibayashi S, Neo M, Nakamura T. Stand-alone interbody cage versus anterior cervical plate for treatment of cervical disc herniation: sequential changes in cage subsidence. *J Clin Neurosci.* (2008) 15:1017–22. doi: 10.1016/j.jocn.2007.05.011
10. Kast E, Derakhshani S, Bothmann M, Oberle J. Subsidence after anterior cervical inter-body fusion. A randomized prospective clinical trial. *Neurosurg Rev.* (2009) 32:207–14; discussion 214. doi: 10.1007/s10143-008-0168-y
11. Igarashi H, Hoshino M, Omori K, Matsuzaki H, Nemoto Y, Tsuruta T, et al. Factors Influencing Interbody Cage Subsidence Following Anterior Cervical Discectomy and Fusion. *Clin Spine Surg.* (2019) 32:297–302. doi: 10.1097/BSD.0000000000000843
12. Kao TH, Wu CH, Chou YC, Chen HT, Chen WH, Tsou HK. Risk factors for subsidence in anterior cervical fusion with stand-alone polyetheretherketone (PEEK) cages: a review of 82 cases and 182 levels. *Arch Orthop Trauma Surg.* (2014) 134:1343–51. doi: 10.1007/s00402-014-2047-z
13. Lee YS, Kim YB, Park SW. Risk factors for postoperative subsidence of single-level anterior cervical discectomy and fusion: the significance of the preoperative cervical alignment. *Spine (Phila Pa 1976).* (2014) 39:1280–7. doi: 10.1097/BRS.0000000000000400
14. Tamai K, Buser Z, Paholpak P, Sessumpun K, Nakamura H, Wang JC. Can C7 Slope Substitute the T1 slope?: an analysis using cervical radiographs and kinematic MRIs. *Spine (Phila Pa 1976).* (2018) 43:520–525. doi: 10.1097/BRS.0000000000002371
15. Miyazaki M, Hong SW, Yoon SH, Morishita Y, Wang JC. Reliability of a magnetic resonance imaging-based grading system for cervical intervertebral disc degeneration. *J Spinal Disord Tech.* (2008) 21:288–92. doi: 10.1097/BSD.0b013e31813c0e59
16. Song KJ, Choi BW, Jeon TS, Lee KB, Chang H. Adjacent segment degenerative disease: is it due to disease progression or a fusion-associated phenomenon? Comparison between segments adjacent to the fused and non-fused segments. *Eur Spine J.* (2011) 20:1940–5. doi: 10.1007/s00586-011-1864-9
17. Pitzen TR, Chrobok J, Stulik J, Ruffing S, Drumm J, Sova L, et al. Implant complications, fusion, loss of lordosis, and outcome after anterior cervical plating with dynamic or rigid plates: two-year results of a multi-centric, randomized, controlled study. *Spine (Phila Pa 1976).* (2009) 34:641–6. doi: 10.1097/BRS.0b013e318198ce10
18. Noordhoek I, Koning MT, Jacobs WCH, Vleggeert-Lankamp CLA. Incidence and clinical relevance of cage subsidence in anterior cervical discectomy and fusion: a systematic review. *Acta Neurochir (Wien).* (2018) 160:873–80. doi: 10.1007/s00701-018-3490-3
19. Lu Y, Fang Y, Shen X, Lu D, Zhou L, Gan M, et al. Does zero-profile anchored cage accompanied by a higher postoperative subsidence compared with cage-plate construct? *A meta-analysis. J Orthop Surg Res.* (2020) 15:189. doi: 10.1186/s13018-020-01711-9

20. Chen Y, Lu G, Wang B, Li L, Kuang L. A comparison of anterior cervical discectomy and fusion (ACDF) using self-locking stand-alone polyetheretherketone (PEEK) cage with ACDF using cage and plate in the treatment of three-level cervical degenerative spondylopathy: a retrospective study with 2-year follow-up. *Eur Spine J.* (2016) 25:2255–62. doi: 10.1007/s00586-016-4391-x
21. Zhu D, Zhang D, Liu B, Li C, Zhu J. Can self-locking cages offer the same clinical outcomes as anterior cage-with-plate fixation for 3-level anterior cervical discectomy and fusion (ACDF) in mid-term follow-up? *Med Sci Monit.* (2019) 25:547–57. doi: 10.12659/MSM.911234
22. Yang JJ, Yu CH, Chang BS, Yeom JS, Lee JH, Lee CK. Subsidence and nonunion after anterior cervical interbody fusion using a stand-alone polyetheretherketone (PEEK) cage. *Clin Orthop Surg.* (2011) 3:16–23. doi: 10.4055/cios.2011.3.1.16
23. Yamagata T, Takami T, Uda T, Ikeda H, Nagata T, Sakamoto S, et al. Outcomes of contemporary use of rectangular titanium stand-alone cages in anterior cervical discectomy and fusion: cage subsidence and cervical alignment. *J Clin Neurosci.* (2012) 19:1673–8. doi: 10.1016/j.jocn.2011.11.043
24. Truumees E, Demetropoulos CK, Yang KH, Herkowitz HN. Effects of disc height and distractive forces on graft compression in an anterior cervical discectomy model. *Spine (Phila Pa 1976).* (2002) 27:2441–5. doi: 10.1097/00007632-200211150-00005
25. Francke EI, Demetropoulos CK, Agabegi SS, Truumees E, Herkowitz HN. Distractive force relative to initial graft compression in an *in vivo* anterior cervical discectomy and fusion model. *Spine (Phila Pa 1976).* (2010) 35:526–30. doi: 10.1097/BRS.0b013e3181bb0e6e
26. Borm W, Seitz K. Use of cervical stand-alone cages. *Eur Spine J.* (2004) 13:474–475; author reply 476-477. doi: 10.1007/s00586-004-0707-3
27. Zhang JD, Poffyn B, Sys G, Uyttendaele D. Are stand-alone cages sufficient for anterior lumbar interbody fusion? *Orthop Surg.* (2012) 4:11–4. doi: 10.1111/j.1757-7861.2011.00164.x
28. Wu WJ, Jiang LS, Liang Y, Dai LY. Cage subsidence does not, but cervical lordosis improvement does affect the long-term results of anterior cervical fusion with stand-alone cage for degenerative cervical disc disease: a retrospective study. *Eur Spine J.* (2012) 21:1374–82. doi: 10.1007/s00586-011-2131-9
29. Cheng CC, Ordway NR, Zhang X, Lu YM, Fang H, Fayyazi AH. Loss of cervical endplate integrity following minimal surface preparation. *Spine (Phila Pa 1976).* (2007) 32:1852–5. doi: 10.1097/BRS.0b013e31811ece5a
30. Opsenak R, Hanko M, Snopko P, Varga K, Kolarovszki B. Subsidence of anchored cage after anterior cervical discectomy. *Bratisl Lek Listy.* (2019) 120:356–61. doi: 10.4149/BLL_2019_058
31. Jang HJ, Chin DK, Kim KH, Park JY. Does graft position affect subsidence after anterior cervical discectomy and fusion? *Global Spine J.* (2020). doi: 10.1177/2192568220963061. [Epub ahead of print].

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: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers in Surgery

ORIGINAL RESEARCH
published: 18 February 2022
doi: 10.3389/fsurg.2022.800664

Comparison of Percutaneous Kyphoplasty With or Without Posterior Pedicle Screw Fixation on Spinal Sagittal Balance in Elderly Patients With Severe Osteoporotic Vertebral Compression Fracture: A Retrospective Study

Quan Zhou†, *Junxin Zhang*†, *Hao Liu*†, *Wei He, Lei Deng, Xinfeng Zhou, Huilin Yang and Tao Liu**

Department of Orthopaedics, The First Affiliated Hospital of Soochow University, Suzhou, China

OPEN ACCESS

Edited by:
Hengxing Zhou,
Tianjin Medical University General Hospital, China

Reviewed by:
Yongwei Jia,
Shanghai Guanghua Hospital of Integrated Traditional Chinese and Western Medicine, China
Jiaming Liu,
The First Affiliated Hospital of Nanchang University, China

***Correspondence:**
Tao Liu
liutao821108@163.com

†*These authors have contributed equally to this work*

Specialty section:
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

Received: *23 October 2021*
Accepted: *27 January 2022*
Published: *18 February 2022*

Citation:
Zhou Q, Zhang J, Liu H, He W, Deng L, Zhou X, Yang H and Liu T (2022) Comparison of Percutaneous Kyphoplasty With or Without Posterior Pedicle Screw Fixation on Spinal Sagittal Balance in Elderly Patients With Severe Osteoporotic Vertebral Compression Fracture: A Retrospective Study. Front. Surg. 9:800664. doi: 10.3389/fsurg.2022.800664

Objective: To compare the effects of percutaneous kyphoplasty (PKP) with or without posterior pedicle screw fixation (PPSF) on spinal sagittal balance in elderly patients with severe osteoporotic vertebral compression fracture (sOVCF).

Methods: From January 2016 to December 2018, 102 elderly patients with single-level thoracolumbar sOVCF were enrolled. Among them, 78 cases underwent PKP (Group A), and 24 cases underwent PPSF+KP (Group B). Clinical evaluation included perioperative parameters, Oswestry Disability Index (ODI) and Visual Analog Scale (VAS) for back pain; Radiographic evaluation included anterior vertebral height (AVH) and rate (AVHr), local kyphotic angle (LKA), and spino-pelvic sagittal balance parameters.

Results: Perioperative parameters including operation time, blood loss, fluoroscopic time and hospital stay in Group A were less than those in Group B ($p < 0.05$). Compared with the pre-operative results, the ODI and VAS scores of both groups decreased significantly in the three follow-ups after surgery ($p < 0.05$). The post-operative ODI and VAS scores of Group A were significantly better than those of Group B, but the results were opposite at the final follow-up ($p < 0.05$). Compared with the pre-operative values, except that there was no significant difference in pelvic incidence (PI) ($p > 0.05$), other radiographic parameters of both groups were improved significantly in the three follow-ups after surgery ($p < 0.05$). The AVH, AVHr, LKA and lumbar lordosis (LL) in Group B were better than those in Group A in the three follow-ups after surgery ($p < 0.05$). At the final follow-up, the sacral slope (SS) and pelvic tilt (PT) differed significantly between the two groups ($p < 0.05$).

Conclusions: Both PPSF+KP and PKP can achieve favorable clinical outcomes and maintain the spinal sagittal balance. Compared with PPSF+KP, PKP showed more significant advantages in the early post-operative period. However, in the long-term follow-up, PPSF+KP showed better clinical outcomes and may be better than PKP in maintaining spinal sagittal balance.

Keywords: osteoporosis, vertebral compression fracture, percutaneous kyphoplasty, posterior pedicle screw fixation, spinal sagittal balance

INTRODUCTION

Spinal sagittal balance is a good state for an individual to maintain the body in a stable position, which plays a crucial role in maintaining the normal biomechanics and physiologic function of the spine (1). When the spinal deformity gradually deteriorates and exceeds the overall compensatory capacity, it is no longer effective to maintain body balance by increasing muscle strength, resulting in the spinal sagittal imbalance. Some researchers have reported that correction of spinal sagittal imbalance is associated with favorable clinical efficacy after lumbar surgery (2, 3). Many spinal diseases, such as spinal deformity, lumbar spondylolisthesis etc., can lead to spinal sagittal imbalance (1, 4, 5). However, the spinal sagittal imbalance caused by osteoporotic vertebral compression fracture (OVCF) has not received enough attention.

OVCF is a fragile fracture caused by osteoporosis under the action of slight external force or not, causing intractable pain, lowering the quality of life, and also increasing the incidence of systemic complications and mortality (6–8). Percutaneous kyphoplasty (PKP) is one of the most widely used surgical methods for OVCF. This minimally invasive technique can achieve some benefits on short-term prognosis by eliminating pain and restoring vertebral height immediately after surgery (9). Although these advantages have been demonstrated, PKP is associated with a high risk of recollapse of fractured vertebrae or fractures in adjacent segments (10, 11). In particular, for patients with severe OVCF (sOVCF), defined as an expected reduction of two-thirds or more in anterior vertebral height (12), PKP alone may not be able to effectively correct severe kyphosis and maintain spinal sagittal balance in the long term, which may also increase the risk of adjacent segment fractures and vertebral recollapse. In addition, pedicle screws show the high biomechanical strength offered by three-column fixation, which can keep the vertebral stable and correct kyphosis to a certain extent. However, if only pedicle screw fixation is used in these patients, there would be a high risk of screw loosening, and late kyphosis deformity due to osteoporosis (13, 14). Therefore, to more effectively reduce the risk of adjacent vertebral fractures, correct kyphosis and maintain spinal sagittal balance, posterior pedicle screw fixation combined with kyphoplasty (PPSF+KP) has been used in recent years.

Some clinical studies have reported that PPSF combined with KP or vertebroplasty (VP) could be a good choice for patients with thoracolumbar OVCF, which can reduce the incidence of vertebral refractures and restore the height of the fractured vertebrae (15–17). So far, however, few studies have compared the prognosis of PKP and PPSF+KP in patients with thoracolumbar sOVCF, especially the long-term effect on spinal sagittal balance. Therefore, this retrospective comparative study was conducted to compare the effects of PKP and PPSF+KP on clinical function and radiographic outcomes in elderly patients with single-level thoracolumbar sOVCF.

DATA AND METHODS

Selection Criteria

Inclusion criteria: (1) patients with a single-level thoracolumbar compression fracture (T11–L2); (2) patients with osteoporosis ($T < -2.5$) on dual energy X-ray absorptiometry (DEXA); (3) patients with sOVCF, defined as an expected reduction of two-thirds or more in anterior vertebral height (AVH); (4) patients with obvious back pain but without symptoms of nerve damage; (5) patients treated with PKP or PPSF+KP; (6) patients over 60 years of age. Exclusion criteria: (1) patients with previous fractures or surgical intervention at the spinal alignment; (2) fractures with tumor, tuberculosis or ankylosing spondylitis; (3) patients who died or were unable to complete 24 months of follow-up.

General Information

According to the inclusion and exclusion criteria, a total of 102 elderly patients with sOVCF from January 2016 to December 2018 were enrolled in this retrospective study. Among them, 78 cases (Group A) received PKP, 24 cases (Group B) received PPSF+KP. All patients' data and imaging materials were obtained from the electronic medical record management system of our hospital. This study was carried out with the approval of our institution's ethics committee.

Surgical Procedure

All patients were operated under general anesthesia. After anesthesia, they were placed in a prone position with the pelvis and manubrium supported by pads. The use of C-arm radiographs facilitated the acquisition of a standard anteroposterior and lateral images of the surgical vertebrae.

For Group A, bilateral transpedicular working channels were penetrated into the surgical vertebrae by the cannula and trocar systems under fluoroscopic guidance. Then, each balloon was placed into the cavity of the intravertebral cleft in the surgical vertebrae through the working channel and inflated to over 150 psi. Polymethyl methacrylate (PMMA)

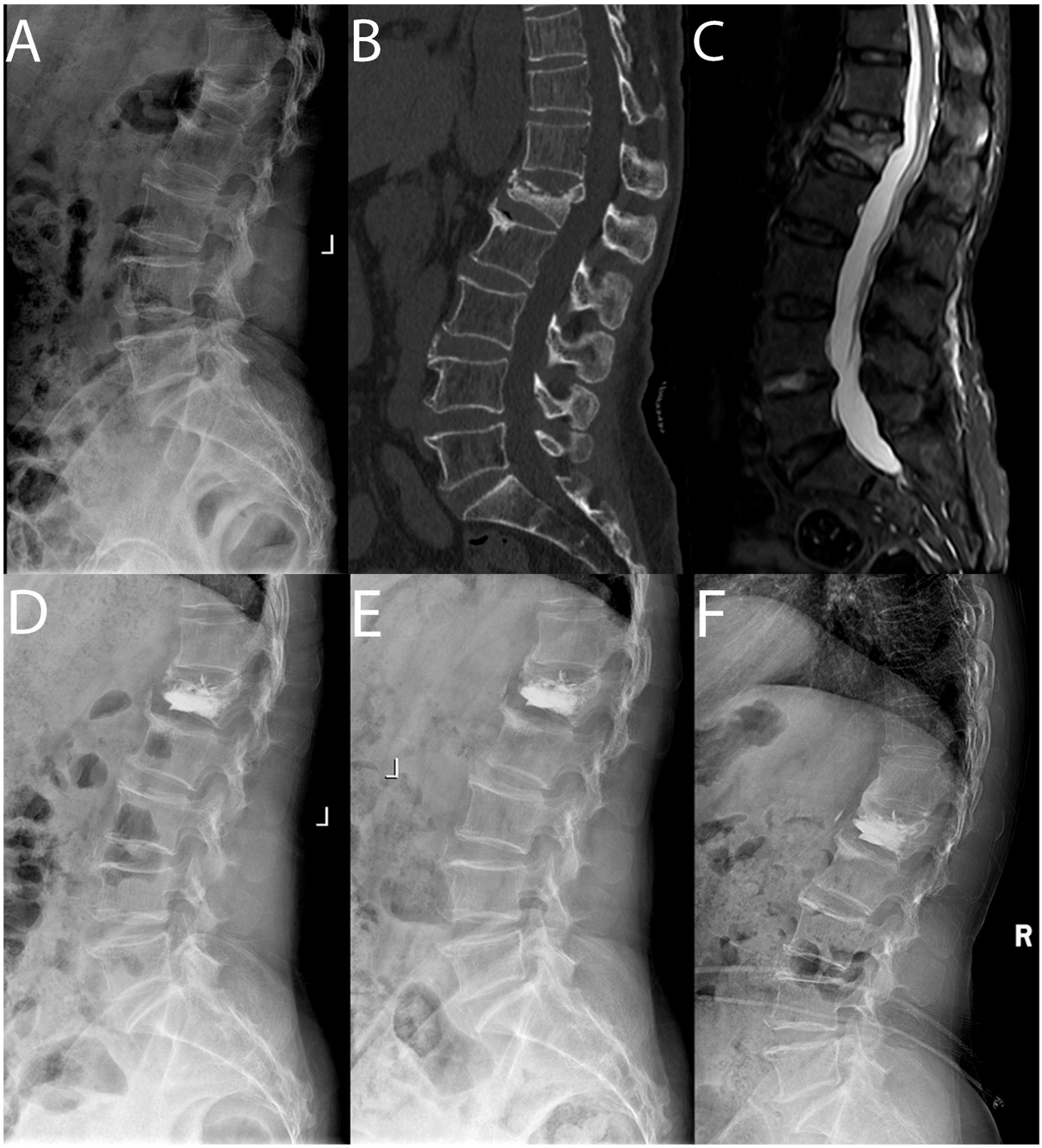


FIGURE 1 | Pre-operative sagittal lateral view **(A)**, sagittal computed tomographic scan **(B)**, sagittal fat-suppressed sequence in MRI **(C)**, post-operative sagittal lateral view **(D)**, sagittal lateral view 1 month after surgery **(E)** and sagittal lateral view at the final follow-up **(F)** of a 64-year-old female patient with L1 sOVCF was treated with PKP.

and non-ionic contrast medium were prepared at 26 g/10 ml and injected carefully into the vertebrae using a bone cement injector under fluoroscopic monitoring. The incremental temperature cement delivery and graded infusion techniques were used in our hospital to minimize the leakage rate (18) (**Figure 1**).

For Group B, a standard open posterior midline approach was performed, centering the fractured vertebrae and

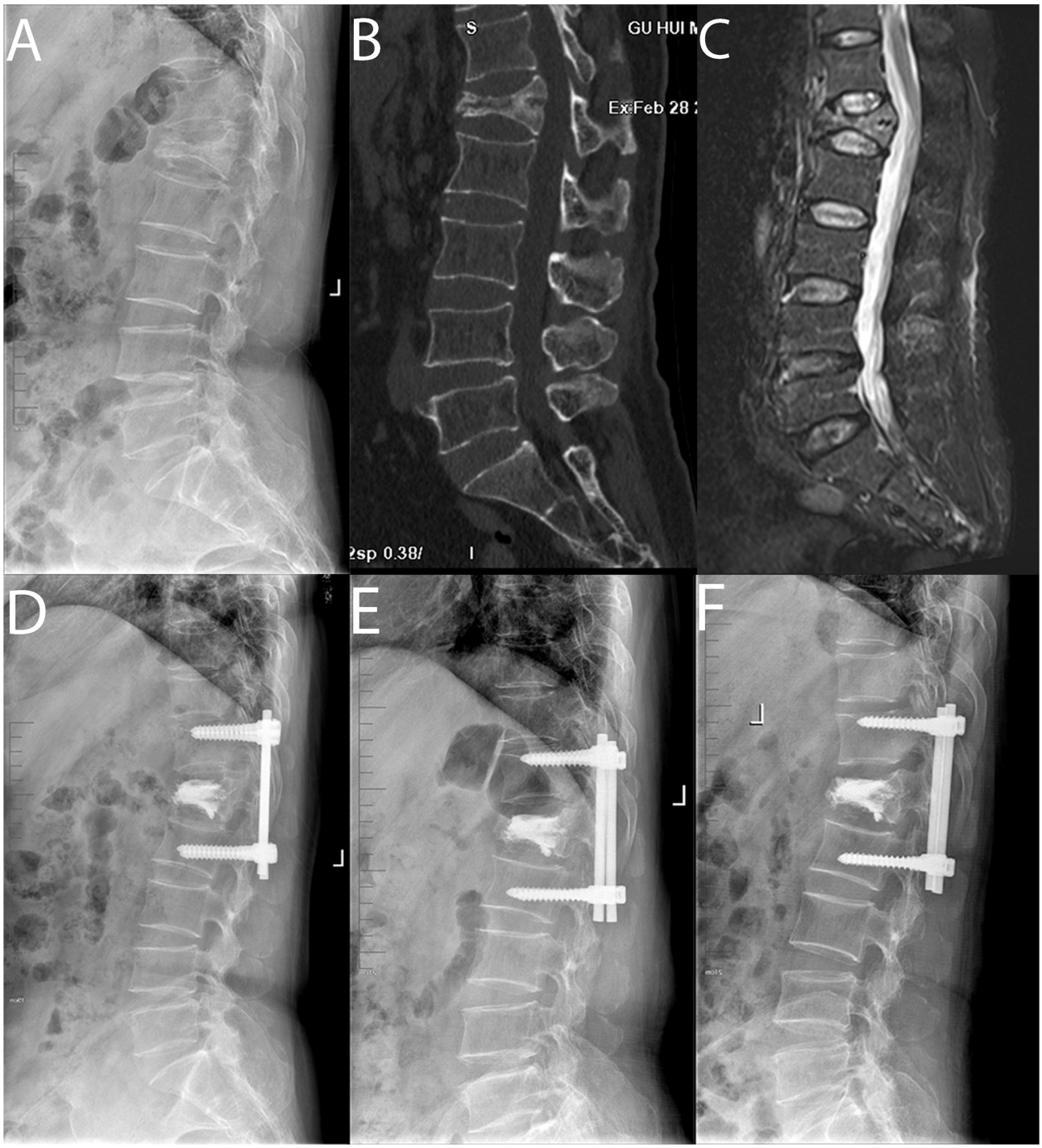


FIGURE 2 | Pre-operative sagittal lateral view **(A)**, sagittal computed tomographic scan **(B)**, sagittal fat-suppressed sequence in MRI **(C)**, post-operative sagittal lateral view **(D)**, sagittal lateral view 1 month after surgery **(E)** and sagittal lateral view at the final follow-up **(F)** of a 62-year-old male patient with L1 sOVCF was treated with PPSF+KP.

systematically revealing the posterior vertebral structure. Under fluoroscopic monitoring, 4 pedicle screws were inserted into the adjacent upper and lower vertebrae of the surgical vertebrae, and the height of the fractured vertebrae was restored by position combined with internal fixation distraction and lateral lifting. In the second surgical phase, the procedure for PKP described above was used (**Figure 2**).

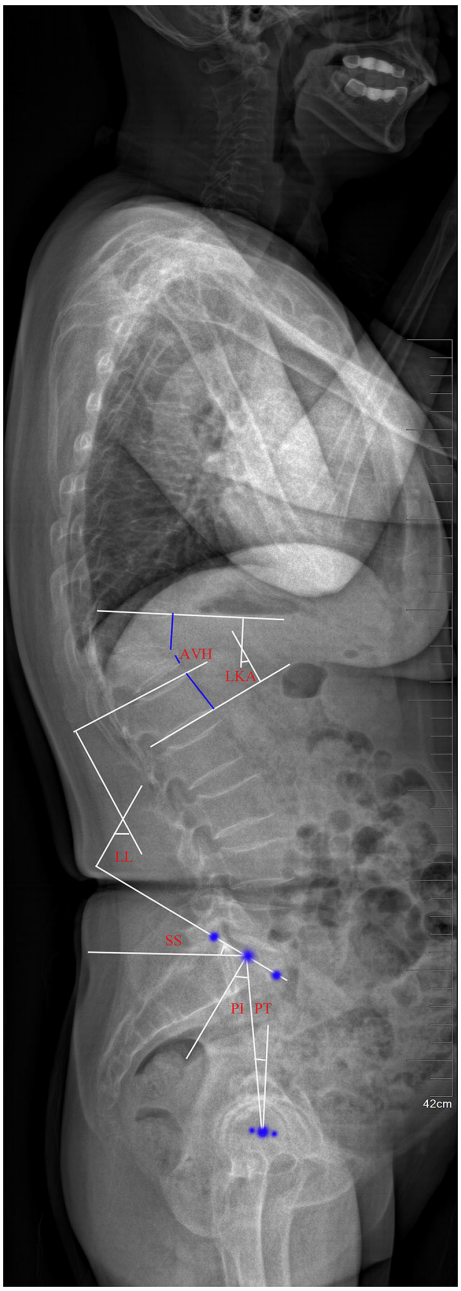


FIGURE 3 | Plain lateral radiograph for measuring radiographic parameters. AVH, anterior vertebral height; LKA, local kyphotic angle; LL, lumbar lordosis; SS, sacral slope; PI, pelvic incidence; PT, pelvic tilt.

During the follow-up period, all patients performed functional exercise of the back muscles and took anti-osteoporosis drugs under the guidance of doctors.

Clinical Evaluation

For the measurement of clinical outcomes, perioperative parameters, including operative time, blood loss, fluoroscopic time, cement volume and hospital stay, were recorded and all patients filled out the following questionnaires pre-operatively, post-operatively, 1 month after surgery and at the final follow-up: Oswestry Disability Index (ODI), and Visual Analog Scale (VAS) for back pain. The ODI scores were used to assess patients' improvement in quality of life, the VAS scores were used to evaluate patients' subjective pain perception (0–10 score, 0 indicated no pain, 10 indicated the most severe pain) (19).

TABLE 1 | Demographic data of both groups.

	Full sample	Group A	Group B	*P*-value
Number of patients	102	78	24	
Age (years)	66.12 ± 5.21	65.82 ± 5.21	67.08 ± 5.22	0.302
Gender (male/female)	17/85	14/64	3/21	0.531
Trauma history (*n*)				0.891
None	26 (25.49%)	20 (25.64%)	6 (25.00%)	
Slight	62 (60.78%)	48 (61.54%)	14 (58.33%)	
Severe	14 (13.73%)	10 (12.82%)	4 (16.67%)	
Fractured segment (*n*)				0.903
T11	9 (8.82%)	7 (8.97%)	2 (8.33%)	
T12	19 (18.63%)	14 (17.95%)	5 (20.83%)	
L1	47 (46.08%)	35 (44.87%)	12 (50%)	
L2	27 (26.47%)	22 (28.21%)	5 (20.83%)	
BMI (kg/m^2)	24.74 ± 3.68	25.05 ± 3.64	23.74 ± 3.70	0.128
BMD (T-score)	−3.15 ± 0.41	−3.17 ± 0.37	−3.07 ± 0.52	0.286
Comorbidity (*n*)				
Hypertension	44 (43.14%)	33 (42.31%)	11 (45.83%)	0.760
Diabetes	37 (36.27%)	26 (33.33%)	9 (37.50%)	0.707
Hyperlipidemia	53 (51.96%)	40 (51.28%)	13 (54.17%)	0.805
Smoking	21 (20.59%)	16 (20.51%)	5 (20.83%)	0.973
Follow-up (months)	34.83 ± 5.90	34.42 ± 6.06	36.17 ± 5.21	0.207

BMI, body mass index; BMD, bone mineral density.

TABLE 2 | Perioperative parameters of both groups.

	Group A (*n* = 78)	Group B (*n* = 24)	*P*-Value
Operative time (min)	44.12 ± 7.40	116.04 ± 17.94	<0.001*
Blood loss (ml)	10.64 ± 4.72	60.63 ± 14.69	<0.001*
Fluoroscopic time (s)	39.19 ± 8.42	64.71 ± 8.99	<0.001*
Cement volume (ml)	6.43 ± 0.69	6.32 ± 0.67	0.483
Hospital stay (days)	4.93 ± 1.72	7.67 ± 2.10	<0.001*

**Significance between the two groups, P < 0.05.*

Radiographic Evaluation

Bone mineral density (BMD) was assessed as T score in the lumbar spine with DEXA (Discovery Wi, Hologic, America). The anteroposterior and lateral radiographs in the standing position were routinely performed pre-operatively, post-operatively, 1 month after surgery, and at the final follow-up. The anterior height of the fractured vertebrae was measured, and the anterior vertebral height rate (AVHr) was calculated as a percentage of the average adjacent upper and lower vertebral height. The local kyphotic angle (LKA) was measured as the angle between the superior endplate of the vertebrae above and the inferior

endplate of the vertebrae below the fractured level. The following parameters of spino-pelvic sagittal balance were measured (20): Lumbar lordosis (LL) was defined by Cobb's method as the angle between the superior endplate of L1 vertebrae and the sacral plate; sacral slope (SS) was defined as the angle formed between the sacral plate and the horizontal line; pelvic incidence (PI) was formed by the line perpendicular to the midpoint of the sacral plate and the line between the midpoint of the sacral plate and the centroid of femoral heads; pelvic tilt (PT) was formed by the angle between the line connecting the midpoint of the sacral plate with the centroid of femoral heads and the vertical line (**Figure 3**).

Statistical Methods

SPSS 26.0 statistical software (SPSS Inc., Chicago, IL) was used for data processing. The measurement data were expressed as mean ± standard deviation ($\bar{x} \pm s$). Paired sample T-test was used for comparison in the same group. χ^2 test was used for categorical variable data. $P<0.05$ was considered statistically significant.

RESULTS

Demographics

Demographic data of both groups were shown in **Table 1**. Among the patients included in this study, the average age was 66.12 ± 5.21 years old, male patients (16.67%) were less than female patients (83.33%), and most patients (60.78%) developed sOVCF after slight trauma. In terms of the fractured segment, L1 (46.08%) was the most common compared with other segments. There were no significant differences between the two groups in terms of age, gender, trauma history and fractured segments ($p > 0.05$). The mean body mass index (BMI) of Group A was slightly higher than that of Group B, but the difference was not statistically significant ($p > 0.05$). The mean BMD of all patients were -3.15 ± 0.41, and there was no significant difference between the two groups ($p > 0.05$). In terms of comorbidities, there were different numbers of patients with hypertension, diabetes, hyperlipidemia and smoking in both groups, but there was no significant difference between the two groups ($p > 0.05$). The average follow-up duration of all patients was 34.83 ± 5.90 months, and there was no significant difference between the two groups ($p > 0.05$).

Clinical Outcomes

Perioperative parameters of both groups were shown in **Table 2**. Operation time, blood loss, fluoroscopic time, and hospital stay in Group A were all less than those in Group B ($p < 0.05$). In terms of injection volume of bone cement, Group A was slightly more than Group B, but there was no statistical difference ($p > 0.05$).

The ODI and VAS scores of both groups were shown in **Figure 4**. Compared with pre-operative results, the ODI and VAS scores of both groups post-operatively, one month after surgery and at the final follow-up all decreased significantly ($p < 0.05$). In addition, the ODI and VAS scores of Group A were significantly better than those of Group B post-operatively ($p < 0.05$), but the ODI and VAS scores of Group B were significantly better than those of Group A at the final follow-up ($p < 0.05$).

Radiographic Outcomes

The AVH and AVHr of both groups were shown in **Figure 5**. Compared with the pre-operative results, the AVH and AVHr were all significantly increased in both groups post-operatively, 1 month after surgery and at the final follow-up ($p<0.05$). In addition, the recoveries of AVH and AVHr in Group A were significantly better than those in Group B post-operatively, 1 month after surgery and at the final follow-up ($p < 0.05$).

The LKA of both groups was shown in **Table 3**. From T11 to L2, the LKA decreased gradually. Compared with pre-operative results, LKA of the fractured vertebrae decreased significantly in both groups post-operatively, 1 month after surgery and at the final follow-up ($p < 0.05$). In addition, the recovery of LKA in Group A was significantly better than that in Group B post-operatively, 1 month after surgery and at the final follow-up ($p < 0.05$).

Spino-pelvic sagittal balance parameters of both groups were shown in **Table 4**. Except that PI of both groups were not statistically different from the pre-operative results, there were significant differences in other parameters post-operatively, 1 month after surgery and at the final follow-up compared with the pre-operative results ($p < 0.05$). In addition, the maintenance of LL in Group A was significantly better than that in Group B post-operatively, 1 month after surgery and at the final follow-up ($p < 0.05$). At the final follow-up, SS and PT differed significantly between the two groups ($p < 0.05$). In terms of PI and PI-LL at the final follow-up, although the values of Group A were slightly higher than those of Group B, they did not reach significant differences ($p > 0.05$).

Related Complications

In terms of related complications, there were 10 cases (12.82%) in Group A and 2 cases (8.33%) in Group B, with no significant difference ($p > 0.05$). Cement leakage was found in 3 cases (3.85%) in Group A and 1 case (4.17%) in Group B, with no statistical difference ($p > 0.05$). None of the above 4 patients with cement leakage had serious symptoms. During follow-up, there were 2 cases (2.56%) of fractured vertebrae recollapse in Group A, with no obvious pain symptoms. Adjacent segment fractures were found in 5 cases (6.41%) in Group A and 1 case (4.17%) in Group B, with no statistical difference ($p > 0.05$). Six patients with adjacent segment fractures did not undergo surgery again due to no obvious pain symptoms and progressive kyphosis.

DISCUSSION

With the accelerated progress of aging society, OVCF, mainly caused by osteoporosis, has become an important health problem all over the world. In recent years, PKP has been widely used in the treatment of OVCF because it can obtain some benefits in short-term prognosis, including rapid pain relief, recovery of AVH and shortening bed rest time. Due to the risk of severe cement leakage and the difficulty of surgical techniques, some authors previously considered sOVCF as an absolute or relative contraindication for PVP (12, 21, 22). However, through the mastery and improvement of surgical techniques, more and more researchers have conducted studies on patients with sOVCF and

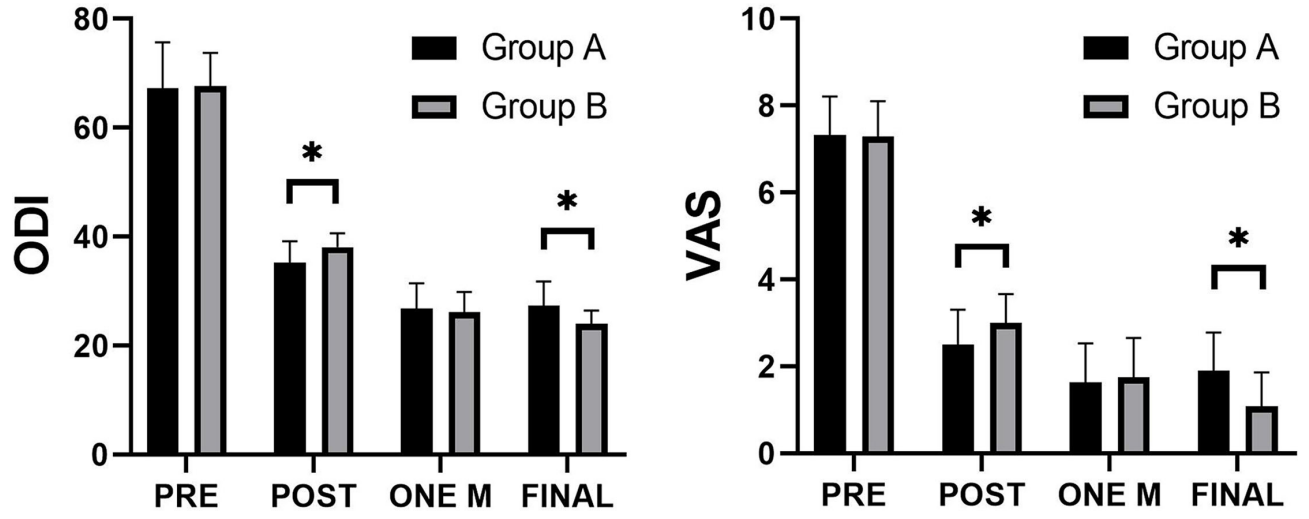


FIGURE 4 | Comparison of the Visual Analog Scale (VAS) and Oswestry disability index (ODI) scores between the two groups. *Significance between the two groups, $P < 0.05$.

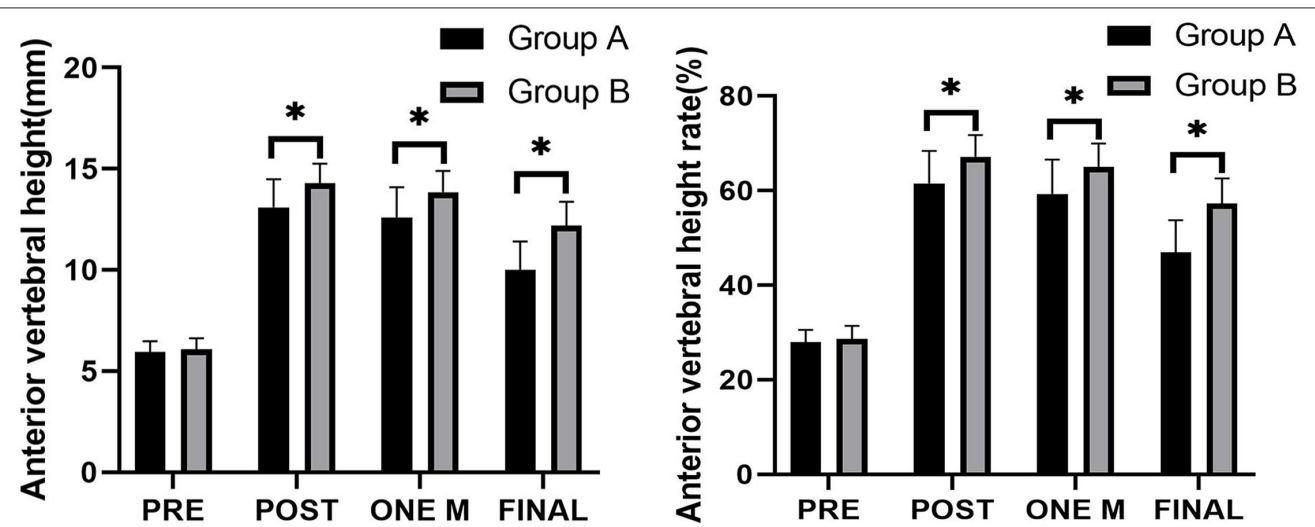


FIGURE 5 | Comparison of the anterior vertebral height (AVH) and anterior vertebral height rate (AVHr) between the two groups. *Significance between the two groups, $P < 0.05$.

confirmed that PKP is also effective for these patients (23–25). In a retrospective study conducted by Wen et al. (25), patients with sOVCF reported satisfactory improvements in VAS and ODI scores, LKA, and AVH after PKP compared with the pre-operative values ($p < 0.05$).

However, with the wide application of PKP and the deepening of related research, the complications caused by PKP have attracted increasingly attention, including cement leakage, fractured vertebrae recollapse and fractures of adjacent segments (26–29). Therefore, to give full play to the advantages of PKP and reduce the incidence of these complications, some studies have applied PPSF combined with KP or VP to treat patients with OVCF (15–17). Gu et al. (15) reported that 68 patients with single-level thoracolumbar OVCF underwent PPSF+VP. The results showed that, compared with the pre-operative values, VAS scores, Cobb angle and AVH were significantly improved, and PPSF+VP had obvious effects on preventing fractured vertebrae recollapse and adjacent segment fractures. In 2021, Huang et al. (16) conducted a retrospective study and concluded that for patients with osteoporotic thoracolumbar fractures, PPSF+KP can not only achieve favorable outcomes but also maintain longer correction and stronger support of the vertebrae compared with PKP. In this study, we retrospectively compared the effects of PKP and PPSF+KP on clinical function and radiographic outcomes in patients with single-level thoracolumbar sOVCF. By evaluating the clinical function and radiological parameters

TABLE 3 | Local kyphotic angle of fractured vertebrae of both groups.

	Group A ($n = 78$)	Group B ($n = 24$)	*P*-value
PRE (°)			
T11 ($n = 9$)	27.43 ± 1.28	27.50 ± 0.50	0.527
T12 ($n = 19$)	24.93 ± 1.61	24.80 ± 1.70	
L1 ($n = 47$)	20.89 ± 5.57	20.00 ± 2.18	
L2 ($n = 27$)	17.95 ± 4.05	16.20 ± 0.70	
Series	21.37 ± 3.61	20.83 ± 3.71	
POST (°)			
T11 ($n = 9$)	19.86 ± 1.81	17.50 ± 0.50	0.029**
T12 ($n = 19$)	17.50 ± 1.04	16.00 ± 3.50	
L1 ($n = 47$)	12.97 ± 4.26	11.67 ± 1.15	
L2 ($n = 27$)	12.27 ± 1.06	9.80 ± 0.70	
Series	14.21 ± 3.02*	12.67 ± 2.84*	
ONE M (°)			
T11 ($n = 9$)	20.14 ± 2.14	18.00 ± 0.00	0.046**
T12 ($n = 19$)	17.79 ± 1.57	16.20 ± 2.70	
L1 ($n = 47$)	13.20 ± 4.87	12.00 ± 1.45	
L2 ($n = 27$)	12.68 ± 1.37	10.60 ± 0.80	
Series	14.50 ± 3.09*	13.08 ± 2.73*	
FIANL (°)			
T11 ($n = 9$)	21.43 ± 2.29	20.00 ± 2.00	0.029**
T12 ($n = 19$)	19.79 ± 2.49	17.40 ± 2.80	
L1 ($n = 47$)	15.03 ± 3.97	14.00 ± 2.00	
L2 ($n = 27$)	14.50 ± 2.83	11.80 ± 2.20	
Series	16.31 ± 3.06*	14.75 ± 2.83*	

PRE, pre-operative; POST, post-operative; ONE M, one month after surgery; FINAL, final follow-up.
**Significance compared with the pre-operative, P < 0.05.*
***Significance between the two groups, P < 0.05.*

TABLE 4 | Spino-pelvic sagittal balance parameters of both groups.

	Group L ($n = 78$)	Group S ($n = 24$)	*P*-Value
LL (°)			
PRE	38.27 ± 2.73	38.88 ± 3.42	0.374
POST	42.32 ± 2.44*	44.17 ± 2.18*	0.001**
ONE M	42.03 ± 2.72*	43.79 ± 2.50*	0.006**
FINAL	41.32 ± 2.38*	42.75 ± 3.42*	0.023**
SS (°)			
PRE	32.63 ± 3.00	32.87 ± 3.58	0.737
POST	36.49 ± 3.04*	37.71 ± 3.56*	0.101
ONE M	36.31 ± 3.10*	37.58 ± 3.75*	0.097
FINAL	35.14 ± 2.54*	36.71 ± 3.74*	0.021**
PT (°)			
PRE	21.47 ± 4.03	21.58 ± 3.46	0.905
POST	17.01 ± 3.50*	15.96 ± 3.16*	0.190
ONE M	17.14 ± 3.50*	16.17 ± 3.25*	0.229
FINAL	19.18 ± 3.99*	17.21 ± 3.30*	0.030**
PI (°)			
PRE	54.10 ± 4.58	54.46 ± 4.39	0.738
POST	53.50 ± 3.72	53.67 ± 3.85	0.849
ONE M	53.45 ± 3.66	53.75 ± 4.00	0.731
FINAL	54.32 ± 4.36	53.92 ± 4.40	0.693
PI-LL (°)			
PRE	15.83 ± 5.54	15.58 ± 5.56	0.847
POST	11.18 ± 4.59*	9.50 ± 4.24*	0.114
ONE M	11.42 ± 4.74*	9.96 ± 4.61*	0.186
FINAL	13.00 ± 5.13*	11.17 ± 5.56*	0.137

LL, lumbar lordosis; SS, sacral slope; PI, pelvic incidence; PT, pelvic tilt; PRE, pre-operative; POST, post-operative; ONE M, one month after surgery; FINAL, final follow-up.
**Significance compared with the pre-operative, P < 0.05.*
***Significance between the two groups, P < 0.05.*

of the two groups, significant improvements were found post-operatively, 1 month after surgery and at the final follow-up compared with the pre-operative results, suggesting that PKP and PPSF+KP were all effective treatment options for patients with single-level thoracolumbar sOVCF. The two surgical methods significantly improved the prognosis of patients, which was consistent with the results of other studies mentioned above. The reason may be that both PKP and PPSF+KP can significantly restore AVH, to effectively improve the stability of the anterior and middle columns of the compression fracture vertebrae and partially restore the anterior support function. In addition, compared with Group A, most perioperative parameters of Group B showed a better side, and the post-operative VAS and ODI scores of Group B were also lower, suggesting that PKP may be better than PPSF+KP in the short-term effects after operation. These were because PPSF+KP was surely more complex compared with PKP and caused greater trauma than PKP, which may affect the early post-operative pain relief and functional recovery.

In recent years, the spinal sagittal imbalance caused by OVCF has attracted some researchers' attention. Sutipornpalangkul et al. (30) confirmed that patients with OVCF had anterior wedge deformity, which led to the progression of kyphosis and the forward movement of the center of gravity, and finally lead to spinal sagittal imbalance. LeHuec et al. (31) reported that patients with OVCF had poor global sagittal alignment and decreased quality of life, and the severity of vertebral compression fracture had a negative impact on global spinal sagittal balance. Furthermore, Cao et al. (32) found that OVCF in the thoracolumbar region had a greater impact on spino-pelvic alignment and global spinal sagittal balance than in other regions. PKP is an effective method for minimally invasive treatment of OVCF, but it is still controversial whether it is conducive to the recovery of global spinal sagittal balance (33–35). Kanayama et al. (33) and Sutipornpalangkul et al. (30) analyzed different numbers of OVCF patients treated with PKP and concluded that PKP was helpful for immediate pain relief, but did not improve the global spinal sagittal balance. However, some scholars have confirmed that PKP can improve spinal sagittal balance by restoring AVH and correcting LKA (32, 36). In our study, by evaluating the radiographic outcomes of both groups, including AVH, AVHr and LKA, PPSF+KP can more significantly restore AVH and AVHr, reduce LKA of the fractured vertebrae and increase LL after surgery than PKP. Furthermore, after more than 2 years of follow-up, AVH, AVHr and LKA, and some spino-pelvic sagittal

balance parameters suggested that PPSF+KP may play a better role in maintaining spinal sagittal balance than PKP. Although few studies reported the effects of PPSF+KP on spino-pelvic sagittal balance in patients with sOVCF, through the discussion of other studies mentioned above, we can infer that the reasons for the differences between the two groups are as follows: On the one hand, PPSF+KP can effectively fix the upper and lower adjacent vertebral bodies of the fractured vertebral body, and exert a certain degree of traction on the compressed and fractured vertebral body, which can maximize the advantages of PKP in restoring AVH during the operation. This may also explain why PPSF+KP is better than PKP alone in the post-operative correction of LKA and maintenance of spinal sagittal balance. On the other hand, although PKP can also significantly restore AVH and correct LKA in the early stage, the loss of AVH and the aggravation of LKA are often caused by intravertebral cleft (37) and osteoporosis (38) with the passage of time. Therefore, without strong support of pedicle screw fixation, some patients may be at risk of spinal sagittal imbalance.

Spino-pelvic sagittal balance plays an important role in maintaining the normal physiological function of the spine, and normal spino-pelvic sagittal balance is crucial to maintain a stable posture and transfer normal axial stress (39). Pelvic parameters include PI, PT and SS. PT is a characteristic of pelvic rotation, and the standard value is about $13^\circ \pm 6^\circ$ (40). Sung-Soo et al. (41) reported that patients with PT improvement showed significantly better VAS and ODI scores than those without improvement. In our study, there was a statistical difference in PT between the two groups at the final follow-up, which may explain why there were differences in ODI and VAS scores between the two groups. SS is defined as the angle between the horizontal line and the line parallel to the sacral plate, which is $\sim 41^\circ \pm 8^\circ$. PI increases from age 4 to 18 but does not change further into adulthood (42, 43), and the standard value is $\sim 53^\circ \pm 9^\circ$ (44). PI, which is not affected by posture, can be used as an indicator to describe the shape of pelvis and sacrum orientation since the above three pelvic parameters fulfill the equation: PI = PT + SS (45). Changes in SS and PT can be viewed as changes to compensate for sagittal imbalance (36). LL is the angle between the superior endplate of L1 vertebrae and the sacral plate, and the standard value is $\sim 46.5^\circ$ (45, 46). There is a close relationship between LL and PI, and the ideal formula is: LL = PI $\pm 9^\circ$. If these two parameters do not match, it would cause the imbalance of spinal sagittal balance. Therefore, a new parameter, PI-LL, has been produced between PI and LL, which can more directly quantify the mismatch between pelvis shape and lumbar curve, so it can be used to guide the lumbar surgery plan and the recovery target of patients after surgery (47). One of the goals of spine pelvis sagittal alignment is that PI-LL $<10^\circ$ threshold (48). In this study, PI-LL of the two groups did not reach the ideal standard before surgery and improved significantly after surgery. Although there was no significant difference in PI-LL between the two groups, it was found that PI-LL of PPSF+KP was slightly lower than that of PKP during post-operative follow-up. Regarding the above results, the reason we infer is that these elderly osteoporotic patients have already a certain degree of spinal deformity before the vertebral fracture, and they often rest or lack daily activities after the operation. Therefore, even if two surgical methods are used to restore the height of the fractured vertebral body and correct the local kyphotic angle, they may have a limited effect on spinopelvic sagittal balance. However, these are only our current inferences, and more in-depth research and longer follow-up are needed to confirm these.

There have been some reports that secondary vertebral fractures after PVP or PKP, including further compression of previously treated vertebrae and new fractures in adjacent vertebrae (11, 16, 49, 50). Kim and Rhyu (49) showed that the incidence of fractured vertebrae recollapse was 12.5%. Lavelle and Cheney (50) found that the incidence of recurrent vertebral fractures after PKP was 10%. Rho et al. (11) reported that 27 (18.4%) of 147 patients treated with PVP or PKP subsequently developed new vertebral fractures, and 66.7% of 27 patients developed new fractures in adjacent vertebrae. In the PKP group of this study, 10 (12.82%) of 78 patients had complications, including cement leakage ($n = 3$), fractured vertebrae recollapse ($n = 2$) and adjacent vertebral fracture ($n = 5$), these incidences are slightly lower than the above-mentioned studies. In addition, Huang et al. (16) reported that 23 patients with osteoporotic thoracolumbar fractures (48.9%) in PKP group had complications, including cement leakage ($n = 10$), fractured vertebrae recollapse ($n = 12$) and reoperation due to refractures ($n = 2$), and the complications in PPSF+KP group were significantly less ($p < 0.05$), including cement leakage ($n = 2$), wound infection ($n = 1$), and recollapse at the final follow-up ($n = 2$). In this study, 3 (20.51%) of 24 patients had complications, including cement leakage ($n = 1$), fractured vertebrae recollapse ($n = 1$) and adjacent segment fracture ($n = 1$), and there was no significant difference in the incidence of each complication between the two groups. The above results may be due to the difference in the numbers of patients between the two groups, leading to a certain degree of statistical bias in the incidence of complications. Therefore, we cannot arbitrarily conclude that there is no difference in complications between the two surgical methods.

This study had several limitations. First, it was designed as a retrospective comparative study, and the sample size was relatively insufficient, especially in patients with PPSF+KP. The difference in the number of patients between the two groups may cause high statistical biases in some data. Second, this study did not study deeply the risk factors that that affected the spinal sagittal balance parameters in both groups. Therefore, future studies may require a prospective randomized controlled study and a longer time to follow up more patients and further analyze the risk factors that affect the spine sagittal balance.

CONCLUSIONS

For elderly patients with single-level thoracolumbar sOVCF, both PPSF+KP and PKP can not only achieve favorable outcomes, but also maintain the spinal sagittal balance well. Compared with PPSF+KP, PKP showed more significant advantages in the early post-operative period due to the simpler process and less trauma during operation. However, in the long-term follow-up,

PPSF+KP showed a better clinical effect and may be better to maintain the spinal sagittal balance than PKP.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

QZ: conceptualization, methodology, investigation, software, and writing—original draft. JZ: methodology, data curation, and investigation. HL: conceptualization, methodology, and writing—original draft. WH: methodology, data curation, and investigation. LD: data curation, validation, and writing—review and editing. XZ: data curation and writing—review and editing. HY: conceptualization, methodology, and writing—review and editing. TL: conceptualization, methodology, validation, writing—review and editing, and funding acquisition. All authors contributed to the article and approved the submitted version.

FUNDING

This work was supported by the National Natural Science Foundation of China (82072476), the Natural Science Foundation of Jiangsu Province (BK20191173), Youth Science and technology project of rejuvenating health through science and education in Suzhou (KJXW2019010), and Bethune special fund for strengthening treatment of pathological spinal fracture (BKJP201702).

ACKNOWLEDGMENTS

Thank you for all the support from the First Affiliated Hospital of Soochow University.

REFERENCES

1. Lamartina C, Berjano P, Petruzzi M, Sinigaglia A, Casero G, Cecchinato R, et al. Criteria to restore the sagittal balance in deformity and degenerative spondylolisthesis. *Eur Spine J*. (2012) 21(Suppl. 1):S27–31. doi: 10.1007/s00586-012-2236-9
2. Lee BH, Park JO, Kim HS, Suk KS, Lee SY, Lee HM, et al. Spinal sagittal balance status affects postoperative actual falls and quality of life after decompression and fusion *in-situ* surgery in patients with lumbar spinal stenosis. *Clin Neurol Neurosurg*. (2016) 148:52–9. doi: 10.1016/j.clineuro.2016.06.016
3. Hikata T, Watanabe K, Fujita N, Iwanami A, Hosogane N, Ishii K, et al. Impact of sagittal spinopelvic alignment for clinical outcome after decompression surgery for lumbar spinal canal stenosis. *Spine J*. (2014) 14:S67. doi: 10.1016/j.spinee.2014.08.175
4. Zhang YL, Shi LT, Tang PF, Sun ZJ, Wang YH. Correlation analysis of osteoporotic vertebral compression fractures and spinal sagittal imbalance. *Orthopade*. (2017) 46:249–55. doi: 10.1007/s00132-016-3359-1
5. Qian J, Qiu Y, Qian BP, Zhu ZZ, Wang B, Yu Y. Compensatory modulation for severe global sagittal imbalance: significance of cervical compensation on quality of life in thoracolumbar kyphosis secondary to ankylosing spondylitis. *Eur Spine J*. (2016) 25:3715–22. doi: 10.1007/s00586-016-4486-4
6. Yang HL, Zhao L, Liu J, Sanford CG Jr, Chen L, Tang T, et al. Changes of pulmonary function for patients with osteoporotic vertebral compression fractures after kyphoplasty. *J Spinal Disord Tech*. (2007) 20:221–5. doi: 10.1097/01.bsd.0000211273.74238.0e
7. Francis RM, Aspray TJ, Hide G, Sutcliffe AM, Wilkinson P. Back pain in osteoporotic vertebral fractures. *Osteoporos Int*. (2008) 19:895–903. doi: 10.1007/s00198-007-0530-x
8. Old JL, Calvert M. Vertebral compression fractures in the elderly. *Am Fam Physician*. (2004) 69:111–6.
9. Majd ME, Farley S, Holt RT. Preliminary outcomes and efficacy of the first 360 consecutive kyphoplasties for the treatment of painful osteoporotic vertebral compression fractures. *Spine J*. (2005) 5:244–55. doi: 10.1016/j.spinee.2004.09.013
10. Lin WC, Lee YC, Lee CH, Kuo YL, Cheng YF, Lui CC, et al. Refractures in cemented vertebrae after percutaneous vertebroplasty: a retrospective analysis. *Eur Spine J*. (2008) 17:592–9. doi: 10.1007/s00586-007-0564-y
11. Rho YJ, Choe WJ, Chun YI. Risk factors predicting the new symptomatic vertebral compression fractures after percutaneous vertebroplasty or kyphoplasty. *Eur Spine J*. (2012) 21:905–11. doi: 10.1007/s00586-011-2099-5
12. Peh WC, Gilula LA, Peck DD. Percutaneous vertebroplasty for severe osteoporotic vertebral body compression fractures. *Radiology*. (2002) 223:121–6. doi: 10.1148/radiol.2231010234
13. Knop C, Fabian HF, Bastian L, Blauth M. Late results of thoracolumbar fractures after posterior instrumentation and transpedicular bone grafting. Spine (2001) 26:88–99. doi: 10.1097/00007632-200101010-00016
14. Sudo H, Ito M, Abumi K, Kotani Y, Takahata M, Hojo Y, et al. One-stage posterior instrumentation surgery for the treatment of osteoporotic vertebral collapse with neurological deficits. *Eur Spine J*. (2010) 19:907–15. doi: 10.1007/s00586-010-1318-9
15. Gu YT, Zhu DH, Liu HF, Zhang F, McGuire R. Minimally invasive pedicle screw fixation combined with percutaneous vertebroplasty for preventing secondary fracture after vertebroplasty. *J Orthop Surg Res*. (2015) 10:31. doi: 10.1186/s13018-015-0172-1
16. Huang D, Ying J, Xu D, Chen J, Zhou L. Comparison of percutaneous kyphoplasty with or without pedicle screw fixation in osteoporotic thoracolumbar vertebral fractures: a retrospective study. *Disease Markers*. (2021) 2021:1–8. doi: 10.1155/2021/4745853
17. Wu J, Xu YQ, Chen HF, Su YY, Zhu M, Zhu CT. Percutaneous kyphoplasty combined with the posterior screw-rod system in treatment of osteoporotic thoracolumbar fractures. *Indian J Orthop*. (2013) 47:230–3. doi: 10.4103/0019-5413.111496
18. Yang H, Liu H, Wang S, Wu K, Meng B, Liu T. Review of percutaneous kyphoplasty in China. *Spine*. (2016) 41(Suppl. 19):B52–8. doi: 10.1097/BRS.0000000000001804
19. Price DD, McGrath PA, Rafii A, Buckingham B. The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. *Pain*. (1983) 17:45–56. doi: 10.1016/0304-3959(83)90126-4
20. Barrey C, Jund J, Perrin G, Roussouly P. Spinopelvic alignment of patients with degenerative spondylolisthesis. *Neurosurgery*. (2007) 61:981–6. doi: 10.1227/01.neu.0000303194.02921.30
21. Nieuwenhuijse MJ, van Erkel AR, Dijkstra PD. Percutaneous vertebroplasty in very severe osteoporotic vertebral compression fractures: feasible and beneficial. *J Vasc Interv Radiol*. (2011) 22:1017–23. doi: 10.1016/j.jvir.2011.02.036
22. Cotten A, Boutry N, Cortet B, Assaker R, Demondion X, Leblond D, et al. Percutaneous vertebroplasty: state of the art. *Radiographics*. (1998) 18:311–20. doi: 10.1148/radiographics.18.2.9536480
23. Lee JH, Lee DO, Lee JH, Lee HS. Comparison of radiological and clinical results of balloon kyphoplasty according to anterior height loss in the osteoporotic vertebral fracture. *Spine J*. (2014) 14:2281–9. doi: 10.1016/j.spinee.2014.01.028
24. Lee JK, Jeong HW, Joo IH, Ko YI, Kang CN. Percutaneous balloon kyphoplasty for the treatment of very severe osteoporotic vertebral compression fractures: a case-control study. *Spine J*. (2018) 18:962–9. doi: 10.1016/j.spinee.2017.10.006

25. Wen Z, Mo X, Zhao S, Lin W, Chen Z, Huang Z, et al. Comparison of percutaneous kyphoplasty and pedicle screw fixation for treatment of thoracolumbar severe osteoporotic vertebral compression fracture with kyphosis. *World Neurosurg.* (2021) 152:e589–96. doi: 10.1016/j.wneu.2021.06.030
26. Leslie-Mazwi T, Deen HG. Repeated fracture of a vertebral body after treatment with balloon kyphoplasty: case illustration. *J Neurosurg Spine.* (2006) 4:270. doi: 10.3171/spi.2006.4.3.270
27. Kim YY, Rhyu KW. Recompression of vertebral body after balloon kyphoplasty for osteoporotic vertebral compression fracture. *Eur Spine J.* (2010) 19:1907–12. doi: 10.1007/s00586-010-1479-6
28. Harrop JS, Prpa B, Reinhardt MK, Lieberman I. Primary and secondary osteoporosis' incidence of subsequent vertebral compression fractures after kyphoplasty. *Spine.* (2004) 29:2120–5. doi: 10.1097/01.brs.0000141176.63158.8e
29. Pflugmacher R, Schroeder RJ, Klostermann CK. Incidence of adjacent vertebral fractures in patients treated with balloon kyphoplasty: two years' prospective follow-up. *Acta Radiol.* (2006) 47:830–40. doi: 10.1080/02841850600854928
30. Sutipornpalangkul W, Zambrana L, Gianakos A, Lane JM. Comparison of sagittal balance between radiofrequency targeted vertebral augmentationand balloon kyphoplasty in treatment of vertebral compression fracture: a retrospective study. *J Med Assoc Thai.* (2016) 99:1025–32.
31. LeHuec J-C, Aunoble S. Pedicle subtraction osteotomy for sagittal imbalance. *Eur Spine J.* (2012) 21:1896–7. doi: 10.1007/s00586-012-2474-x
32. Cao Z, Wang G, Hui W, Liu B, Liu Z, Sun J. Percutaneous kyphoplasty for osteoporotic vertebral compression fractures improves spino-pelvic alignment and global sagittal balance maximally in the thoracolumbar region. *PLoS ONE.* (2020) 15:e0228341. doi: 10.1371/journal.pone.0228341
33. Kanayama M, Oha F, Iwata A, Hashimoto T. Does balloon kyphoplasty improve the global spinal alignment in osteoporotic vertebral fracture? *Int Orthop.* (2015) 39:1137–43. doi: 10.1007/s00264-015-2737-3
34. Friedrich HC, Friedrich HJ, Kneisel P, Drumm J, Pitzen T. Balloon kyphoplasty improves back pain but does not result in a permanent realignment of the thoracolumbar spine. *Cen Eur Neurosurg.* (2011) 72:176–80. doi: 10.1055/s-0031-1284415
35. Lee TO, Jo DJ, Kim SM. Outcome and efficacy of height gain and sagittal alignment after kyphoplasty of osteoporotic vertebral compression fractures. J Korean Neurosurg Soc (2007) 42:271–275. doi: 10.3340/jkns.2007.42.4.271
36. Yokoyama K, Kawanishi M, Yamada M, Tanaka H, Ito Y, Kawabata S, et al. Postoperative change in sagittal balance after Kyphoplasty for the treatment of osteoporotic vertebral compression fracture. *Eur Spine J.* (2015) 24:744–9. doi: 10.1007/s00586-014-3678-z
37. Chongyan W, Zhang X, Li S, Liu J, Shan Z, Wang J, et al. Mechanism of formation of intravertebral clefts in osteoporotic vertebral compression fractures: an *in vitro* biomechanical study. *Spine J.* (2018) 18:2297–301. doi: 10.1016/j.spinee.2018.07.020
38. Borgen TT, Bjornerem A, Solberg LB, Andreasen C, Brunborg C, Stenbro MB, et al. High prevalence of vertebral fractures and low trabecular bone score in patients with fragility fractures: a cross-sectional sub-study of NoFRACT. *Bone.* (2019) 122:14–21. doi: 10.1016/j.bone.2019.02.008
39. Emmanuelle, Chaléat-Valayer, Jean-Marc, Mac-Thiong, Jérôme, Paquet, et al. Sagittal spino-pelvic alignment in chronic low back pain. *Eur Spine J.* (2011) 20 (Suppl. 5):634–40. doi: 10.1007/s00586-011-1931-2
40. Greimel F, Wolkerstorfer S, Sporrer JF, Zeman F, Hoffstetter P, Grifka J, et al. Radiological outcome of postoperative sagittal balance on standing radiographs in comparison to intraoperative radiographs in prone position when performing lumbar spinal fusion. *Arch Orthop Trauma Surg.* (2017) 137:1319–25. doi: 10.1007/s00402-017-2755-2
41. Sung-Soo C, Whan E, Eun-Sang K, Sun-Ho L, Mi K, Chong-Suh L. The impact of sagittal balance on clinical results after posterior interbody fusion for patients with degenerative spondylolisthesis: a Pilot study. *BMC Musculoskel Disord.* (2011) 12:69. doi: 10.1186/1471-2474-12-69
42. Huec J, Faundez A, Dominguez D, Hoffmeyer P, Aunoble S. Evidence showing the relationship between sagittal balance and clinical outcomes in surgical treatment of degenerative spinal diseases: a literature review. *Int Orthop.* (2015) 39:87–95. doi: 10.1007/s00264-014-2516-6
43. Mac-Thiong JM, Berthonnaud E, Dimar JR II, Betz RR, Labelle H. Sagittal alignment of the spine and pelvis during growth. *Spine.* (2004) 29:1642–7. doi: 10.1097/01.BRS.0000132312.78469.7B
44. Boulay C, Tardieu C, Hecquet J, Benaim C, Mouilleseaux B, Marty C, et al. Sagittal alignment of spine and pelvis regulated by pelvic incidence: standard values and prediction of lordosis. *Eur Spine J.* (2006) 15:415–22. doi: 10.1007/s00586-005-0984-5
45. 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) 7:99–103. doi: 10.1007/s005860050038
46. Vaz G, Roussouly P, Berthonnaud E, Dimnet J. Sagittal morphology and equilibrium of pelvis and spine. *Eur Spine J.* (2002) 11:80–7. doi: 10.1007/s005860000224
47. Diebo BG, Varghese JJ, Lafage R, Schwab FJ, Lafage V. Sagittal alignment of the spine: what do you need to know? *J Biol Chem.* (2015) 139:295–301. doi: 10.1016/j.clineuro.2015.10.024
48. Schwab F, Patel A, Ungar B, Farcy JP, Lafage V. Adult spinal deformity-postoperative standing imbalance: how much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery. *Spine.* (2010) 35:2224–31. doi: 10.1097/BRS.0b013e3181ee6bd4
49. Kim YY, Park CG, Rhyu KW. Recompression of vertebral bodies after balloon kyphoplasty for vertebral compression fractures - preliminary report. *J Korean Soc Spine Surg.* (2009) 16. doi: 10.4184/jkss.2009.16.2.89
50. Lavelle WF, Cheney R. Recurrent fracture after vertebral kyphoplasty. *Spine J.* (2006) 6:488–93. doi: 10.1016/j.spinee.2005.10.013

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.

frontiers in Surgery

ORIGINAL RESEARCH
published: 14 March 2022
doi: 10.3389/fsurg.2022.849096

Finite Element Analysis of Spinal Cord Stress in a Single Segment Cervical Spondylotic Myelopathy

Shaofeng Yang[1†], *Luqiang Qu*[1,2†], *Lijie Yuan*[2], *Junjie Niu*[1], *Dawei Song*[1], *Huilin Yang*[1] *and Jun Zou*[1*]

[1] *Department of Orthopaedic Surgery, The First Affiliated Hospital of Soochow University, Suzhou, China,* [2] *Department of Orthopaedic Surgery, Taicang Affiliated Hospital of Soochow University, Taicang, China*

OPEN ACCESS

Edited by:
Hengxing Zhou,
Tianjin Medical University General Hospital, China

Reviewed by:
Mohammad Nikkhoo,
Islamic Azad University, Iran
Lin Cong,
The First Affiliated Hospital of China Medical University, China
Peng Yin,
Capital Medical University, China
Ai-Min Wu,
Wenzhou Medical University, China

***Correspondence:**
Jun Zou
jzou@suda.edu.cn

[†] *These authors have contributed equally to this work*

Specialty section:
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

Received: *05 January 2022*
Accepted: *16 February 2022*
Published: *14 March 2022*

Citation:
Yang S, Qu L, Yuan L, Niu J, Song D, Yang H and Zou J (2022) Finite Element Analysis of Spinal Cord Stress in a Single Segment Cervical Spondylotic Myelopathy. Front. Surg. 9:849096. doi: 10.3389/fsurg.2022.849096

Background: Spinal cord ischemia is largely caused by cervical spondylotic myelopathy (CSM), which has a corresponding biomechanical basis. Finite element analysis of spinal cord stress in diseased segments of CSM was performed to provide a biomechanical basis for the pathogenesis of CSM.

Methods: A single segment (C4-5) in a patient with CSM was selected for mechanical simulation of three-dimensional (3D) computed tomography scanning, and a 3D finite element model of the cervical vertebra was constructed. Based on the patient's age, sex, height, weight, and other parameters, a finite element analysis model of an individual with healthy cervical vertebrae in our hospital was selected as the control to compare the stress changes between the patient and control groups in the analysis of the cervical vertebrae under anterior flexion, posterior extension, lateral flexion, and rotating load in the diseased spinal cord segment.

Results: In the CSM patient, the diseased segment was C4-5. Under loading conditions of forward flexion, posterior extension, left flexion, right flexion, left rotation, and right rotation, the maximum stress on the spinal cord in the control group was 0.0044, 0.0031, 0.00017, 0.00014, 0.0011, and 0.001 MPa, respectively, whereas those in the spinal cord in the CSM group were 0.039, 0.024, 0.02, 0.02, 0.0194, and 0.0196 MPa, respectively.

Conclusion: The maximum stress on the diseased segments of the spinal cord in the CSM group was higher than that in the control group, which contributed to verifying the imaging parameters associated with spinal cord compression stress.

Keywords: cervical spondylotic myelopathy, finite element analysis, vertebral canal volume, maximum stress, spinal cord compression stress

BACKGROUND

Cervical spondylotic myelopathy (CSM) is caused by spinal cord compression in the spinal canal due to degeneration of the cervical vertebrae, intervertebral discs, and ligaments (1, 2). Its incidence is high, and the early symptoms are often hidden. The symptoms appear when most cases progress to the middle and late stages, and irreversible damage to the spinal cord occurs

(3, 4). The pathophysiological mechanism of CSM mainly includes the following three aspects: anatomic abnormalities, kinetic factors, and spinal cord ischemia. Anatomical abnormalities and kinetic factors are mutually causal, and spinal cord ischemia is largely secondary to the above two factors, indicating that spinal cord injury caused by CSM has a corresponding biomechanical basis (5). In general, the methods of spinal biomechanics research mainly include experimental biomechanics and theoretical biomechanics. Experimental biomechanics mainly refers to the use of various models for biomechanical research, including experimental animals, cadaver specimens, and physical materials, but these models have certain limitations. Theoretical biomechanics refers to the biomechanical research carried out through theoretical calculations. With the development of computer science and technology, finite element calculations have been gradually applied widely in the biomechanical research of orthopedics. Recent studies (6–8) suggest that the fusion of three-dimensional (3D) finite element models and biomechanical models based on images can simulate the stress state of joints more accurately. Brekelmans et al. (9) used this method to preliminarily analyze the influence of vertebral body material properties and geometry on the stress distribution of intervertebral discs. In this study, a 3D finite element model of a single-segment CSM was constructed based on normal computed tomography (CT) scan images, and the stress changes of the diseased segments (C4-5) of the spinal cord under daily anterior flexion, posterior extension, lateral flexion, and rotating load were investigated to explore the pathogenesis of CSM.

METHODS

This study was approved by the Medical Ethics Committee of the First Affiliated Hospital of Soochow University. Selection of subjects: A female participant with typical symptoms of CSM (Japanese Orthopedic Association score of 10) was randomly selected from the clinically confirmed cases of CSM at the First Affiliated Hospital of Soochow University. After participant selection, the purpose of this study, implementation method, risks, and benefits were explained, and informed consent was obtained. Based on the age, sex, height, and weight of the patient, an existing healthy cervical spine finite element analysis model of our team was selected as the control.

Establishment of Cervical (C4-5) Finite Element Model

To materialize two-dimensional CT data, DICOM files need to be converted and processed. At present, CT, magnetic resonance imaging (MRI), and other medical image workstations adopt volumetric 3D reconstruction, which cannot be directly used in engineering processing. Mimics software, developed by Materialize, Belgium, is a tool for the segmentation and processing of CT and MRI images. DICOM data were imported into Mimics software, and the view direction was set. The sagittal plane, coronal plane, and cross section were defined, and multiple DICOM data were sequentially discharged. At the interface, grayscale images, including bone tissue and background, were obtained. First, the image was preprocessed to improve its resolution and smoothness. Mimics software was used to perform regular treatment of the marrow cavity. According to the grayscale values of tissues of different densities, the corresponding thresholding interval was set by using the "Thresholding" command to extract the image data of bone-removing tissues. Using Boolean operation, models including the peri-osseous facet joints and intervertebral discs were obtained. At this point, there were many artifacts, holes, and noise in the model. The self-extraction function and erasure and filling function of the software were used to improve the quality of the tissue images layer by layer. Rough models of bone and soft tissue were obtained and saved in the STL file format. Geomagics exported the 3D model data in the STP format and imported it to PROE5.0 for model assembly and to manipulate the parts or features that needed to be processed.

TABLE 1 | Material properties of finite element analysis models.

Component	Young modulus (MPa)	Poisson ratio
Cortical bone	12,000	0.3
Cancellous bone	100	0.2
Bony end-plate	24	0.25
Pedicle	3,500	0.25
Small joints	15	0.45
Gray matter of spinal cord	0.656	0.499
ALL	20	0.3
PLL	70	0.3
LF	50	0.3
Soft backbone	142	0.45
Nucleus pulposus	1	0.499
Fiber ring	4.2	0.45
White matter of spinal cord	0.277	0.499

ALL, anterior longitudinal ligament; PLL, posterior longitudinal ligament; LF, ligamentum flavum.

The material properties (10) used in recent studies on the CSM are shown in **Table 1**. The ROM of the intact model at C4/5 was 7.56° in flexion, 6.21° in extension, 5.81° in lateral bending, and 4.51° in axial rotation (11). Based on the relaxed and analytical model of the cervical spine, the stress distribution diagrams of the patients with CSM and control were compared, and the stress change and maximum stress difference of the spinal cord at the C4-5 segments were compared between the two cervical vertebrae under anterior flexion, posterior extension, lateral flexion, and rotating load.

RESULTS

The C4-5 finite element models of the control and patients with CSM are shown in **Figures 1A,B**, respectively. The von Mises stress in the control and CSM patients was extracted from the spinal cord at the corresponding position of the disc under the

Abbreviations: CSM, cervical spondylotic myelopathy; CT, computed tomography; MRI, magnetic resonance imaging.

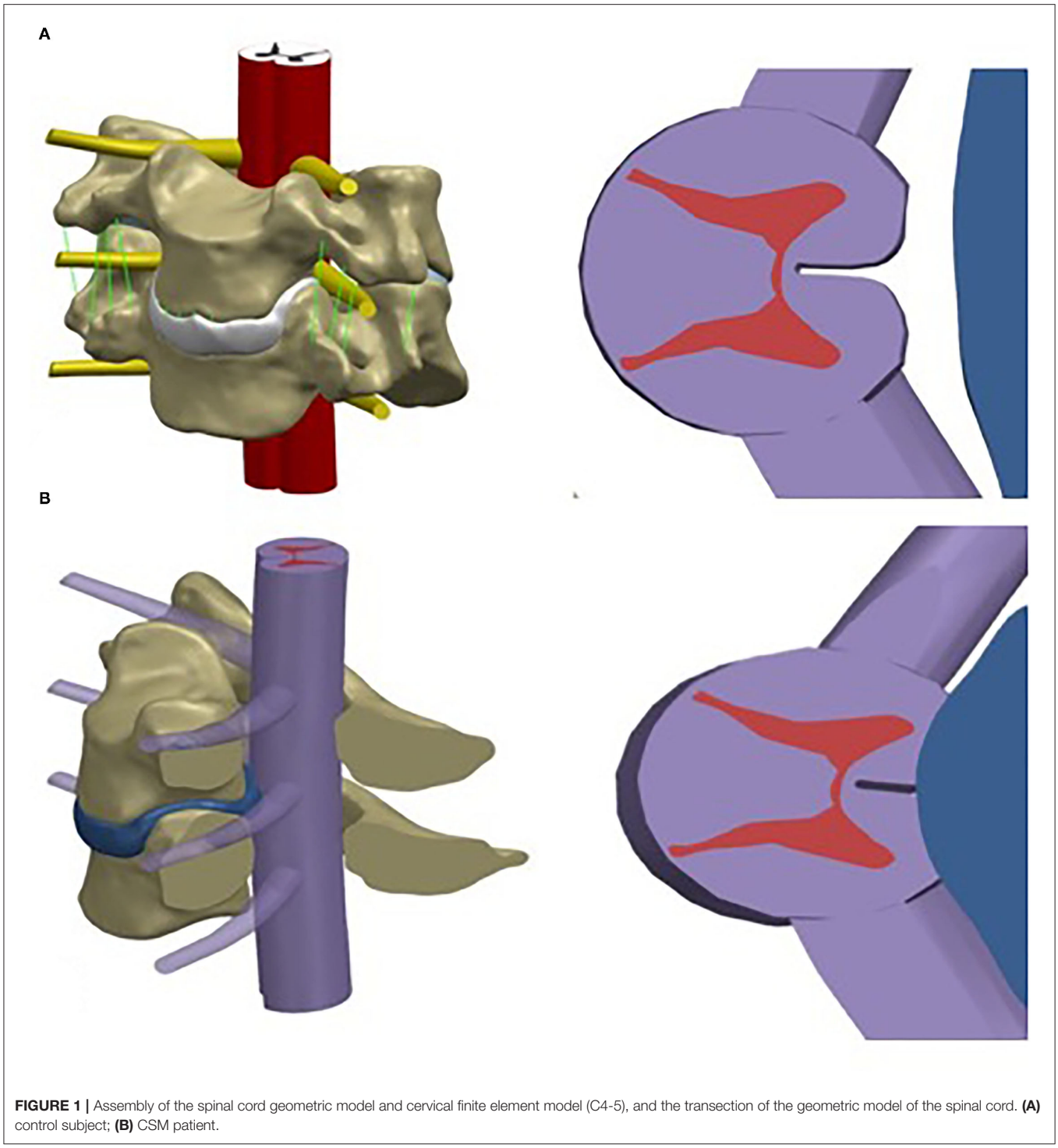


FIGURE 1 | Assembly of the spinal cord geometric model and cervical finite element model (C4-5), and the transection of the geometric model of the spinal cord. **(A)** control subject; **(B)** CSM patient.

corresponding load, and the stress distribution nephograms are shown in **Figures 2**, **3**. Under the loading conditions of forward flexion (**Figure 2A**), posterior extension (**Figure 2B**), left flexion (**Figure 2C**), right flexion (**Figure 2D**), left rotation (**Figure 2E**), and right rotation (**Figure 2F**), the maximum stress of the spinal cord in the control group was 0.0044, 0.0031, 0.00017, 0.00014, 0.0011, and 0.001 MPa, respectively, while the maximum stress of the spinal cord in the CSM group was 0.039 (**Figure 3A**), 0.024 (**Figure 3B**), 0.02 (**Figure 3C**), 0.02 (**Figure 3D**), 0.0194 (**Figure 3E**), and 0.0196 MPa (**Figure 3F**), respectively.

DISCUSSION

CSM is a complex disease caused by a combination of factors, including congenital spinal stenosis, static compression of the spinal cord due to degenerative changes, and dynamic

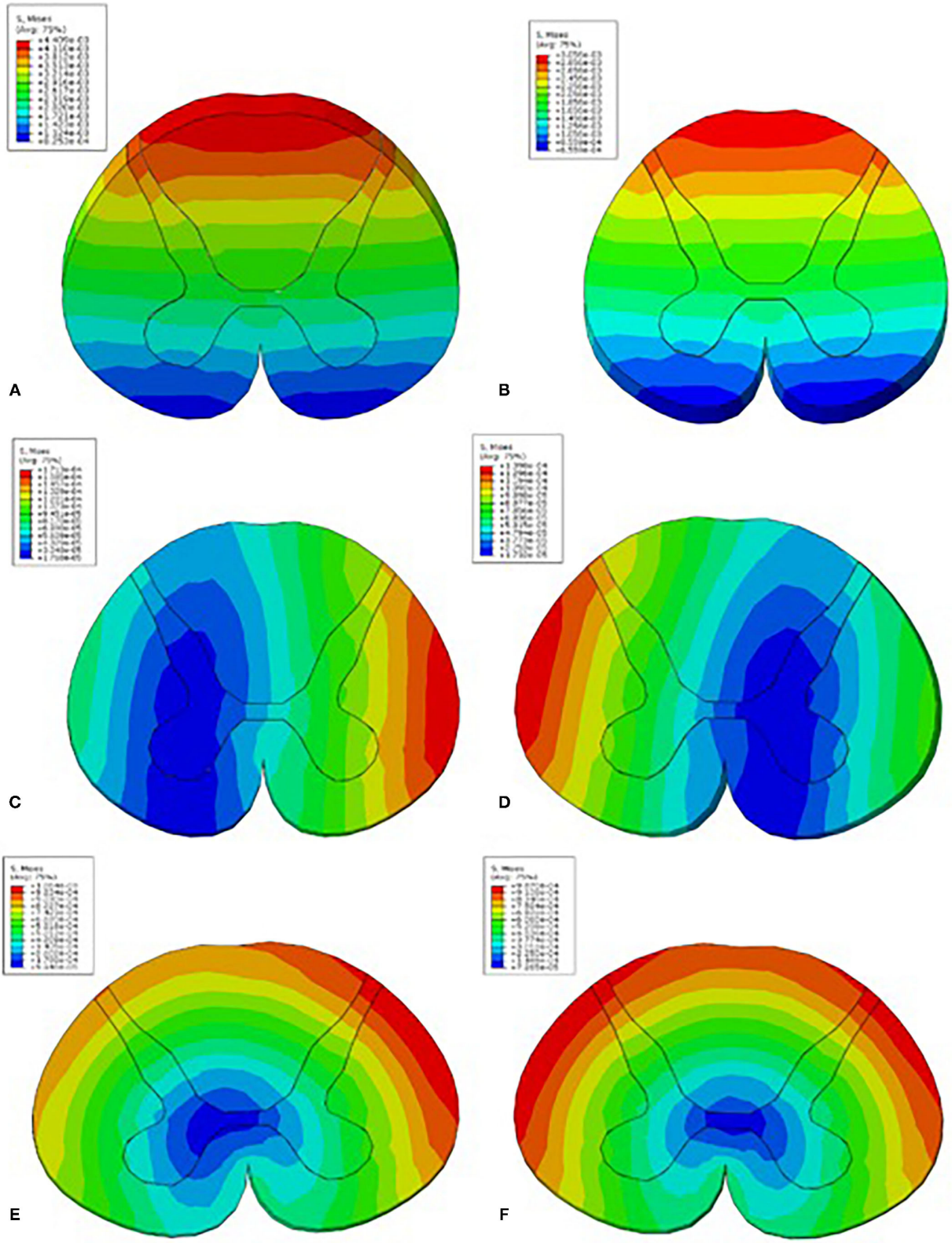


FIGURE 2 | The Mises stress in the control patient under loading conditions in the C4-5 segment of forward flexion **(A)**, posterior extension **(B)**, left flexion **(C)**, right flexion **(D)**, left rotation **(E)**, and right rotation **(F)**.

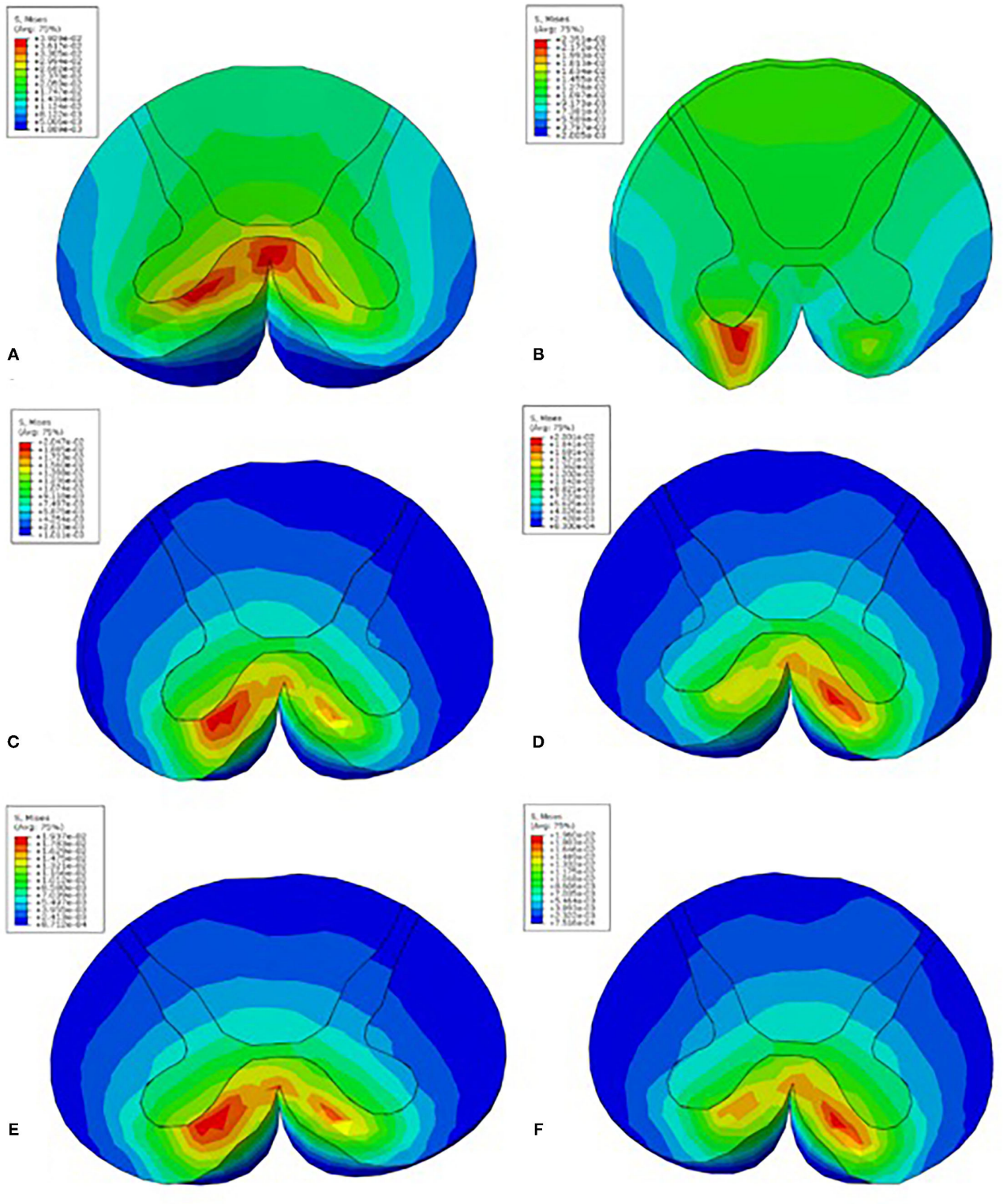


FIGURE 3 | The Mises stress in the CSM patient under loading conditions in the C4-5 segment of forward flexion **(A)**, posterior extension **(B)**, left flexion **(C)**, right flexion **(D)**, left rotation **(E)**, and right rotation **(F)**.

impingement secondary to micromotion of the spinal column. It represents the most common cause of dysfunction in people over the age of 55 (12) and is found in 10–15% of all patients with cervical spondylosis. It can present in many ways and is typically characterized by neurological dysfunction, matching the pattern of spinal cord compression seen on radiography. Modern imaging modalities, especially MRI, with excellent soft tissue contrast, greatly facilitate the diagnosis and surgical planning of CSM (13). However, it generally provides a neutral supine evaluation and does not account for dynamic pathophysiological factors that may be present only during postural extension (14, 15).

In general, the methods of spinal biomechanics research mainly include experimental biomechanics and theoretical biomechanics. Experimental biomechanics mainly refers to the use of various models for biomechanical research, including experimental animals, cadaver specimens, and physical materials, but these models have certain limitations. Theoretical biomechanics refers to the biomechanical research carried out through theoretical calculations. With the development of computer science and technology, finite element calculations represented by it have been gradually applied widely in biomechanical research of orthopedics, especially the spine, as a supplement to clinical research and cadaver experimental models *in vitro* (16). In biomechanical evaluation, the load modes most commonly used and closest to physiological motion are generally applied in flexion, extension, lateral flexion, and rotation. Therefore, the experimental results of the model are often compared with those of previous 3D finite element models. After modeling, a certain amount of torque value is usually applied to the model for pre-loading, and the stress of the model under loading conditions such as forward bending, backward extension, lateral bending, and rotation is observed.

The cervical biomechanical behavior follows the non-linear distribution of each component; hence, previous studies (17, 18) focused on computer modeling and analysis of discs. This study focused on the vertebral body, intervertebral discs, ligaments, and spinal cord during cervical spine non-linear stress conditions and the overall analysis of the cervical spine and changes in soft tissue morphology of the neck in patients with CSM and control. The stress condition after the retroflexion movement was stereologically reproduced. In this study, the control and CSM patients were subjected to the same external force. Due to the normal structure and function of the healthy cervical vertebra, the curvature of the cervical vertebra increases when an external force is applied, that is, the cervical vertebra is displaced. At this point, the cervical vertebrae of the control subjects in our study could withstand greater stress without injury. However, due to changes in the physiological curvature of the cervical vertebra in patients with CSM, the mechanics of the main components of the cervical vertebrae were unbalanced, the stress that the neck could bear was reduced, and the range of motion of the cervical vertebra was reduced.

This study had some limitations. Although special attention and analysis are given during model development, finite element analysis has limitations, similar to cadaver studies and other published finite element studies. Simple elastic model for analysis in this study. Other hyperelastic or hyperporoelastic models can be considered in future studies. Caution should be used in interpreting the results of this study, as the complete finite element analysis was based on a single scan of a normal male. The purpose of computational simulations is to provide trends rather than actual data. Comparisons in the finite element analysis were not statistically significant. It is just a biomechanical trend analysis and comparison, similar to many finite element analysis studies. In our finite element study, the neck muscles were missing. Muscles mainly control the range of motion of the cervical spine. The loss of neck muscles may have an impact on the biomechanical values of the limited units. In addition, the von Mises stress is a simple stress parameter, which has some limitations.

CONCLUSION

The maximum stress on the diseased segments of the spinal cord in the CSM group was higher than that in the control group, which verified the above imaging parameters associated with spinal cord compression stress.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

This clinical study was approved by the Ethics Committee of the First Affiliated Hospital of Soochow University, and written informed consent was obtained from all participants.

AUTHOR CONTRIBUTIONS

SY and LQ were responsible for designing and drafting the manuscript. LY, JN, and DS performed the data collection and statistical analyses. HY and JZ critically revised the manuscript. All authors read and approved the final manuscript.

REFERENCES

1. Machino M, Yukawa Y, Imagama S, Ito K, Katayama Y, Matsumoto T, et al. Age-related and degenerative changes in the osseous anatomy, alignment, and range of motion of the cervical spine. *Spine.* (2016) 41:476–82. doi: 10.1097/BRS.0000000000001237
2. Jalai CM, Worley N, Marascalchi BJ, Challier V, Vira S, Yang S, et al. The impact of advanced age on peri-operative outcomes in the surgical treatment of cervical spondylotic myelopathy: a nationwide study between 2001 and 2010. *Spine.* (2016) 41:E139. doi: 10.1097/BRS.0000000000001181
3. Kumaresan S, Yoganandan N, Pintar FA, Maiman DJ, Goel VK. Contribution of disc degeneration to osteophyte formation in the

cervical spine: a biomechanical investigation. *J Orthop Res.* (2001) 19:977–84. doi: 10.1016/S0736-0266(01)00010-9
4. Kadanka Z, Bednarík J, Novotný O, Urbánek I, Dušek L. Cervical spondylotic myelopathy: conservative versus surgical treatment after 10 years. *Eur Spine J.* (2011) 20:1533–8. doi: 10.1007/s00586-011-1811-9
5. Young WF. Cervical spondylotic myelopathy: a common cause of spinal cord dysfunction in older persons. *Am Family Physic.* (2000) 62:1064–70. doi: 10.1016/S0095-4543(05)70190-1
6. Dagneaux L, Allal R, Pithioux M, Chabrand P, Ollivier M, Argenson JN. Femoral malrotation from diaphyseal fractures results in changes in patellofemoral alignment and higher patellofemoral stress from a finite element model study. *Knee.* (2018) 25:807–13. doi: 10.1016/j.knee.2018.06.008
7. TarniŢă D, Calafeteanu DM, Geonea ID, Petcu A, TarniŢă DN. Effects of malalignment angle on the contact stress of knee prosthesis components, using finite element method. *Rom J Morphol Embryol.* (2017) 58:831–6. doi: 10.1016/s0268-0033(01)00109-7
8. Kang KT, Son J, Kwon SK, Kwon OR, Koh YG. Preservation of femoral and tibial coronal alignment to improve biomechanical effects of medial unicompartment knee arthroplasty: computational study. *Biomed Mater Eng.* (2018) 29:651–64. doi: 10.3233/BME-181015
9. Brekelmans WA, Poort HW, Slooff TJ. A new method to analyse the mechanical behaviour of skeletal parts. *Acta Orthop Scand.* (1972) 43:301–17. doi: 10.3109/17453677208998949
10. Liu Y, Li N, Wei W, Deng Y, Hu Y, Ye B, et al. Prognostic value of lordosis decrease in radiographic adjacent segment pathology after anterior cervical corpectomy and fusion. *Sci Rep.* (2017) 7:14414. doi: 10.1038/s41598-017-14300-4
11. Li Z, Liu H, Yang M, Zhang W. A biomechanical analysis of four anterior cervical techniques to treating multilevel cervical spondylotic myelopathy: a finite element study. *BMC Musculoskelet Disord.* (2021) 22:278–90. doi: 10.1186/s12891-021-04150-7
12. Bernhardt M, Hynes RA, Blume HW, White AA 3rd. Cervical spondylotic myelopathy. *Am J Bone Joint Surg.* (1993) 75:119–28. doi: 10.2106/00004623-199301000-00016
13. Dvorák J, Panjabi MM, Grob D, Novotny JE, Antinnes JA. Clinical validation of functional flexion/extension radiographs of the cervical spine. *Spine.* (1993) 18:120–7. doi: 10.1097/00007632-199301000-00018
14. Stein J. Failure of magnetic resonance imaging to reveal the cause of a progressive cervical myelopathy related to postoperative spinal deformity: a case report. *Am J Phys Med Rehabil.* (1997) 76:73–5. doi: 10.1097/00002060-199701000-00016
15. Hayashi T, Wang JC, Suzuki A, Takahashi S, Scott TP, Phan K, et al. Risk factors for missed dynamic canal stenosis in the cervical spine. *Spine.* (2014) 39:812–9. doi: 10.1097/BRS.0000000000000289
16. Panjabi MM. Cervical spine models for biomechanical research. *Spine.* (1998) 23:2680–700. doi: 10.1097/00007632-199812150-00008
17. Arun MW, Yoganandan N, Stemper BD, Zheng M, Masoudi A, Snyder B. Sensitivity and stability analysis of a nonlinear material model of cervical intervertebral disc under cyclic loads using the finite element method. *Biomed Sci Instrum.* (2014) 50:19–30. doi: 10.1007/s00586-019-06113-y
18. Wu LP, Huang YQ, Manas D, Chen YY, Fan JH, Mo HG. Real-time monitoring of stresses and displacements in cervical nuclei pulposi during cervical spine manipulation: a finite element model analysis. *J Manipulative Physiol Ther.* (2014) 37:561–8. doi: 10.1016/j.jmpt.2014.05.007

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: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers in Surgery

SYSTEMATIC REVIEW
published: 14 March 2022
doi: 10.3389/fsurg.2022.829469

Surgical Treatments for Lumbar Spine Diseases (TLIF vs. Other Surgical Techniques): A Systematic Review and Meta-Analysis

Kanthika Wasinpongwanich[1,2†], *Tanawin Nopsopon*[3†] *and Krit Pongpirul*[2,3,4*†]

[1] Department of Orthopedics, Faculty of Medicine, Suranaree University of Technology, Nakhon Ratchasima, Thailand, [2] Bumrungrad International Hospital, Bangkok, Thailand, [3] Department of Preventive and Social Medicine, Faculty of Medicine, Chulalongkorn University, Bangkok, Thailand, [4] Department of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, United States

Objective: The purpose of this study is to compare fusion rate, clinical outcomes, complications among transforaminal lumbar interbody fusion (TLIF), and other techniques for lumbar spine diseases.

Design: This is a systematic review and meta-analysis.

Data Sources: PubMed, EMBASE, Scopus, Web of Science, and CENTRAL databases were searched from January 2013 through December 2019.

Eligibility Criteria for Selecting Studies: Randomized controlled trials (RCTs) that compare lumbar interbody fusion with posterolateral fusion (PLF) and/or other lumbar interbody fusion were included for the review.

Data Extraction and Synthesis: Two independent reviewers extracted relevant data and assessed the risk of bias. Meta-analysis was performed using a random-effects model. Pooled risk ratio (RR) or mean difference (MD) with a 95% confidence interval of fusion rate, clinical outcomes, and complications in TLIF and other techniques for lumbar spinal diseases.

Results: Of 3,682 potential studies, 15 RCTs (915 patients) were included in the meta-analysis. Compared to other surgical techniques, TLIF had slightly lower fusion rate [RR = 0.84 (95% CI = 0.72–0.97), $p = 0.02$, $I^2 = 0.0\%$] at 1-year follow-up whereas there was no difference on fusion rate at 2-year follow-up [RR = 1.06 (95% CI = 0.96–1.18), $p = 0.27$, $I^2 = 69.0\%$]. The estimated RR of total adverse events [RR = 0.90 (95% CI = 0.59–1.38), $p = 0.63$, $I^2 = 0.0\%$] was similar to no fusion, PLF, PLIF, and XLIF groups, and revision rate [RR = 0.78 (95% CI = 0.34–1.79), $p = 0.56$, $I^2 = 39.0\%$] was similar to PLF and XLIF groups. TLIF had approximately half an hour more operative time than other techniques (no fusion, ALIF, PLF, PLIF, XLIF) [MD = 31.88 (95% CI = 5.33–58.44), $p = 0.02$, $I^2 = 92.0\%$]. There was no significant difference

OPEN ACCESS

Edited by:
Hengxing Zhou,
Tianjin Medical University General Hospital, China

Reviewed by:
Reuben C. Soh,
Singapore General Hospital, Singapore
Hongli Wang,
Fudan University, China
Vadim Byvaltsev,
Irkutsk State Medical University, Russia

***Correspondence:**
Krit Pongpirul
doctorkrit@gmail.com

†ORCID:
Kanthika Wasinpongwanich
orcid.org/0000-0002-2649-2846
Tanawin Nopsopon
orcid.org/0000-0003-0428-973X
Krit Pongpirul
orcid.org/0000-0003-3818-9761

Specialty section:
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

Received: *05 December 2021*
Accepted: *11 February 2022*
Published: *14 March 2022*

Citation:
Wasinpongwanich K, Nopsopon T and Pongpirul K (2022) Surgical Treatments for Lumbar Spine Diseases (TLIF vs. Other Surgical Techniques): A Systematic Review and Meta-Analysis. Front. Surg. 9:829469. doi: 10.3389/fsurg.2022.829469

between TLIF and other techniques in terms of blood loss (no fusion, PLIF, PLF) and clinical outcomes (PLF).

Conclusions: Besides fusion rate at 1-year follow-up and operative time, TLIF has a similar fusion rate, clinical outcomes, parameters concerning operation and complications to no fusion, PLF, and other interbody fusion (PLIF, ALIF, XLIF).

Systematic Review Registration: https://www.crd.york.ac.uk/prospero/, identifier: CRD42020186858.

Keywords: transforaminal lumbar interbody fusion, lumbar disease, meta-analysis, spondylolisthesis, spine fusion surgery

INTRODUCTION

Surgical treatment is mandatory in some patients with lumbar spine diseases. Whereas, cases without clinical or radiographic instability require only decompression, most lumbar spine diseases with instability especially the degenerative condition further proceed to spinal arthrodesis. The purpose of the treatment is to achieve solid fusion, correction of deformity, indirect nerve decompression, and stabilization. To obtain spine fusion, many operative techniques have been developed with different fusion rates and clinical results. The spinal fusion procedures could be categorized into posterior fusion (PF), posterolateral fusion (PLF), posterior lumbar interbody fusion (PLIF), transforaminal lumbar interbody fusion (TLIF), anterior lumbar interbody fusion (ALIF), extreme lateral interbody fusion (XLIF), the so-called lateral lumbar interbody fusion (LLIF), and oblique lumbar interbody fusion (OLIF). Total disc replacement (TDR) is an alternative option for patients to preserve spinal mobility.

Cloward et al. first described PLIF in 1952 (1) whereas Harm and Rollinger introduced TLIF three decades later (2). In early 2002, the minimally invasive surgical (MIS) approach was promoted to TLIF by Foley and Lefkowitz to improve peri–post-operative morbidity and clinical results (3). ALIF has a long history in the tuberculous spine; however, the technique was adapted to other lumbar spine diseases (4). Ozgur et al. describe a novel spine procedure called the XLIF in 2006 (5).

Several systematic reviews compared either MIS-TLIF or open TLIF with other fusion techniques, for example, MIS vs. open TLIF/PLIF (6), TLIF vs. ALIF (7), MIS-TLIF vs. LLIF (8), TLIF vs. PLIF (9), and TLIF vs. PLF (10). The studies were conducted from 2014 to 2020 (6–8, 10–13). Most of them compared only one or two techniques with TLIF for lumbar spine diseases (6–13). Half of them concluded that the level of evidence in their study was low and need more randomized controlled trials (RCTs) (6–8, 10, 14). The comparison of fusion rates, clinical outcomes, and complications among operative techniques for lumbar spine diseases has been inconclusive.

This systematic review and meta-analysis aimed to offer results based on fusion rate, clinical outcomes (VAS back and leg pain, ODI), parameters concerning operation and complications between TLIF, decompression alone (no fusion), PLF, and other interbody fusion (PLIF, ALIF, and XLIF).

METHODS

This study was conducted following the recommendations of the Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA) statement. We prospectively registered the systematic review with PROSPERO International Prospective Register of Ongoing Systematic Reviews (registration number: CRD42020186858).

Search Strategy

The PubMed, EMBASE, Scopus, Web of Science, and CENTRAL databases were searched for studies published between January 2010 and January 2019. The electronic databases were searched up to February 13, 2020. The reproducible search strategy was presented in detail in the **Supplementary Material**. Besides, the reference lists of included articles were searched, as well as related citations from other journals *via* Google Scholar.

Study Selection

Only RCTs that compare lumbar interbody fusion with PLF and/or other lumbar interbody fusion were anticipated in this review. Inclusion criteria were established as follows: (1) the studies with a population of patients aged more than 18 years (2) RCT investigating lumbar spine disease treated with any lumbar interbody fusion or PLF or no fusion, (3) the study included at least one outcome (fusion rate, disability and pain or complications, operative time, blood loss, and hospital length of stay). Exclusion criteria were as follows: (1) biomechanical and cadaveric studies, (2) paper that is not in English, (3) duplicated studies.

The title and abstracts of each study were independently reviewed by two authors (KW and TN) to assess for inclusion in the meta-analysis. For studies that meet the inclusion criteria, two reviewers (KW and TN) independently reviewed the full manuscripts. Discrepancies between the two reviewers were resolved by discussion until reached consensus among the authors. In accordance with PRISMA guidelines, the process is presented in a flow chart (15) (**Figure 1**).

Data Extraction

The following data items were independently extracted by two authors (KW and TN) from the included studies; study

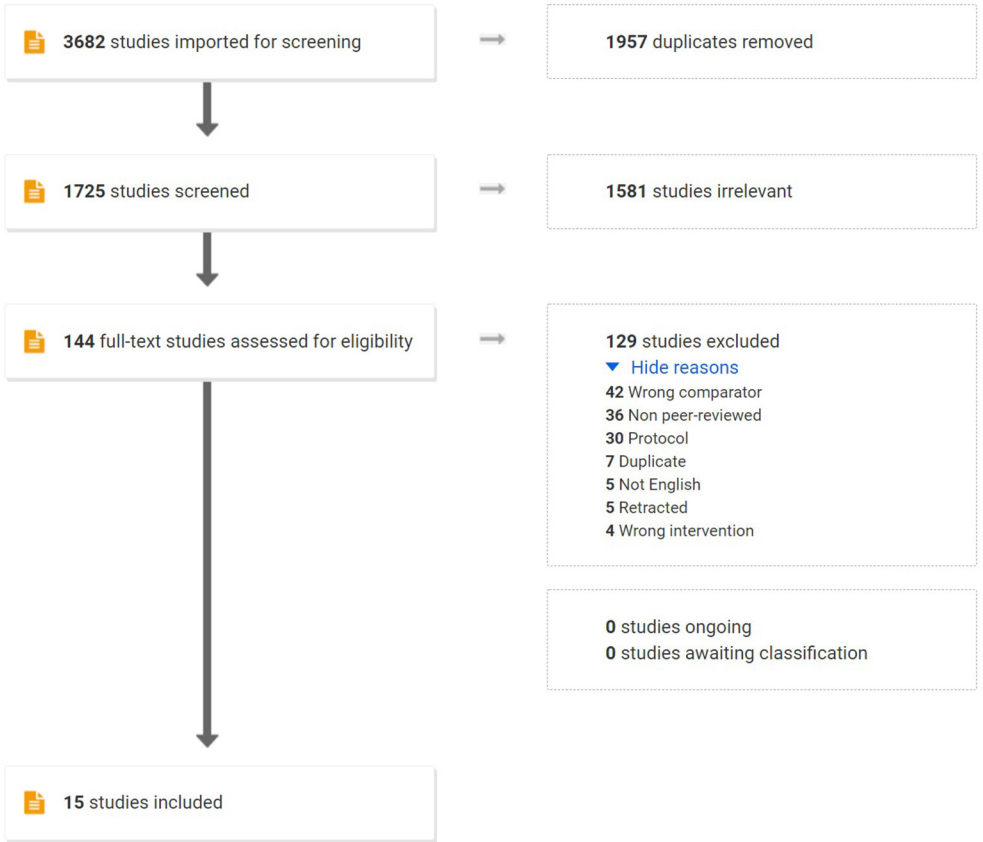


FIGURE 1 | Flowchart of this systematic review with meta-analysis of prospective studies. RCTs, randomized controlled trials.

design (author, year, and country), study population (number of included patients, age, and indication for surgery), visual analog score (VAS) for back and leg pain, Oswestry Disability Index (ODI), and parameters concerning operation (operative time, length of hospital stay, blood loss, revision) complications (total adverse events, infection, dural tear, etc.). Discrepancies were resolved by consensus.

Quality Assessment

The authors worked independently to assess the risk of bias in the included trials using the Cochrane Risk of Bias tool 2.0 for an RCT study (16). We assessed the randomization process, deviations from intended intervention, missing outcome data, measurement of the outcome, and selection of the reported result. We assigned each domain as a low risk of bias, some concerns, and a high risk of bias. We contacted the authors if there was not enough information to assess. If the trial authors did not respond within 14 days, we conducted the assessment using available data. We resolved the disagreement through discussion. We presented our risk of bias assessment in **Figures 2**, **3**.

Statistical Analysis

The primary outcome was the fusion rate. The clinical outcomes measured were the mean difference for VAS back and leg pain, Oswestry Disability Index (ODI) score, and parameters concerning operation (operative time, blood loss, and length of hospital stay) with an associated 95% CI. Fusion rate, total adverse events, infection rate, revision rate, and dural tear were reported as the risk ratio (RR) with 95% CI. The results of the studies were included in the meta-analysis and presented in a forest plot, which also showed statistical powers, confidence intervals, and heterogeneity. The variability within-a study and between studies was assessed by an I^2 estimate of heterogeneity. We regarded the level of heterogeneity for I^2 statistics as defined in Chapter 9 of the Cochrane Handbook for Systematic Reviews of Interventions: 0–40% might not be important; 30–60% may represent moderate heterogeneity; 50–90% may represent substantial heterogeneity; and 75–100% considerable heterogeneity. The random effects meta-analysis by DerSimonian and Laird method was used as clinical, methodological, and statistical heterogeneity encountered. Prespecified subgroup analyses by the type of comparators were performed. We assessed publication bias by computing each study effect size against standard error and plotted it as a funnel plot to assess asymmetry visually. The significant asymmetry indicated the possibility of publication bias or heterogeneity. The meta-analysis was performed using Revman 5.3 (Cochrane Collaboration, Oxford, UK).

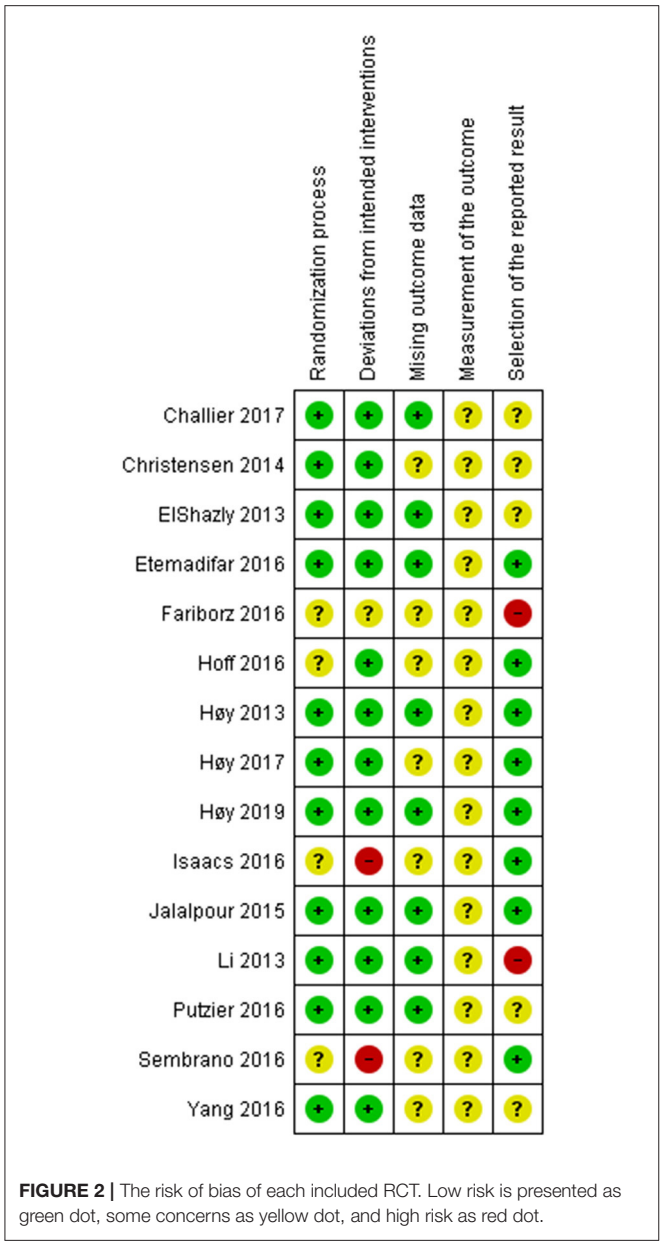


FIGURE 2 | The risk of bias of each included RCT. Low risk is presented as green dot, some concerns as yellow dot, and high risk as red dot.

Patient and Public Involvement

It was not possible to involve patients or the public in the design, conduct, reporting, and dissemination plan of this systematic review and meta-analysis.

RESULTS

Systematic Review

A systematic search identified 3,682 potential English articles, among them 1,957 were removed due to duplication. Two reviewers assessed the title and abstracts of 1,725 studies which 144 manuscripts remained for full-text assessment. Eventually, 18 RCTs were met the inclusion criteria. A number of 2 RCTs were considered the same population of the TLIF group; therefore, one study was excluded from the analysis. The studies that did not report the variation were excluded. A PRISMA diagram is shown in **Figure 1**.

There were 15 RCTs included with 915 patients (470 TLIF, 258 PLF, 87 PLIF, 26 ALIF, 29 XLIF, and 45 no fusion) (17–31). The TLIF group in the 2 studies was in addition to PLF. Publication years ranged from 2013 to 2019. Three studies reported outcomes at 1-year follow-up whereas the other reported at least 2-year follow-up. Study characteristics are provided in **Table 1**.

Quality Assessment

For the risk of bias assessment, the included RCTs had a relatively high percentage of low risk in the randomization process and deviations from intended intervention domains. All included RCTs had some concerns risk of bias in the measurement of the outcome. There was some high risk of bias in deviations from intended interventions and selection of the reported result domains. Detailed risk-of-bias assessment for included RCTs is provided in **Figure 2**. A summary of the percentages of RCTs which were at low, some concerns, and high risk for each risk of bias domain was presented in **Supplementary File 1**. The funnel plots showed no significant asymmetry which highlighted no evidence of publication bias on the fusion rate, total adverse events, and revision rate (**Supplementary File 1**).

Meta-Analysis

A total of 15 included studies were included in the meta-analysis with 915 patients (470 TLIF, 258 PLF, 87 PLIF, 26 ALIF, 29 XLIF, and 45 no fusion).

Fusion Rate

Fusion rate was 72.7% on TLIF group at 1-year follow-up whereas 87.03% fusion rate was reported on other techniques [PLF, PLIF, XLIF; 4 studies]. TLIF had slightly lower fusion rate at 1-year follow-up compared to other techniques [PLF, PLIF, XLIF; 5 studies] [RR = 0.84 (95% CI = 0.72–0.97), $p = 0.02$, $I^2 = 0.0\%$] (**Figure 3**). However, the fusion rate at 2 years did not show any statistically significant differences [RR = 1.06 (95% CI = 0.96–1.18), $p = 0.27$, $I^2 = 69.0\%$] as shown in **Supplementary File 1**.

Complications: Total Adverse Events, Revision, Infection, and Dural Tear

Total adverse events were reported in 10 studies. TLIF had similar total adverse events compared with PLIF, XLIF, and no fusion group [RR = 0.90 (95% CI = 0.59–1.38), $p = 0.63$, $I^2 = 0.0\%$] as shown in **Figure 4**. For the revision needed after surgical procedures, the results indicated a different revision rate among groups [no fusion, PLF, PLIF, XLIF] [RR = 0.78 (95% CI 0.34–1.79), $p = 0.56$, $I^2 = 39.0\%$] as shown in **Supplementary File 1**.

Infection was reported in 6 studies [no fusion, PLF, PLIF], and overall infection was similar among groups [RR = 1.78 (95% CI 0.58–5.46), $p = 0.31$, $I^2 = 0.0\%$]. More infection was reported in the TLIF group but was not statistically significant. The dural tear was higher in other techniques especially XLIF group but not statistically significant [RR = 1.19 (95% CI = 0.49–2.89), $p = 0.70$, $I^2 = 0.0\%$]. The results of secondary outcomes were reported as shown in **Table 2**.

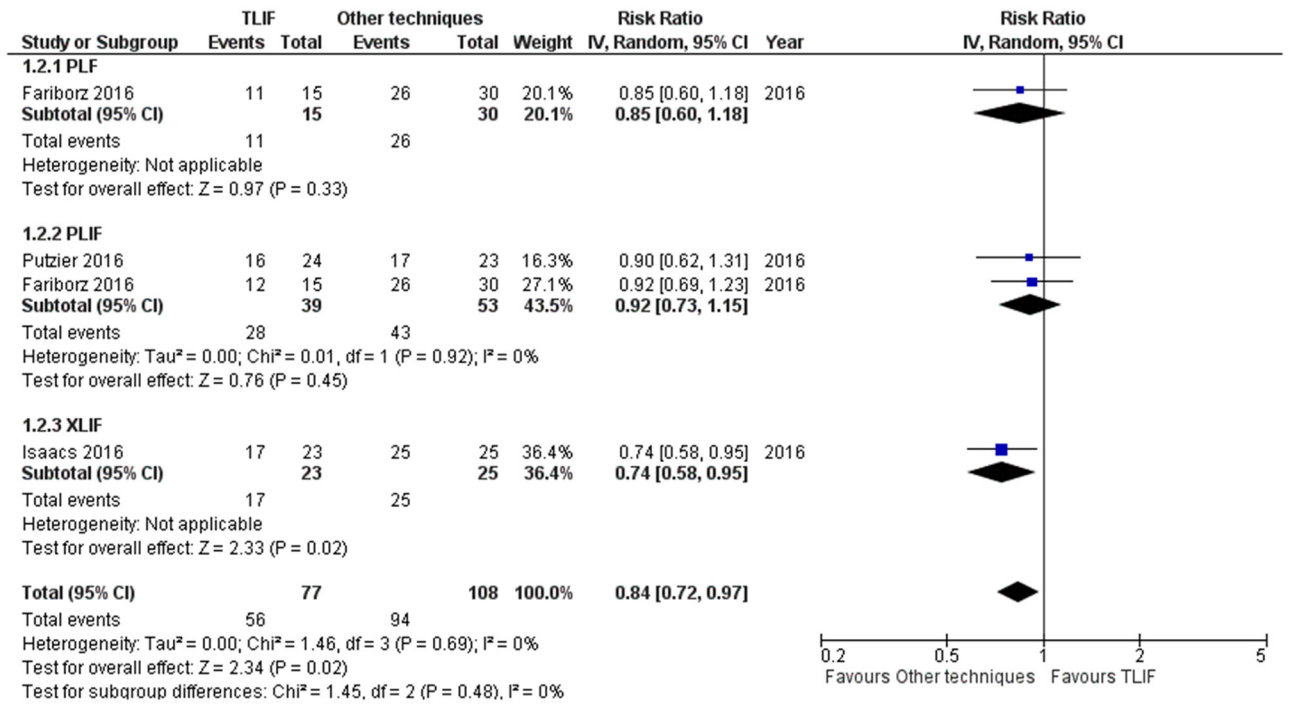


FIGURE 3 | Forest plot and tabulated data illustrated the RR for fusion rate at 1 year between TLIF, PLF, PLIF, and XLIF showing that other techniques had a better arm fusion rate at 1 year and were therefore superior to TLIF in this respect. *CI,* confidence interval; *df,* degrees of freedom.

TABLE 1 | Study characteristics.

References	Surgical technique	TLIF, *n*	Other techniques, *n*	Follow-Up
Challier et al. (17)	PLF + TLIF vs. PLF	30	30	2 y
Christensen et al. (18)	TLIF vs. PLF	51	49	1, 2 y
El Shazly et al. (19)	Discectomy + TLIF vs. no fusion	15	15	2 y
	Discectomy + TLIF vs. Discectomy + PLF	15	15	2 y
Etemadifar et al. (20)	PLF + TLIF vs. PLF	25	25	1.5, 3, 6 m, 1, 2 y
Fariborz et al. (21)	TLIF vs. PLIF	30	30	6 m, 1 y
	TLIF vs. PLF	30	30	6 m, 1 y
	TLIF vs. no fusion + instrumentation	30	30	6 m, 1 y
Hoff et al. (22)	TLIF vs. ALIF TDR	24	26	1, 3 y
Høy et al. (23)*	TLIF vs. PLF	51	49	1, 2 y
Høy et al. (24)*	TLIF vs. PLF	44	44	1, 2, 5–10 y
Høy et al. (25)*	TLIF vs. PLF	51	49	1, 2 y
Isaacs et al. (26)**	TLIF vs. XLIF	26	29	1, 2 y
Jalalpour et al. (27)	TLIF vs. PLF	68	67	1, 2 y
Li et al. (28)	TLIF vs. PLF	19	18	2–5 y
Putzier et al. (29)	TLIF vs. PLIF	24	23	1 y
Sembrano et al. (30)**	TLIF vs. XLIF	55	26	1 y
Yang et al. (31)	TLIF vs. PLIF	32	34	3 m, 1–2 y

**Same sample group, **same sample group.*

Operative Time

Anterior lumbar interbody fusion, PLF, and no fusion groups have shorter operative time whereas PLIF has longer operative time compared to TLIF. The pooled mean difference in operative time of other techniques was 31.88 min shorter than TLIF [no fusion, ALIF, PLF, PLIF, XLIF: 7 studies] [MD = 31.88 (95% CI = 5.33–58.44), $p = 0.02$, $I^2 = 92.0\%$].

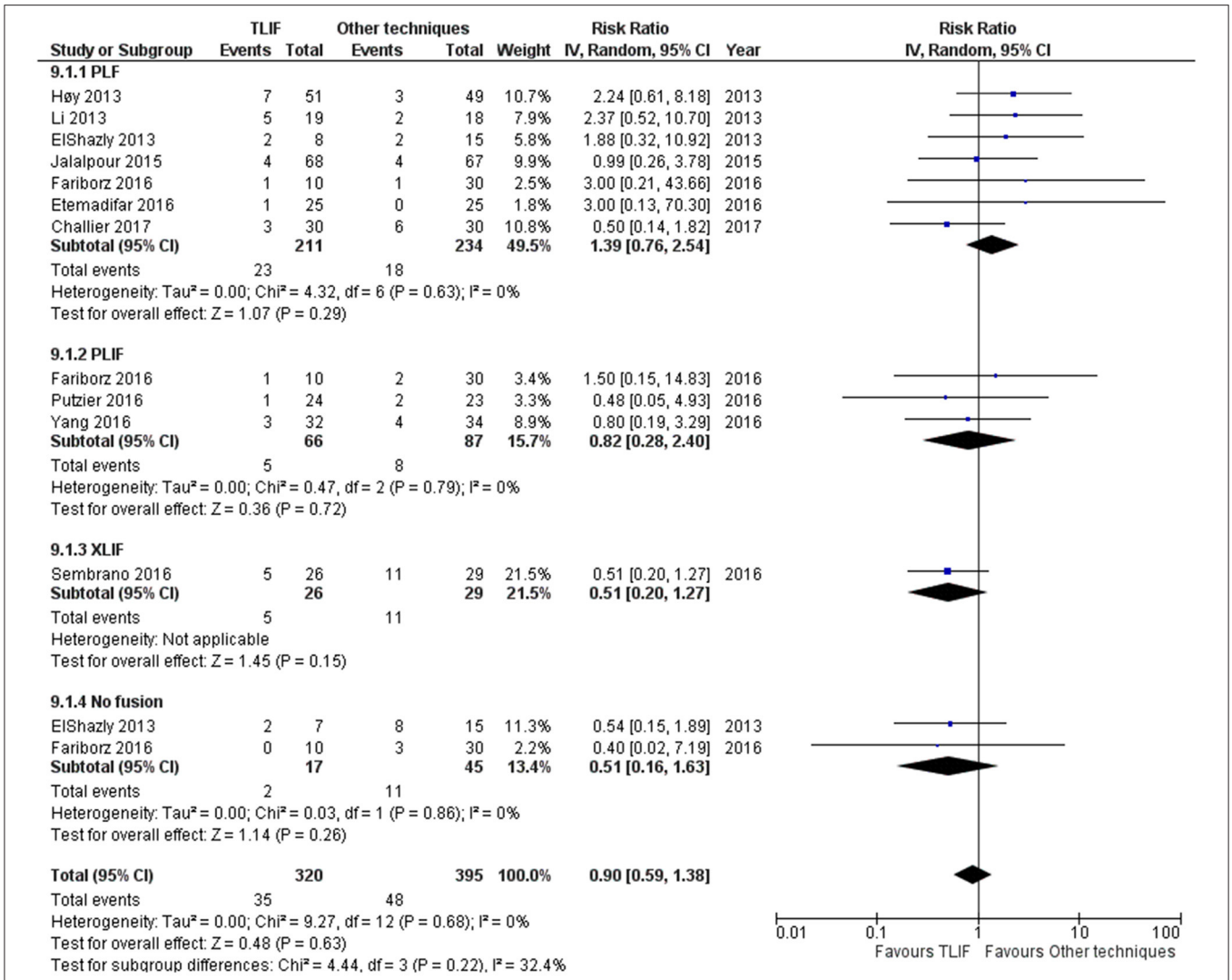


FIGURE 4 | Forest plot and tabulated data illustrated the RR for adverse events between TLIF, PLF, PLIF, XLIF, and no fusion showing that there was no significant difference in adverse events between procedures. *CI,* confidence interval; *df,* degrees of freedom.

TABLE 2 | Secondary outcomes.

Outcomes	Studies	Patients	Statistical method	Effect size [95% CI]
Infection	6	433	IV, random, 95% CI	RR = 1.78 [95% CI = 0.58–5.46], $p = 0.31$, $I^2 = 0.0\%$
Dural tear	7	570	IV, random, 95% CI	RR = 1.19 [95% CI = 0.49–2.89], $p = 0.70$, $I^2 = 0.0\%$
Operative time	6	353	IV, random, 95% CI	MD = 31.88 [95% CI = 5.33–58.44], $p = 0.02$, $I^2 = 92.0\%$
Blood loss	4	248	IV, random, 95% CI	191.00 [95% CI = −53.93–435.93], $p = 0.13$, $I^2 = 90.0\%$
Length of hospital stay	3	200	IV, random, 95% CI	MD = 0.12 [95% CI = −0.30–0.54], $p = 0.58$, $I^2 = 0.0\%$
VAS back at last follow-up	6	335	IV, random, 95% CI	MD = 0.13 [95% CI = −0.40–0.66], $p = 0.62$, $I^2 = 82.0\%$
VAS leg at last follow-up	2	150	IV, random, 95% CI	MD = −0.07 [95% CI = −1.43–1.30], $p = 0.92$, $I^2 = 77.0\%$
ODI at last follow-up	7	521	IV, random, 95% CI	MD = −4.82 [95% CI = −11.72–2.08], $p = 0.17$, $I^2 = 90.0\%$

CI, confidence interval; IV, inverse variance; MD, mean difference; RR, risk ratio; VAS, visual analog scale.

Blood Loss

Transforaminal lumbar interbody fusion has less blood loss than PLIF 88.80 ml. No fusion has less blood loss among groups [no fusion, PLF, PLIF: 5 studies]. Pooled mean difference in blood loss showed no significant difference [MD = 191.00 (95% CI −53.93–435.93), $p = 0.13$, $I^2 = 90.0\%$].

Length of Hospital Stay

Length of hospital stay between subgroup was not significantly different. Pooled mean difference in hospital stay was 0.12 [MD = 0.12 (95% CI = −0.30–0.54), $p = 0.58$, $I^2 = 0.0\%$] [no fusion, PLF, XLIF: 4 studies].

Back and Leg Pain

Visual analog scale (VAS) for back were extracted from 7 studies. There was no difference between back pain at last follow-up in TLIF and other technique groups [MD = 0.13 (95% CI = −0.40–0.66), $p = 0.62$, $I^2 = 82.0\%$] [no fusion, ALIF, PLF, PLIF: 7]. ALIF [MD = 1.20 (95% CI = 0.53–1.87), $p < 0.01$] and no fusion techniques [MD = 0.60 (95% CI = 0.08–1.12), $p = 0.02$] were shown less back pain at last follow-up. VAS for leg was extracted from only 2 PLF studies. There was no difference between leg pain at last follow-up in TLIF and PLF groups [MD = −0.07 (95% CI = −1.43–1.30), $p = 0.92$, $I^2 = 77.0\%$].

ODI

No difference in ODI was observed [MD = −4.82 (95% CI = −11.72–2.08), $p = 0.17$, $I^2 = 90.0\%$]. Compared to TLIF, no fusion group had higher ODI at last follow-up [MD = −41.30 (95% CI = −5–0.15–−32.45), $p < 0.001$] [no fusion, ALIF, PLF, PLIF: 9 studies].

DISCUSSION

Patients with degenerative lumbar spine disease require surgical intervention when the conservative treatments failed (7–10). The operative methods are varyingly selected among spine surgeons. Therefore, the fusion rates and other clinical outcomes were reported in different studies. This systematic review and meta-analysis attempted to investigate the benefits and risks of lumbar interbody fusion, no fusion, and posterolateral fusion by comparing the fusion rate, clinical outcomes, and parameters concerning operation, as well as complications.

The surgical techniques of PLIF vary across studies whereas one study did not mention the details of the surgical procedure (23). Putzier et al. used the conventional five centimeters midline approach and place a cage bilaterally (29). Yang et al. performed PLIF in the standard fashion with two rectangular cages packed with autogenous bone grafts (31). The ALIF procedure uses a pararectal retroperitoneal approach. A stand-alone PEEK cage filled with freeze-dried allogenic cancellous bone was fixed with four angle-stable screws at L5-S1 and a prosthesis at L5-S1 (24). The XLIF utilizes a mini-open, 90° off-midline, retroperitoneal, trans-psoas approach for ALIF. Two RCTs (26, 30) included in this study had equal sample sizes. The authors described using the same technique that was previously described (5, 32). Direct decompression was not performed in XLIF patients.

Of the three RCTs on MIS-TLIF (26, 29, 30), two were open TLIF (22, 27) and the other did not specify surgical details of TLIF. We compared the clinical outcomes and complications among operative techniques; therefore, we included MIS-TLIF, open TLIF, and no details mentioned TLIF as a TLIF group. Nonetheless, MIS-TLIF and open TLIF have demonstrated similar clinical outcomes (33–35) whereas the comparison of open TLIF vs. MIS-TLIF is beyond the scope of this study.

From the currently available evidence, findings from our study were similar to the previous systematic review that reported an 89.1% fusion rate and 12.5% reoperation rate (36). Manzur et al. reported an 85.6% fusion rate on LLIF (37). The evidence that supports a higher fusion rate compared with TLIF was rare (10). Lan's et al. study in which PLIF compared with TLIF demonstrated similar outcomes (11). The TLIF has a slightly low fusion rate at 1 year and remains unchanged at 2 years. Further study on potential multifactorial factors supports the fusion (9).

In terms of pain, there was less back pain in the non-fusion group and similar back pain among fusion groups. In no fusion group, the surgery was less invasive compared to the fusion group, therefore resulting in less back pain. In pooled outcome data, there was no significant difference in ODI scores between surgical techniques. At the last follow-up, the no fusion group had a higher ODI score compared to the TLIF group. As time passes, patients in the no fusion group may result in higher disability. Less paravertebral dissection of no fusion group affected in less operative time and blood loss. PLIF has the longest operative time when compared to no fusion, PLF, ALIF, and TLIF. PLIF has also more blood loss than TLIF. This might result from a posterior approach in which more paravertebral muscle was dissected and the bone structure was resected more than TLIF (14).

Surgical complications evaluated by total adverse events were not shown statistically significant differences among lumbar interbody fusion, no fusion, and posterolateral fusion. However, our result TLIF seems to be safer than PLIF and ALIF in neural, spinal, and vascular events. Those findings were similar to a previous study by Chi et al. (9). Nonetheless, Yavin et al. demonstrated more complications in the fusion group compared to the non-fusion group (38).

The strength of this study was that we included only RCTs that showed no significant asymmetry that highlighted no evidence of publication bias on the fusion rate, total adverse events, and revision rate. However, the small number of RCT on TLIF was the limitation of our study. The heterogeneity of the enrolled studies was another limitation. The study (19) with the procedure of TLIF + discectomy was counted as the TLIF group. Furthermore, there was the same sample group in three studies as shown in **Table 1** (23–25). We try to reduce the bias by excluding the repeated data from the analysis. For lumbar spine disease, the included studies were different in treatment protocol which may affect the results, for example, fusion rate (because not all studies have reported outcomes at 2-year follow-up). Furthermore, the results are referred to only single-level surgery as the included studies.

CONCLUSION

Besides fusion rate at 1-year follow-up and operative time, TLIF has a similar fusion rate, clinical outcomes, parameters concerning operation and complications to decompression alone (no fusion), posterolateral fusion, and other interbody fusion (PLIF, ALIF, and XLIF).

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.

AUTHOR CONTRIBUTIONS

KW and KP contributed to the study conception and design. Material preparation and data collection were performed by KW and TN. Data analysis was performed by TN. All authors wrote the first draft of the manuscript and revised and approved the final manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsurg.2022.829469/full#supplementary-material

REFERENCES

1. Cloward RB. The treatment of ruptured lumbar intervertebral discs by vertebral body fusion. I. Indications, operative technique, aftercare. *J Neurosurg.* (1953) 10:154–68. doi: 10.3171/jns.1953.10.2.0154
2. Harms J, Rolinger H. Die operative behandlung der spondylolisthese durch dorsale aufrichtung und ventrale verblockung [A one-stager procedure in operative treatment of spondylolistheses: dorsal traction-reposition and anterior fusion (author's transl)]. *Z Orthop Ihre Grenzgeb.* (1982) 120:343–7. doi: 10.1055/s-2008-1051624
3. Foley KT, Lefkowitz MA. Advances in minimally invasive spine surgery. *Clin Neurosurg.* (2002) 49:499–517.
4. Choy WJ, Abi-Hanna D, Cassar LP, Hardcastle P, Phan K, Mobbs RJ. History of integral fixation for anterior lumbar interbody fusion (ALIF): the hartshill horseshoe. *World Neurosurg.* (2019) 129:394–400. doi: 10.1016/j.wneu.2019.06.134
5. Ozgur BM, Aryan HE, Pimenta L, Taylor WR. Extreme lateral interbody fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. *Spine J.* (2006) 6:435–43. doi: 10.1016/j.spinee.2005.08.012
6. Goldstein CL, Macwan K, Sundararajan K, Rampersaud YR. Perioperative outcomes and adverse events of minimally invasive versus open posterior lumbar fusion: meta-analysis and systematic review. *J Neurosurg Spine.* (2016) 24:416–27. doi: 10.3171/2015.2.SPINE14973
7. Phan K, Thayaparan GK, Mobbs RJ. Anterior lumbar interbody fusion versus transforaminal lumbar interbody fusion–systematic review and meta-analysis. *Br J Neurosurg.* (2015) 29:705–11. doi: 10.3109/02688697.2015.1036838
8. Joseph JR, Smith BW, La Marca F, Park P. Comparison of complication rates of minimally invasive transforaminal lumbar interbody fusion and lateral lumbar interbody fusion: a systematic review of the literature. *Neurosurg Focus.* (2015) 39:E4. doi: 10.3171/2015.7.FOCUS15278
9. Chi KY, Cheng SH, Kuo YK, Lin EY, Kang YN. Safety of lumbar interbody fusion procedures for degenerative disc disease: a systematic review with network meta-analysis of prospective studies. *Global Spine J.* (2020) 11:751–60. doi: 10.1177/2192568220938024
10. Zhang BF, Ge CY, Zheng BL, Hao DJ. Transforaminal lumbar interbody fusion versus posterolateral fusion in degenerative lumbar spondylosis: a meta-analysis. *Medicine.* (2016) 95:e4995. doi: 10.1097/MD.0000000000004995
11. Lan T, Hu SY, Zhang YT, Zheng YC, Zhang R, Shen Z, et al. Comparison between posterior lumbar interbody fusion and transforaminal lumbar interbody fusion for the treatment of lumbar degenerative diseases: a systematic review and meta-analysis. *World Neurosurg.* (2018) 112:86–93. doi: 10.1016/j.wneu.2018.01.021
12. Keorochana G, Setrkraising K, Woratanarat P, Arirachakaran A, Kongtharvonskul J. Clinical outcomes after minimally invasive transforaminal lumbar interbody fusion and lateral lumbar interbody fusion for treatment of degenerative lumbar disease: a systematic review and meta-analysis. *Neurosurg Rev.* (2018) 41:755–70. doi: 10.1007/s10143-016-0806-8
13. Zhang Q, Yuan Z, Zhou M, Liu H, Xu Y, Ren Y. A comparison of posterior lumbar interbody fusion and transforaminal lumbar interbody fusion: a literature review and meta-analysis. *BMC Musculoskelet Disord.* (2014) 15:367. doi: 10.1186/1471-2474-15-367
14. Teng I, Han J, Phan K, Mobbs R. A meta-analysis comparing ALIF, PLIF, TLIF and LLIF. *J Clin Neurosci.* (2017) 44:11–7. doi: 10.1016/j.jocn.2017.06.013
15. Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* (2009) 6:e1000097. doi: 10.1371/journal.pmed.1000097
16. Sterne J, Savović J, Page M, Elbers RG, Blencowe NS, Boutron I, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ.* (2019) 366:i4898 doi: 10.1136/bmj.l4898
17. Challier V, Boissiere L, Obeid I, Vital JM, Castelain JE, Bénard A, et al. One-Level lumbar degenerative spondylolisthesis and posterior approach: is transforaminal lateral interbody fusion mandatory? A randomized controlled trial with 2-year follow-up. *Spine.* (2017) 42:531–539. doi: 10.1097/BRS.0000000000001857
18. Christensen A, Høy K, Bünger C, Helmig P, Hansen ES, Andersen T, et al. Transforaminal lumbar interbody fusion vs. posterolateral instrumented fusion: cost-utility evaluation along side an RCT with a 2-year follow-up. *Eur Spine J.* (2014) 23:1137–43. doi: 10.1007/s00586-014-3238-6
19. El Shazly AA, El Wardany MA, Morsi AM. Recurrent lumbar disc herniation: a prospective comparative study of three surgical management procedures. *Asian J Neurosurg.* (2013) 8:139–46. doi: 10.4103/1793-5482.121685
20. Etemadifar MR, Hadi A, Masouleh MF. Posterolateral instrumented fusion with and without transforaminal lumbar interbody fusion for the treatment of adult isthmic spondylolisthesis: a randomized clinical trial with 2-year follow-up. *J Craniovertebr Junction Spine.* (2016) 7:43–9. doi: 10.4103/0974-8237.176623
21. Fariborz S, Gharedaghi M, Khosravi A, Samini M. Comparison of results of 4 methods of surgery in grade 1 lumbosacral spondylolisthesis. *Neurosurg Q.* (2016) 26:14–8 doi: 10.1097/WNQ.0000000000000197
22. Hoff EK, Strube P, Pumberger M, Zahn RK, Putzier M. ALIF and total disc replacement versus 2-level circumferential fusion with TLIF: a prospective, randomized, clinical and radiological trial. *Eur Spine J.* (2016) 25:1558–66. doi: 10.1007/s00586-015-3852-y
23. Høy K, Bünger C, Niederman B, Helmig P, Hansen ES, Li H, et al. Transforaminal lumbar interbody fusion (TLIF) versus posterolateral instrumented fusion (PLF) in degenerative lumbar disorders: a randomized clinical trial with 2-year follow-up. *Eur Spine J.* (2013) 22:2022–9 doi: 10.1007/s00586-013-2760-2
24. Høy K, Truong K, Andersen T, Bünger C. Addition of TLIF does not improve outcome over standard posterior instrumented fusion. 5-10 years long-term follow-up: results from a RCT. *Eur Spine J.* (2017) 26:658–65. doi: 10.1007/s00586-016-4592-3
25. Høy K, Grycel B, Andersen T, Bünger C. Does transforaminal lumbar interbody fusion produce leg pain?-Results from a RCT. *J Orthop Surg.* (2019) 27:2309499019869469. doi: 10.1177/2309499019869469
26. Isaacs RE, Sembrano JN, Tohmeh AG; SOLAS Degenerative Study Group. Two-Year comparative outcomes of MIS lateral and MIS transforaminal interbody fusion in the treatment of degenerative spondylolisthesis:

part II: radiographic findings. *Spine.* (2016) 41 (Suppl. 8):S133–44. doi: 10.1097/BRS.0000000000001472
27. Jalalpour K, Neumann P, Johansson C, Hedlund R. a randomized controlled trial comparing transforaminal lumbar interbody fusion and uninstrumented posterolateral fusion in the degenerative lumbar spine. *Global Spine J.* (2015) 5:322–8. doi: 10.1055/s-0035-1549033
28. Li FC, Chen QX, Chen WS, Xu K, Wu QH, Chen G. Posterolateral lumbar fusion versus transforaminal lumbar interbody fusion for the treatment of degenerative lumbar scoliosis. *J Clin Neurosci.* (2013) 20:1241–5. doi: 10.1016/j.jocn.2012.10.031
29. Putzier M, Hartwig T, Hoff EK, Streitparth F, Strube P. Minimally invasive TLIF leads to increased muscle sparing of the multifidus muscle but not the longissimus muscle compared with conventional PLIF-a prospective randomized clinical trial. *Spine J.* (2016) 16:811–9. doi: 10.1016/j.spinee.2015.07.460
30. Sembrano JN, Tohmeh A, Isaacs R; SOLAS Degenerative Study Group. Two-year comparative outcomes of MIS lateral and MIS transforaminal interbody fusion in the treatment of degenerative spondylolisthesis: part I: clinical findings. *Spine*. (2016) 41 (Suppl. 8):S123–32. doi: 10.1097/BRS.0000000000001471
31. Yang EZ, Xu JG, Liu XK, Jin GY, Xiao W, Zeng BF, et al. An RCT study comparing the clinical and radiological outcomes with the use of PLIF or TLIF after instrumented reduction in adult isthmic spondylolisthesis. *Eur Spine J.* (2016) 25:1587–94. doi: 10.1007/s00586-015-4341-z
32. Peterson MD, Youssef JA. Extreme lateral interbody fusion (XLIF1): lumbar surgical technique. In: Goodrich JA, Volcan IJ, editors. *Extreme Lateral Interbody Fusion (XLIF1).* 2nd ed. St. Louis, MO: Quality Medical Publishing, Inc (2013). p. 159–78.
33. Hammad A, Wirries A, Ardeshiri, A, Nikiforov O, Geiger F. Open versus minimally invasive TLIF: literature review and meta-analysis. *J Orthop Surg Res*. (2019) 14:229. doi: 10.1186/s13018-019-1266-y
34. Kim CH, Easley K, Lee JS, Hong JY, Virk M, Hsieh PC, et al. Comparison of minimally invasive versus open transforaminal interbody lumbar fusion. *Global Spine J.* (2020) 10 (2 Suppl):143S−50S. doi: 10.1177/2192568219882344
35. Sulaiman WA, Singh M. Minimally invasive versus open transforaminal lumbar interbody fusion for degenerative spondylolisthesis grades 1-2: patient-reported clinical outcomes and cost-utility analysis. *Ochsner J.* (2014) 14:32–7.
36. Phillips FM, Slosar PJ, Youssef JA, Andersson G, Papatheofanis F. Lumbar spine fusion for chronic low back pain due to degenerative disc disease: a systematic review. *Spine.* (2013) 38:E409–22. doi: 10.1097/BRS.0b013e3182877f11
37. Manzur MK, Steinhaus ME, Virk SS, Jivanelli B, Vaishnav AS, McAnany SJ, et al. Fusion rate for stand-alone lateral lumbar interbody fusion: a systematic review. *Spine J.* (2020) 20:1816–25. doi: 10.1016/j.spinee.2020.06.006
38. Yavin D, Casha S, Wiebe S, Feasby TE, Clark C, Isaacs A, et al. Lumbar fusion for degenerative disease: a systematic review and meta-analysis. *Neurosurgery.* (2017) 80:701–15. doi: 10.1093/neuros/nyw162

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: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers in Surgery

ORIGINAL RESEARCH
published: 16 March 2022
doi: 10.3389/fsurg.2022.850342

Prediction of Long-Term Recovery From Disability Using Hemoglobin-Based Models: Results From a Cohort of 1,392 Patients Undergoing Spine Surgery

Matteo Briguglio[1]*, *Paolo Perazzo*[2], *Francesco Langella*[3], *Tiziano Crespi*[2], *Elena De Vecchi*[4], *Patrizia Riso*[5], *Marisa Porrini*[5], *Laura Scaramuzzo*[6], *Roberto Bassani*[7], *Marco Brayda-Bruno*[8], *Giuseppe Banfi*[1,9] *and Pedro Berjano*[3]

[1] IRCCS Orthopedic Institute Galeazzi, Scientific Direction, Milan, Italy, [2] IRCCS Orthopedic Institute Galeazzi, Intensive Care Unit, Milan, Italy, [3] IRCCS Orthopedic Institute Galeazzi, GSpine 4, Milan, Italy, [4] IRCCS Orthopedic Institute Galeazzi, Laboratory of Clinical Chemistry and Microbiology, Milan, Italy, [5] University of Milan, Department of Food, Environmental and Nutritional Sciences, Division of Human Nutrition, Milan, Italy, [6] IRCCS Orthopedic Institute Galeazzi, Spine Unit 1, Milan, Italy, [7] IRCCS Orthopedic Institute Galeazzi, Spine Unit 2, Milan, Italy, [8] IRCCS Orthopedic Institute Galeazzi, Spine Unit 3, Milan, Italy, [9] Vita-Salute San Raffaele University, Faculty of Medicine and Surgery, Milan, Italy

Hemoglobin and its associated blood values are important laboratory biomarkers that mirror the strength of constitution of patients undergoing spine surgery. Along with the clinical determinants available during the preadmission visit, it is important to explore their potential for predicting clinical success from the patient's perspective in order to make the pre-admission visit more patient-centered. We analyzed data from 1,392 patients with spine deformity, disc disease, or spondylolisthesis enrolled between 2016 and 2019 in our institutional Spine Registry. Patient-reported outcome measure at 17 months after surgery was referred to the Oswestry disability index. High preoperative hemoglobin was found to be the strongest biochemical determinant of clinical success along with high red blood cells count, while low baseline disability, prolonged hospitalization, and long surgical times were associated with poor recovery. The neural network model of these predictors showed a fair diagnostic performance, having an area under the curve of 0.726 and a sensitivity of 86.79%. However, the specificity of the model was 15.15%, thus providing to be unreliable in forecasting poor patient-reported outcomes. In conclusion, preoperative hemoglobin may be one of the key biomarkers on which to build appropriate predictive models of long-term recovery after spine surgery, but it is necessary to include multidimensional variables in the models to increase the reliability at the patient's level.

Keywords: preoperative care, orthopedic procedures, vertebral column, hemoglobin, anemia, patient-reported outcome measures, enhanced recovery after surgery, spine surgery

OPEN ACCESS

Edited by:
Hengxing Zhou,
Tianjin Medical University General Hospital, China

Reviewed by:
Brandon Sherrod,
The University of Utah, United States
Tatsunori Ikemoto,
Aichi Medical University, Japan

***Correspondence:**
Matteo Briguglio
matteo.briguglio@grupposandonato.it

Specialty section:
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

Received: *07 January 2022*
Accepted: *17 February 2022*
Published: *16 March 2022*

Citation:
Briguglio M, Perazzo P, Langella F, Crespi T, De Vecchi E, Riso P, Porrini M, Scaramuzzo L, Bassani R, Brayda-Bruno M, Banfi G and Berjano P (2022) Prediction of Long-Term Recovery From Disability Using Hemoglobin-Based Models: Results From a Cohort of 1,392 Patients Undergoing Spine Surgery. Front. Surg. 9:850342. doi: 10.3389/fsurg.2022.850342

INTRODUCTION

Spinal disorders are common and the prevalence increases in the aging population (1). In view of the recent advancements in spine treatments, surgery is considered clinically effective from a medical perspective. However, healthcare systems are progressively moving toward value-based business models (2), with the definition of clinical success increasingly based on patient-reported outcome measures (PROMs) (3). The Oswestry disability index (ODI) is a widely-used, validated, and self-administered questionnaire to assess a patient's functional impairment related to the spinal condition, encompassing questions about personal care, movements, sleeping, and social life (4), and can be used to evaluate the outcomes from the patient's perspective (5). The advent of PROMs calls for more patient-centric healthcare, which outlines the need for early preoperative pathways. Identifying the determinants that affect the individual's daily activities in the long term can help maintain high-quality standards (6). One of the parameters known to mirror the functional reservoirs required for proper recovery is hemoglobin (7–9). An abnormal circulating level before surgery is considered a risk factor for poor medical and surgical outcomes in spinal patients (10), also being a predictor of mortality in the most severe conditions (11). Hemoglobin is an assembly of four globular polypeptide chains that fill the warp of red blood cells, carrying up to four oxygen molecules attached to iron atoms. Together with the erythrocytes and their volume over total blood (i.e., hematocrit), hemoglobin reflects oxygen carrying capacity, functional iron levels, and correct erythropoiesis (12). Hemoglobin concentration is one of the benchmarks for planning transfusion therapy strategy (13) along with other laboratory parameters such as hematocrit (14). Therefore, preoperative iron optimization is considered a key aspect of patient blood management (15) and enhanced recovery after surgery (16). To the authors' knowledge, there are no studies in spine surgery that have investigated the potential of preoperative hemoglobin in predicting clinical success from a patient's point of view. We studied a large cohort of patients undergoing spine surgery for deformities, disc disease, and other back conditions to identify predictors of long-term functional status using hemoglobin-based models.

MATERIALS AND METHODS

Study Population

The research included patients enrolled in the institutional Spine Registry (SpineReg; ClinicalTrials.gov number: NCT03644407), which is a prospective observational registry recruiting patients undergoing spine surgery incepted in 2015 by our hospital IRCCS Orthopedic Institute Galeazzi of Milan (Italy). To answer the research question, we extracted from the registry the patients who met the following eligibility criteria: $\geq$18 years of age, enrolment between 2016 and 2019, the presence of at least one ODI assessment at 6-, 12-, or 24-month follow-up. The extraction excluded data of patients with a diagnosis of tumors, admission for complications, and surgical procedures involving the cervical spine. A 30% reduction from baseline was considered as the minimum clinically important difference (MCID) in the ODI score in order to categorize the outcomes (17). A secondary analysis was planned using the raw reduction of 12.7 points as classification threshold, which is more restrictive in categorizing successful surgeries (18). Patients who had a preoperative ODI $<$ 12.7 were excluded from the extraction query. After data extraction and integration with routine parameters, the study sample comprised 1,392 patients with seventeen variables: gender, age, red blood cells (RBCs), hematocrit (Ht), serum concentration of hemoglobin (Hb), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCH), C-reactive protein (CRP), type of diagnosis, American society of anesthesiologists physical status classification system (ASA), duration of surgery (DS), length of hospital stay (LOS), preoperative ODI (PREOP ODI), 6-month ODI, 12-month ODI, and 24-month ODI. The number of missing values counted 85 CRP, 14 DS, 555 6-month ODI, 422 12-month ODI, and 731 24-month ODI.

Data Handling

The simple imputation technique of the last observation carried forward (LOCF) was used to include patients with incomplete 24-month ODI, with the last reported scores being used in place of the missing values. The months of follow-up were then weighed on the imputations, thus obtaining the ODI scores at 17 months (661 24-month ODI + 576 12-month ODI + 155 6-month ODI). In **Table 1** is reported the structure of the dataset. Subsequently, three new variables were imputed. The first variable was the difference between the baseline ODI and the last ODI at 17 months (ΔODI PRE vs. last 17). The second variable was the presence or absence (1,0) of clinical improvement at 17 months (17-month progress 30%), calculated as a 30% decrease from baseline ODI to the last ODI at 17 months. The third variable was the presence or absence (1,0) of clinical improvement at 17 months (17-month progress 12.7), calculated as a raw reduction in the ODI score$\geq$12.7 from baseline ODI to the last ODI at 17 months. Two new sets classified the sample by gender code (males = 0, females = 1) and diagnosis (spine deformities: 4, disc diseases: 5; back surgeries: 6). Specifically, the group of spine deformities included kyphosis and scoliosis, and the group of back surgeries included spondylosis, spondylolisthesis, stenosis, and elective treatment of fractures. The dataset was explored for what concerned the presence of outliers among the primary variables, and a new dataset for regression analysis was created after the elimination of outliers. The following number of outliers were excluded based on the interquartile range rule of three: 4 RBCs, 27 MCV, 36 MCH, 2 MCHC, 96 CRP, 2 DS, and 21 LOS.

Statistics

The IBM SPSS 22 statistics package was used for all statistical analysis. The descriptive variables were reported as means, standard deviation, minimum and maximum values to be reported in **Tables 2**, **3** (baseline examination), regardless of the type of distribution. In **Table 4** (outcome exploration) it was planned to report the most significant biochemical descriptors

TABLE 1 | Structure and missing data of the study group dataset.

Captions	Cases *n*	Missing *n* (%)
Age (years, continuous)	1,392	0
Gender (dichotomous)	1,392	0
RBCs (10^6/μl, continuous)	1,392	0
Hematocrit (%, continuous)	1,392	0
Hemoglobin (g/dl, continuous)	1,392	0
MCV (fl/cell, continuous)	1,392	0
MCH (pg/cell, continuous)	1,392	0
MCHC (g/dl, continuous)	1,392	0
CRP (mg/dl, continuous)	1,307	85 (6.11%)
Diagnosis (categorical)	1,392	0
ASA (ordinal)	1,392	0
DS (minutes, continuous)	1,378	14 (1.01%)
LOS (days, continous)	1,392	0
Baseline ODI (continuous)	1,392	0
6-month ODI (continuous)	837	555 (39.87%)
12-month ODI (continuous)	970	422 (30.32%)
24-month ODI (continuous)	661	731 (52.51%)
LOCF 17-month ODI (continuous)	1,392	0
	TOTAL	1,807 (7.77%)

RBCs, red blood cells; MCV, mean corpuscular volume; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; CRP, C-reactive protein; ASA, American Society of Anesthesiologists physical status classification system (1, healthy; 2, mild; 3, severe; 4, life threatening; 5, moribund; 6, brain-dead); DS, duration of surgery; LOS, length of hospital stay; ODI, Oswestry Disability Index, ranging from 0 (no disability) to 100 (maximum disability); LOCF, last observation carried forward.

TABLE 2 | Baseline demographic and biochemical characteristics of the study group.

Descriptors	Values	Cases *n*
Age (years)	56.41 ± 15.24 (18.00; 88.00)	1,392
Gender	567 males, 825 females	1,392
Biochemistry		
RBCs (10^6/μl)	04.76 ± 00.49 (02.50; 06.88)	1,392
Hematocrit (%)	42.31 ± 03.64 (27.20; 54.10)	1,392
Hemoglobin (g/dl)	14.04 ± 01.38 (09.20; 18.90)	1,392
MCV (fl/cell)	89.16 ± 05.69 (54.60; 115.20)	1,392
MCH (pg/cell)	29.58 ± 02.20 (18.00; 37.60)	1,392
MCHC (g/dl)	33.16 ± 01.02 (27.50; 36.50)	1,392
CRP (mg/dl)	00.35 ± 00.67 (00.01; 08.74)	1,307

RBCs, red blood cells; MCV, mean corpuscular volume; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; CRP, C-reactive protein.

against the outcomes. Based on the results from the Shapiro-Wilk test on the dataset without outliers, Ht ($p = 0.989$), Hb ($p = 0.281$), and MCHC ($p = 0.078$) were assumed to have normal distribution. Age ($p < 0.05$), RBCs ($p < 0.05$), MCV ($p < 0.05$), MCH ($p < 0.05$), CRP ($p < 0.05$), DS ($p < 0.05$), LOS ($p < 0.05$), and baseline ODI ($p < 0.05$) were assumed to be skewed. The newly created dataset without outliers was used for running descriptive statistics, whereas the raw dataset was planned to be used for inferential statistics. The existence of a difference in the biochemical parameters between males and females was planned to be investigated through the independent *t*-test or the Mann-Whitney *U*-test for normally or not normally distributed values, respectively, and controlling for the homogeneity of variance by Levene's test for equality of variances (adjusted degree of freedom). The existence, strength, and direction of the association between the biochemical parameters and the demographic variable of age were examined using the Pearson product-moment correlation for continuous normally distributed variables or the Spearman rank-order correlation coefficient for skewed data. Regardless of data distribution, blood values and years of age were planned to be reported in scatter plots against the baseline ODI together with the Pearson's correlation and linear regression coefficients (*unstandardized B*). The difference between males and females in baseline ODI was investigated likewise through the Mann-Whitney *U*-test.

Concerning outcome exploration, the Chi-Square test was used to investigate the differences in gender between outcome groups at 17 months using both 30% reduction and the raw 12.7 points reduction. Similarly, it was planned the Mann-Whitney *U*-test for the years of age and the biochemical parameters, taking into account the result of Levene's test for equality of variances based on median (adjusted degree of freedom). The Chi-Square test was also used to investigate the different outcomes according to ASA, diagnosis, DS, and LOS. Subsequently, the probe of two prediction regression models was planned; the first model (PRE_{BIO}) would be based on the seven preoperative biochemical markers, while the second model ($PERI_{BIODEMCLI}$) would have included the biochemical, the demographic (gender and age), and the clinical (diagnosis, ASA, baseline ODI, DS, and LOS) variables. The prediction potential of each of the two models on the last ODI was explored through multiple regression analysis on the dataset without outliers. The models were planned to be based on the stepwise method to serially add the next strongest predictor feasibly removing the previously entered predictor not significant. The most significant predictors would be chosen to report the predictive equations. The Wilcoxon signed-rank test was run to match the regression predicted values from the estimated regression equation with the real values of the dataset. The main predictors of each model were tested for the clinically significant outcomes (1,0) by using binary logistic regression (enter method). Neural Networks (NN) analysis was planned to observe the forecasting outcome as a function of each variable-specific model: PRE_{BIO}(NN) and $PERI_{BIODEMCLI}$(NN). Given the non-linear nature of this tool, the authentications between inputs and outputs have been run on the raw dataset through the supervised learning technique of Multilayer Perceptron (MLP) procedure to produce a predictive model for clinical success based on the values of the demographic, biochemical, and clinical predictors. After data whitening (the distributions were rescaled so that the mean was zero and the standard deviation was one), the training sample was set at 70%, the testing sample to track prediction at 20%, and the holdout sample to assess the final

TABLE 3 | Baseline surgical descriptors of the study group.

Descriptors	ASA	Baseline ODI	DS *minutes*	LOS *days*
Total cases (n = 1,392)	01.86 ± 00.57	46.84 ± 16.40	220.01 ± 142.28	04.83 ± 03.61
	(01.00; 03.00)	(13.00; 100.00)	(47.93; 813.80)	(01.00; 48.00)
Clusters of diagnosis				
Spine deformities (n = 216)	01.95 ± 00.55	45.81 ± 16.26	415.46 ± 146.47	08.50 ± 05.75
	(01.00; 03.00)	(13.00; 82.00)	(113.43; 813.80)	(02.00; 48.00)
Disc diseases (n = 628)	01.72 ± 00.56	47.75 ± 16.75	171.41 ± 114.13	03.69 ± 02.17
	(01.00; 03.00)	(13.00; 100.00)	(48.02; 772.32)	(01.00; 16.00)
Other back surgeries (n = 548)	01.99 ± 00.57	46.21 ± 16.03	197.91 ± 98.86	04.69 ± 02.80
	(01.00; 03.00)	(13.00; 94.00)	(47.93; 690.03)	(01.00; 27.00)

ASA, American Society of Anesthesiologists physical status classification system (1, healthy; 2, mild; 3, severe; 4, life threatening; 5, moribund; 6, brain-dead); ODI, Oswestry Disability Index, ranging from 0 (no disability) to 100 (maximum disability); DS, duration of surgery; LOS, length of hospital stay. Spine deformities (kyphosis, scoliosis). Disc diseases (back regions). Back surgeries (spondylosis, spondylolisthesis, stenosis, fractures).

TABLE 4 | Baseline differences in biochemical parameters according to the long-term recovery.

Descriptors	17-month failure	17-month success	Between-group *p*
RBCs (10^6/μl)	4.69 ± 0.50 (2.86; 6.31)	4.79 ± 0.48 (2.50; 6.88)	$p < 0.01$
Hematocrit (%)	41.84 ± 3.95 (30.50; 53.30)	42.48 ± 3.50 (27.20; 54.10)	$p < 0.01$
Hemoglobin (g/dl)	13.81 ± 1.47 (9.70; 18.00)	14.12 ± 1.34 (9.20; 18.90)	$p < 0.001$
MCV (fl/cell)	89.54 ± 6.16 (60.20; 106.60)	89.02 ± 5.52 (54.60; 115.20)	$p < 0.01$
MCH (pg/cell)	29.54 ± 2.35 (19.50; 36.60)	29.59 ± 2.14 (18.00; 37.60)	Not significant
MCHC (g/dl)	32.98 ± 1.02(29.80; 36.30)	33.23 ± 1.01 (27.50; 36.50)	$p < 0.001$
CRP (mg/dl)	0.36 ± 0.60 (00.01; 04.39)	0.34 ± 0.69 (00.01; 08.74)	Not significant

RBCs, red blood cells; MCV, mean corpuscular volume; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; CRP, C-reactive protein. Clinical success, a 30% decrease from preoperative ODI at 17 months after surgery.

NN at 10%. The NN architecture was planned to be based on two hidden layers with Sigmoid activation function (real-valued arguments are transformed to the range 0, 1) and on Softmax activation for the output layer (the vector of real-valued arguments is transformed to a vector whose elements fall in the range 0, 1 and sum to 1). The Receiver Operating Characteristic (ROC) curve evaluated the Area Under the Curve (AUC), the sensitivity (true positive outcome), specificity (true negative outcome), and 1–specificity (false positive rate) of model-specific predictors in three successive run of NN, with the normalized importance of the independent predictors independent being reported for the most significant multivariate model.

RESULTS

Preoperative Examination

The demographic and preoperative biochemical variables are reported in **Table 2**. The study cohort showed a prevalence of about 41% of males and 59% of females, with men showing higher values than females of RBCs (05.02 ± 00.46 10^6/μl vs. 04.58 ± 00.42 10^6/μl; $U = 104{,}835.00$, $Z = -17.389$, $p < 0.00001$), Ht (44.53 ± 03.17% vs. 40.79 ± 03.12%; *equal variances* $t_{(1,390)} = 21.833$, $p < 0.00001$), Hb (14.93 ± 01.20 g/dl vs. 13.43 ± 01.14 g/dl; *equal variances* $t_{(1,390)} = 23.722$, $p < 0.00001$), MCH (29.84 ± 02.15 pg/cell vs. 29.40 ± 02.21 pg/cell; $U = 182{,}475.00$, $Z = -5.633$, $p < 0.00001$), and MCHC (33.53 ± 00.99 g/dl vs. 32.91 ± 00.96 g/dl; *equal variances* $t_{(1,388)} = 11.909$, $p < 0.00001$). No sex differences for MCV (88.98 ± 05.67 fl/cell in males vs. 89.28 ± 05.71 fl/cell in females; $U = 219{,}466.00$, $Z = -0.742$, $p = 0.458$) and CRP (00.34 ± 00.70 mg/dl in males vs. 00.35 ± 00.65 mg/dl in females; $U = 173{,}124.00$, $Z = -0.665$, $p = 0.506$).

Males had a mean age of 55.15 ± 15.63 years old and females had 57.28 ± 14.92 years old. A negative association was found between age and RBCs ($Rho = -00.184$, $p < 0.00001$), Ht ($Rho = -00.116$, $p = 0.00001$), Hb ($Rho = -0.164$, $p < 0.00001$), and MCHC ($Rho = -00.207$, $p < 0.00001$). Conversely, age positively associated with MCV ($Rho = +00.203$, $p < 0.00001$), MCH ($Rho = +00.068$, $p = 0.012$), and CRP ($Rho = +00.198$, $p < 0.00001$). The variables concerning surgical and anesthetic parameters are reported in **Table 3**, indicating data for each of the three clusters of spine diagnosis.

The association of sex, the years of age, and the biochemical markers with the ODI score at baseline are reported in **Figure 1**. There was found a positive association between the preoperative disability with the years of age ($B = +0.197$, $p < 0.00001$, 95% CI = +1.142: +0.253) and CRP ($B = +10.985$, $p < 0.00001$, 95% CI = +6.162: +15.807). An inverse association was observed for RBCs ($B = -4.117$, $p < 0.00001$, 95% CI = −5.931: −2.302), Ht ($B = -0.579$, $p < 0.00001$, 95% CI = −0.814: −0.343), Hb ($B = -1.736$, $p < 0.00001$, 95% CI = −2.355: −1.117), and

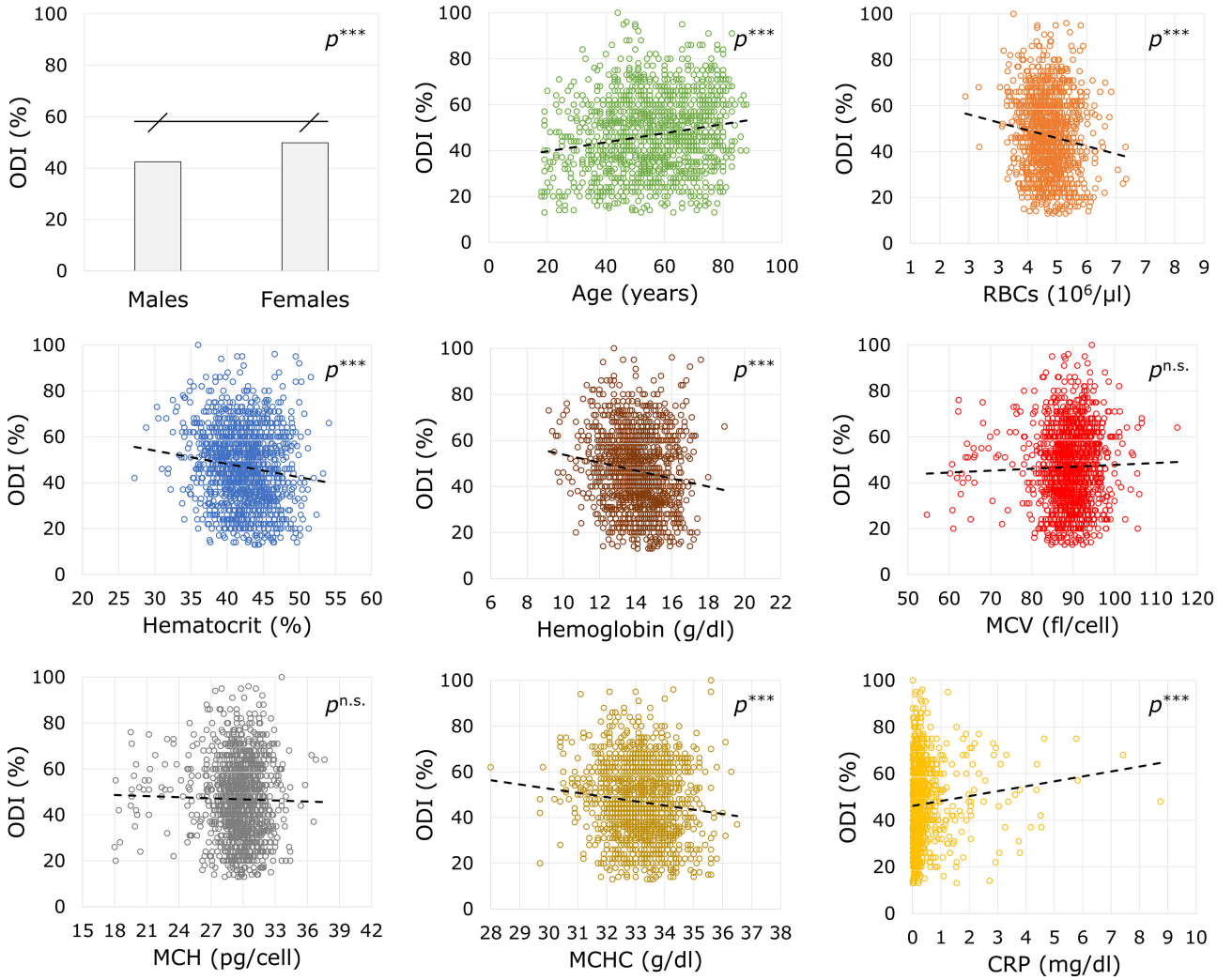


FIGURE 1 | Associations between demographic and biochemical variables with the disability index before surgery. ODI, Oswestry Disability Index, ranging from 0 (no disability) to 100 (maximum disability); RBCs, red blood cells; MCV, mean corpuscular volume; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; CRP, C-reactive protein. Statistics: $^{***}p < 0.001$; $^{n.s.}p$ not significant.

MCHC ($B = -1.829$, $p = 0.00003$, 95% CI = −2.686: −0.972). No association were found with circulating MCV ($B = 0.121$, $p = 0.219$, 95% CI = −0.072: +0.314) or MCH ($B = -0.176$, $p = 0.511$, 95% CI = −0.701: +0.349). Men showed lower values of disability against women (42.42 ± 16.22% vs. 49.88 ± 15.86%; $U = 172{,}804.50$, $Z = -8.294$, $p < 0.00001$).

Exploration of the Outcome

In the whole cohort, 1,022 patients recovered at least 30% from baseline ODI at 17 months, while the reduction of 12.7 points counted 1,019 successful outcomes. The recovery from disability considering 30% reduction showed an association with gender [$\chi_{(1)} = 5.339$, $p = 0.021$], with about 76.72% of males and 71.15% of females encountering a recovery. However, the gender association was not confirmed [$\chi_{(1)} = 0.017$, $p = 0.895$] after considering the reduction of 12.7 points. Patients with a unsuccessful recovery of at least 30% reduction were older at baseline ($U = 156{,}017.50$, $Z = -4.990$, $p < 0.00001$) with lower values of RBCs ($U = 165{,}980.50$, $Z = -3.385$, $p = 0.001$), Ht ($U = 170331.50$, $Z = -2.828$, $p = 0.005$), Hb ($U = 163{,}994.50$, $Z = -3.786$, $p = 0.0001$), MCHC ($U = 158{,}815.00$, $Z = -4.521$, $p < 0.00001$), but higher values of MCV ($U = 164{,}810.00$, $Z = -2.603$, $p = 0.009$). No differences for baseline MCH ($U = 178{,}818.50$, $Z = -0.051$, $p = 0.960$) and CRP ($U = 130{,}854.50$, $Z = -1.711$, $p = 0.087$). Considering the reduction of 12.7 points, the results were confirmed for age ($p = 0.002$), MCH ($p = 0.920$), MCHC ($p = 0.026$), and CRP ($p = 0.540$), but no differences were found for RBCs ($p = 0.098$), Ht ($p = 0.122$), Hb ($p = 0.059$), and MCV ($p = 0.147$). There was found a significant association between the 30% reduction and ASA [successful outcome in 81.07% with ASA 1, 72.55% with ASA 2, and 61.23% with ASA 3; $\chi_{(2)} = 36.381$, $p = 0.00002$], diagnosis [successful

outcome in 61.11% of spine deformities, 80.57% of disc disease, and 70.07% of back surgeries; $\chi_{(2)} = 36.381$, $p < 0.00001$], DS (209.83 ± 137.15 vs. 248.13 ± 152.25 min; $U = 156{,}271.50$, $Z = -4.339$, $p = 0.00001$), and LOS (4.58 ± 3.35 vs. 5.53 ± 4.17 days; $U = 155{,}719.00$, $Z = -4.077$, $p = 0.00004$). Considering the reduction of 12.7 points, the results were confirmed for ASA ($p = 0.016$), diagnosis ($p = 0.00001$), DS ($p = 0.002$), and LOS ($p = 0.005$), with baseline ODI resulting different between groups ($p < 0.00001$).

Predictive Model PRE_{BIO}

The values of RBCs, Ht, Hb, MCV, MCH, MCHC, and CRP were entered in the regression model to predict the variation of ODI at 17 months after surgery. The predictive model ($N = 1{,}179$) with the highest correlation was RBCs (*standardized* $B = -0.071$, $p = 0.015$, 95% CI = −5.857: −0.622). The model reported below significantly predicted the ODI variation [$F_{(1,1177)} = 5.895$, $p = 0.015$, $R^2 = 0.005$].

$$\mathbf{PRE_{BIO}\ (17\ months)} = \mathbf{-9.121 - 3.239}\left(\mathbf{RBCs}\frac{\mathbf{10^6}}{\mu\mathbf{l}}\right)$$

The estimated values calculated using the regression equation (−24.63 ± 1.53; min = −30.75; max = −18.48) showed no difference from real values (−24.37 ± 20.81; min = −96.00; max = +58.00) ($Z = -0.079$, $p = 0.937$). Using the 17-month reduction of 30% from baseline ODI score, increasing RBCs was associated with an increased likelihood of exhibiting a positive clinical outcome ($B = 0.431$, $p = 0.001$). The OR for having a positive outcome resulted in 1.539 (95% CI = 1.188: 1.992). The logistic regression model with RBCs correctly classified 73.34% of cases and was able to explain 1.14% (*Nagelkerke* R^2) of the variance in the clinical outcome, with very low misspecification in its predictive capacity [Hosmer-Lemeshow test $\chi^2_{(8)} = 13.207$, $p = 0.105$]. The RBCs-based NN analysis using the progress of 30% showed 34.75, 20.00, 24.48% of incorrect predictions of the holdout phase. The models resulted to be a poor diagnostic instrument (first run AUC = 0.553; second run AUC = 0.565; third run AUC = 0.559). Using the reduction of 12.7 from baseline, increasing RBCs was not significantly associated with an increased likelihood of exhibiting a positive clinical outcome ($B = 0.185$, $p = 0.152$). The OR for having a positive outcome resulted in 1.203 (95% CI = 0.934: 1.550). The logistic regression model correctly classified 73.19% of cases and was able to explain 0.2% of the variance in the clinical outcome. The NN analyses using the variation of −12.7 points showed 27.70, 29.14, and 24.27% of incorrect predictions of the holdout phase. In conclusion, the RBCs-based PRE_{BIO}(NN) resulted to be a poor diagnostic instrument (first run AUC = 0.527; second run AUC = 0.533; third run AUC = 0.528).

Predictive Model $PERI_{BIODEMCLI}$

The preoperative biomarkers were used to build the model at 17 months together with the two demographic variables of age and gender and the five clinical variables of diagnosis, ASA, baseline ODI, DS, and LOS. The model that resulted statistically significant [$F_{(5,1365)} = 93.487$, $p < 0.00001$, $R^2 = 0.255$] included the following predictor-specific coefficients: Hb (*standardized* $B = -0.067$, $p = 0.006$, 95% CI = −1.710: −0.281), age (*standardized* $B = +0.100$, $p = 0.0003$, 95% CI = +0.063: +0.207), ASA (*standardized* $B = +0.063$, $p = 0.024$, 95% CI = +0.300: +4.230), baseline ODI score (*standardized* $B = -0.500$, $p < 0.00001$, 95% CI = −0.688: −0.570), and LOS (*standardized* $B = +0.129$, $p < 0.00001$, 95% CI = +0.698: +1.498). Gender ($p = 0.088$), RBCs ($p = 0.698$), Ht ($p = 0.100$), MCV ($p = 0.839$), MCH ($p = 0.992$), MCHC ($p = 0.140$), CRP ($p = 0.083$), diagnosis ($p = 0.820$), and DS ($p = 0.265$) were excepted.

$$\begin{aligned}\mathbf{PERI_{BIODEMCLI}(17\ months)} &= \mathbf{+2.021} - \left[\mathbf{0.995}\times\left(\mathbf{Hb}\,\frac{\mathbf{g}}{\mathbf{dl}}\right)\right] \\ &+ \left[\mathbf{0.135}\times(\mathbf{years\ of\ age})\right] \\ &+ \left[\mathbf{2.265}\times(\mathbf{ASA})\right] \\ &- \left[\mathbf{0.629}\times(\mathbf{preoperative\ ODI})\right] \\ &+ \left[\mathbf{1.098}\times(\mathbf{days\ of\ hospital\ stay})\right]\end{aligned}$$

However, the extreme distributions of the regression predicted values (−24.65 ± 10.42%; min = −64.55; max = +0.62) differenced from real values ($p < 0.05$) (−24.37 ± 20.81%; min = −96.00; max = +58.00). Using the reduction of 30% from baseline ODI score, a greater likelihood of exhibiting positive outcome was again associated with increasing Hb ($B = 0.100$, $p = 0.035$, OR = 1.106, 95% CI = 1.007: 1.213), decreasing age ($B = -0.016$, $p = 0.001$, OR = 0.984, 95% CI = 0.975: 0.994), and shorter LOS ($B = -0.093$, $p = 0.0003$, OR = 0.911, 95% CI = 0.866: 0.958). However, no association was found with the preoperative ODI score ($B = 0.008$, $p = 0.051$, OR = 1.008, 95% CI = 1.000: 1.013) and ASA ($B = -0.196$, $p = 0.136$, OR = 0.822, 95% CI = 0.636: 1.064). The logistic regression model correctly classified 73.67% of cases and was able to explain 5.39% (*Nagelkerke* R^2) of the variance in the clinical outcome, with very low misspecification in its predictive capacity [Hosmer-Lemeshow test $\chi^2_{(8)} = 3.896$, $p = 0.866$]. In **Table 5** are reported the percentages of clinical success based on ranges of RBCs and Hb. There were expected 96.5% of true positives and 92.7% of false positives after setting a value of RBCs to 4 $10^6/\mu$l. Similarly, setting a value of Hb to 12 g/dl exhibited about 93.8% of the positive outcomes correctly classified as positive, but 88.9% of the negative outcomes incorrectly specified as positive.

Considering RBCs, Hb, the two demographic variables, and the five clinical variables, the $PERI_{BIODEMCLI}$(NN) with 30% reduction showed 29.46, 22.63, 25.71% of incorrect predictions in the holdout phase. The model resulted to be a fair diagnostic instrument (first run AUC = 0.628; second run AUC = 0.632; third run AUC = 0.626), with normalized importance of 100.00% given by age in the first and third run and LOS in the second run. Using the 17-month progress of −12.7 from baseline ODI score, the odds were confirmed for age ($p = 0.002$), ASA ($p = 0.154$), and LOS ($p = 0.001$), but Hb was no more a significant predictor ($p = 0.088$) whereas baseline ODI significantly predicted the outcome ($p < 0.00001$). The logistic regression model correctly classified 74.91% of cases and was able to explain 10.81% of the variance in the clinical outcome. The $PERI_{BIODEMCLI}$(NN) with 12.7 point reduction showed 34.69, 30.22, 29.17% of incorrect

TABLE 5 | Recovery from disability trends using scaled erythrocytes and hemoglobin.

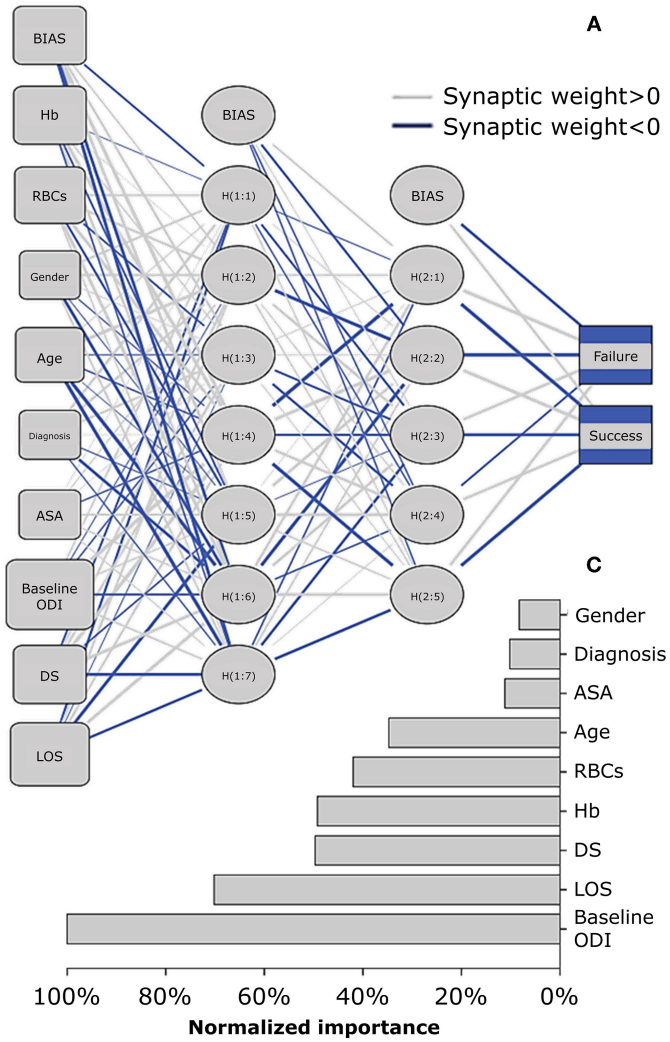
Predictors	Baseline ODI	17-month ODI	17-month success %
RBCs ($10^6/\mu l$)			
<4 ($n = 63$)	55.48 ± 16.41 (24.00; 100.00)	32.54 ± 21.67 (00.00; 86.00)	58.73%
4–4.49 ($n = 327$)	48.45 ± 15.85 (14.00; 95.00)	25.47 ± 20.38 (00.00; 93.00)	70.64%
4.5–4.49 ($n = 606$)	46.04 ± 15.76 (13.00; 95.00)	21.83 ± 19.20 (00.00; 86.00)	73.93%
5–5.49 ($n = 300$)	45.68 ± 17.00 (13.00; 96.00)	19.52 ± 19.07 (00.00; 97.00)	77.33%
≥5.50 ($n = 96$)	44.33 ± 18.15 (14.00; 95.00)	18.95 ± 20.65 (00.00; 86.00)	77.08%
Hb (g/dl)			
<12 ($n = 87$)	54.83 ± 14.82 (20.00; 84.00)	33.01 ± 23.78 (00.00; 86.00)	58.62%
12–12.9 ($n = 195$)	50.08 ± 16.57 (14.00; 100.00)	26.64 ± 19.92 (00.00; 93.00)	67.18%
13–13.9 ($n = 373$)	47.41 ± 15.22 (14.00; 95.00)	23.39 ± 19.00 (00.00; 80.00)	73.73%
14–14.9 ($n = 380$)	44.68 ± 15.69 (13.00; 91.00)	19.36 ± 18.88 (00.00; 97.00)	77.63%
15–15.9 ($n = 237$)	44.45 ± 16.83 (14.00; 88.00)	20.23 ± 19.31 (00.00; 90.00)	75.95%
≥16 ($n = 120$)	45.57 ± 19.38 (14.00; 96.00)	19.53 ± 20.29 (00.00; 78.00)	75.00%

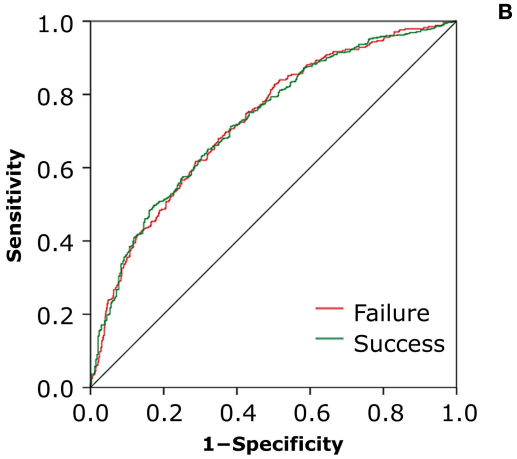
ODI, Oswestry Disability Index, ranging from 0 (no disability) to 100 (maximum disability); RBCs, red blood cells; Hb, hemoglobin. Clinical success, a 30% decrease from preoperative ODI at 17 months after surgery.

predictions in the holdout phase. The model resulted to be a fair diagnostic instrument (first run AUC = 0.720; second run AUC = 0.726; third run AUC = 0.723), with normalized importance of 100.00% given by baseline ODI.

DISCUSSION

It is foreseeable that the workload of spine surgery centers will intensify in the coming years as the population is getting older and debilitating polymorbid conditions are becoming not uncommon (19, 20). Technological advances in spine treatments help maintain short-term patient satisfaction high (21). However, it is necessary to plan patient-centered care pathways to achieve long-term results, thus revising the determinants of clinical success that simultaneously capture the perspective of the surgeon, the anesthesiologist, and the patient. In the present study, we analyzed the predictive potential of the preoperative biochemical markers on the ODI score at 17 months after surgery in patients enrolled in the institutional SpineReg of IRCCS Orthopedic Institute Galeazzi. The study cohort involved 1,392 patients undergoing surgery for deformity, disc disease, or other back spine disorders, and consisted of a majority of female older adults (**Table 2**). In absolute terms, an improvement in disability at the last follow-up was observed in over 88% of patients. Considering the more restrictive MCID of the ODI, about 73% of patients reported a successful recovery. Similar rates have already been observed in spine patients (5). There were no differences in recovery between males and females, but individuals who did not experience a clinical improvement were older at the time of surgery, had higher ASA, and lower ODI. Equally, these trends based on clinical determinants are in line with previous studies (22). Patients with spinal deformities experienced lower recovery rates than the other clusters of diagnosis, conceivably due to the greater surgical complexity that requires longer operative times and prolonged hospitalization (**Table 3**). Analyses of laboratory values confirmed that males generally have higher levels of RBCs and Hb than females and that there is a significant depletion with increasing age, feasibly mirroring iron supply discrepancies common in older adults. Similarly, the positive association of MCV and MCH with age would suggest an etiology from cobalamin or folate deficiency, which are known to cause macrocytic anemia in older individuals with poor strength of constitution (23, 24). This consideration was corroborated by increased disability and inflammation found in older patients (**Figure 1**). Based on available laboratory parameters, predictive modeling demonstrated that RBCs and Hb levels prior to surgery were the strongest determinants of clinical success at 17 months in all types of spine surgery. In particular, the univariate linear model explains 0.5 of the postoperative change in disability, with each unit increase in RBCs being associated up to 1.539 times the probability of clinical success. However, the corresponding neural network models showed poor diagnostic performance, having an erroneous prediction rate of up to 34.75% and an AUC of 0.565, making it unreliable in terms of sensitivity and specificity. Furthermore, only slight reductions in disability scores (−17 to −31 for RBCs) could be predicted. The prediction accuracy for poor outcomes did not improve after setting lower blood values, failing to identify both highly successful outcomes and worsening observed in 140 patients at 17 months. Therefore, it can be reasonably argued that stratification of patients based on univariate cut-offs may not be recommended and that studying laboratory biomarkers as continuous variables might be preferable (25, 26). In fact, the results in **Table 5** showing a comparable trend between blood parameters and success rates give both RBCs and Hb a strong connotation that is also relevant for the patient. With the inclusion of clinical parameters, the variables in the multivariate linear models were able to explain ∼25.1% at 17 months. The crude contribution thus accounts for both worsening and notable improvements in respect to the previous univariate model. Although the equation was not still adequate in the prediction of postoperative recovery, the neural network





Dependent variable	Outcome	AUC
Progress at 17 months	Failure	0.726
	Success	0.726

D

Classification

Sample	Observed	Predicted		
		Failure	Success	Percent correct
Training	Failure	72	191	27.38%
	Success	45	634	93.37%
	Overall %	12.42%	87.58%	74.95%
Testing	Failure	18	56	24.32%
	Success	17	206	92.38%
	Overall %	11.79%	88.22%	75.42%
Holdout	Failure	5	28	15.15%
	Success	14	92	86.79%
	Overall %	13.67%	86.33%	69.78%

FIGURE 2 | Multiplayer perceptron network predicting 17-month clinical recovery from disability using baseline biochemical, demographic, and clinical parameters. The Multilayer Perceptron Network (MPN) shows the prediction of 17-month recovery set as a raw decrease of 12.7 points from baseline ODI. **(A)** The architecture has two hidden layers, with the Sigmoid and Softmax being the hidden and output functions, respectively (criteria training = batch; optimization = scaled conjugate). **(B)** The network ROC curve (Receiver Operating Characteristic) shows a fair diagnostic performance of the parameters in predicting the last ODI score at 17 months after spine surgery. **(C)** The independent variables were rescaled (standardized) to show their normalized contribution in the model: gender (8.25%), diagnosis (10.20%), ASA (11.18%), age (34.72%), RBCs (41.95%), Hb (49.22%), DS (49.67%), LOS (70.20%), baseline ODI (100.00%). **(D)** The classification table of predicted vs. observed values was set with a training sample at 70%, a testing sample to track prediction at 20%, and a holdout sample to assess the final model at 10%. The final percent correct shows a high performance in predicting the clinically successful outcomes, but poor reliability to forecast negative outcomes. ODI, Oswestry Disability Index, ranging from 0 (no disability) to 100 (maximum disability); Hb, hemoglobin; RBCs, red blood cell count; ASA, American Society of Anesthesiologists physical status classification system (1, healthy; 2, mild; 3, severe; 4, life threatening; 5, moribund; 6, brain-dead); DS, duration of surgery; LOS, length of hospital stay.

model at the last follow-ups showed the highest diagnostic performance even for the more restrictive MCID (AUC between 0.720 and 0.726 with up to 15.15% of correct prediction of negative outcomes), providing a decreasing order of importance of the preoperative determinants: ODI, LOS, DS, Hb, RBCs, age, ASA, diagnosis, gender (**Figure 2**). Thus, Hb seems to have a high predictive potential even greater than variables of demographic or clinical nature. The importance of preoperative Hb has already been studied in relation to complications in children, adults, and older adults undergoing spinal surgery (27–29), but it is unclear how it affects patients' long-term daily activities. It is plausible to think that the blood concentration reflects not only the strength of the patient's constitution (e.g., nutritional status) (8, 9, 30), but also the disease-specific weaknesses whose complications might consequently affect the daily activities of the patients (31). For example, there was found an inverse association between Hb levels and the number of patients reporting fatigue and shortness of breath (32). Whatever the connection, it is undeniable the recognition of the predictive potential that Hb has in the many surgical fields (33, 34). This study has

limitations. Although patients admitted for complications were excluded from this research, information on intraoperative (e.g., transfusion-associated complications) or postoperative events that did not require access in our hospital was not accessible, thus possibly explaining the inability of the models to predict worsening. Furthermore, the study cohort might not represent the population of patients undergoing spinal surgery in our hospital, being indicative only of those who have agreed to participate in the registry over the years. While the completeness of the registry was satisfactory, missing data at predefined follow-ups reached 40% and may have provided some bias to the results. However, the models at 17 months were built on the scores at the last controls, thus making the results consistent (35). Lastly, although they can be estimated on the basis of surgical plan, both operative times and days of hospitalization are information available only after the intervention, which could undermine the preoperative nature of models.

In conclusion, our study sheds light on the role of preoperative Hb and RBCs in predicting long-term recovery reported by patients. Based on this research, values of RBCs $< 4\ 10^6/\mu l$ and of Hb < 12 g/dl in both genders may be associated with excessive rates of long-term failure after spine surgery from a patient's perspective. However, the model is not reliable in its current form and should be integrated with multidimensional variables of demographic, laboratory, and clinical nature to investigate further recovery determinants, such as body weight (36), the psychological distress (37), or the propensity for postoperative movement (38) and social participation (39). The ideal predictive model should have both high sensitivity and low false-positive rates. This is especially relevant when the consequence of not identifying patients at risk for negative outcomes could affect long-term daily activities. The performance of predictive models also varies according to the extent of recovery considered clinically relevant (17, 18), a concept that places the need to involve the patient in planning the treatment path, thus making the pre-admission visit more patient-centered. In the future, the correct stratification of individuals at risk will ensure opportunities to optimize patient's health in time for surgery, more affordable clinical care, and greater patient's satisfaction (16, 40, 41).

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

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

MB, PP, FL, TC, and ED conceived and designed the research. MB, FL, TC, and ED collected the data and managed the database. MB analyzed the data and wrote the first draft of the manuscript. PP, FL, TC, ED, PR, MP, LS, RB, MB-B, GB, and PB revised the first draft and contributed to the manuscript sections. GB and PB supervised the study. All authors contributed to the manuscript revision and approved the submitted version.

ACKNOWLEDGMENTS

This study was part of the project Ricerca Corrente del Ministero della Salute (Italian Ministry of Health).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsurg.2022.850342/full#supplementary-material

REFERENCES

1. Parenteau CS, Lau EC, Campbell IC, Courtney A. Prevalence of spine degeneration diagnosis by type, age, gender, and obesity using Medicare data. *Sci Rep.* (2021) 11:5389. doi: 10.1038/s41598-021-84724-6
2. Zanotto BS, Etges A, Marcolino MAZ, Polanczyk CA. Value-based healthcare initiatives in practice: a systematic review. *J Healthc Manag.* (2021) 66:340–65. doi: 10.1097/JHM-D-20-00283
3. Finkelstein JA, Schwartz CE. Patient-reported outcomes in spine surgery: past, current, future directions. *J Neurosurg Spine.* (2019) 31:155–64. doi: 10.3171/2019.1.SPINE18770
4. Fairbank JC, Pynsent PB. The oswestry disability index. *Spine (Phila Pa 1976).* (2000) 25:2940–52; discussion 2952. doi: 10.1097/00007632-200011150-00017
5. Nielsen CJ, Lewis SJ, Oitment C, Martin AR, Lenke LG, Qiu Y, et al. Stratifying outcome based on the Oswestry Disability Index for operative treatment of adult spinal deformity on patients 60 years of age or older: a multicenter, multi-continental study on Prospective Evaluation of Elderly Deformity Surgery (PEEDS). *Spine J.* (2021) 21:1775–83. doi: 10.1016/j.spinee.2021.07.007
6. Prodinger B, Taylor P. Improving quality of care through patient-reported outcome measures (PROMs): expert interviews using the NHS PROMs Programme and the Swedish quality registers for knee and hip arthroplasty as examples. *BMC Health Serv Res.* (2018) 18:87. doi: 10.1186/s12913-018-2898-z
7. Briguglio M, Gianola S, Aguirre MF, Sirtori P, Perazzo P, Pennestri F, et al. Nutritional support for enhanced recovery programs in orthopedics: Future perspectives for implementing clinical practice. *Nutr Clin Métab.* (2019) 33:190–8. doi: 10.1016/j.nupar.2019.04.002
8. Xu B, Xu WX, Lao YJ, Ding WG, Lu D, Sheng HF. Multimodal nutritional management in primary lumbar spine surgery: a randomized controlled trial. *Spine (Phila Pa 1976).* (2019) 44:967–74. doi: 10.1097/BRS.0000000000002992
9. Sachdeva I, Carmouche JJ. Postoperative anemia predicts length of stay for geriatric patients undergoing minimally invasive lumbar spine fusion surgery. *Geriatr Orthop Surg Rehabil.* (2020) 11:2151459320911874. doi: 10.1177/2151459320911874
10. Suresh KV, Wang K, Sethi I, Zhang B, Margalit A, Puvanesarajah V, et al. Spine surgery and preoperative hemoglobin, hematocrit, and

hemoglobin A1c: a systematic review. *Global Spine J.* (2022) 12:155–65. doi: 10.1177/2192568220979821
11. Briguglio M, Crespi T, Pino F, Mazzocchi M, Porta M, De Vecchi E, et al. Clinical characteristics of severe COVID-19 patients admitted to an intensive care unit in lombardy during the italian pandemic. *Front Med.* (2021) 8:582896. doi: 10.3389/fmed.2021.582896
12. Briguglio M, Hrelia S, Malaguti M, De Vecchi E, Lombardi G, Banfi G, et al. Oral supplementation with sucrosomial ferric pyrophosphate plus L-ascorbic acid to ameliorate the martial status: a randomized controlled trial. *Nutrients*. (2020) 12:386. doi: 10.3390/nu12020386
13. Barrie U, Youssef CA, Pernik MN, Adeyemo E, Elguindy M, Johnson ZD, et al. Transfusion guidelines in adult spine surgery: a systematic review critical summary of currently available evidence. *Spine J.* (2022) 22:238–48. doi: 10.1016/j.spinee.2021.07.018
14. Mehta VA, Van Belleghem F, Price M, Jaykel M, Ramirez L, Goodwin J, et al. Hematocrit as a predictor of preoperative transfusion-associated complications in spine surgery: a NSQIP study. *Clin Neurol Neurosurg.* (2021) 200:106322. doi: 10.1016/j.clineuro.2020.106322
15. Murphy MF, Goodnough LT. The scientific basis for patient blood management. *Transfus Clin Biol.* (2015) 22:90–96. doi: 10.1016/j.tracli.2015.04.001
16. Debono B, Wainwright TW, Wang MY, Sigmundsson FG, Yang MMH, Smid-Nanninga H, et al. Consensus statement for perioperative care in lumbar spinal fusion: Enhanced Recovery After Surgery (ERAS(R)) Society recommendations. *Spine J.* (2021) 21:729–52. doi: 10.1016/j.spinee.2021.01.001
17. Vanti C, Ferrari S, Villafane JH, Berjano P, Monticone M. Responsiveness and minimum important change of the Oswestry Disability Index in Italian subjects with symptomatic lumbar spondylolisthesis. *J Orthop Traumatol.* (2017) 18:145–50. doi: 10.1007/s10195-017-0446-y
18. Monticone M, Baiardi P, Vanti C, Ferrari S, Pillastrini P, Mugnai R, et al. Responsiveness of the Oswestry Disability Index and the Roland Morris Disability Questionnaire in Italian subjects with sub-acute and chronic low back pain. *Eur Spine J.* (2012) 21:122–9. doi: 10.1007/s00586-011-1959-3
19. Sethi R, Bohl M, Vitale M. State-of-the-art reviews: safety in complex spine surgery. *Spine Deform.* (2019) 7:657–68. doi: 10.1016/j.jspd.2019.04.002
20. Briguglio M. The burdens of orthopedic patients and the value of the HEPAS approach (healthy eating, physical activity, sleep hygiene). *Front Med.* (2021) 8:650947. doi: 10.3389/fmed.2021.650947
21. Mooney J, Michalopoulos GD, Alvi MA, Zeitouni D, Chan AK, Mummaneni PV, et al. Minimally invasive versus open lumbar spinal fusion: a matched study investigating patient-reported and surgical outcomes. *J Neurosurg Spine.* (2021) 14:1–14. doi: 10.3171/2021.10.SPINE211128
22. Aghayev E, Mannion AF, Fekete TF, Janssen S, Goodwin K, Zwahlen M, et al. Risk factors for negative global treatment outcomes in lumbar spinal stenosis surgery: a mixed effects model analysis of data from an International Spine Registry. *World Neurosurg.* (2020) 136:e270–83. doi: 10.1016/j.wneu.2019.12.147
23. Puvanesarajah V, Jain A, Kebaish K, Shaffrey CI, Sciubba DM, De la Garza-Ramos R, et al. Poor nutrition status and lumbar spine fusion surgery in the elderly: readmissions, complications, and mortality. *Spine (Phila Pa 1976).* (2017) 42:979–83. doi: 10.1097/BRS.0000000000001969
24. Briguglio M, Lombardi G, Sansoni V, Perego S, Colonna V, Stella D, et al. Vitamin D, cardio-inflammation, and endothelial dysfunction in older adults after orthopedic surgery: results from an open-label trial to ameliorate cardiac function. *Nutr Clin Métab.* (2020) 34:313–18. doi: 10.1016/j.nupar.2020.06.003
25. Leu S, Kamenova M, Mehrkens A, Mariani L, Scharen S, Soleman J. Preoperative and postoperative factors and laboratory values predicting outcome in patients undergoing lumbar fusion surgery. *World Neurosurg.* (2016) 92:323–38. doi: 10.1016/j.wneu.2016.05.011
26. Briguglio M, Hrelia S, Malaguti M, Lombardi G, Riso P, Porrini M, et al. The central role of iron in human nutrition: from folk to contemporary medicine. *Nutrients*. (2020) 12:1761. doi: 10.3390/nu12061761
27. Seicean A, Seicean S, Alan N, Schiltz NK, Rosenbaum BP, Jones PK, et al. Preoperative anemia and perioperative outcomes in patients who undergo elective spine surgery. *Spine (Phila Pa 1976).* (2013) 38:1331–41. doi: 10.1097/BRS.0b013e3182912c6b
28. Elsamadicy AA, Adogwa O, Ongele M, Sergesketter AR, Tarnasky A, Lubkin DET, et al. Preoperative hemoglobin level is associated with increased health care use after elective spinal fusion (>/=3 levels) in elderly male patients with spine deformity. *World Neurosurg.* (2018) 112:e348–54. doi: 10.1016/j.wneu.2018.01.046
29. Fontanals M, O'Leary JD, Zaarour C, Skelton T, Faraoni D. Preoperative anemia increases the risk of red blood cell transfusion and prolonged hospital length of stay in children undergoing spine arthrodesis surgery. *Transfusion.* (2019) 59:492–9. doi: 10.1111/trf.15055
30. Wu M, Lian XJ, Jia JM, Cao WT, Yan N, Xin YM, et al. The role of the Patient-Generated Subjective Global Assessment (PG-SGA) and biochemical markers in predicting anemia patients with cancer. *Support Care Cancer.* (2019) 27:1443–8. doi: 10.1007/s00520-018-4462-0
31. Moazzeni K, Kazemi KA, Khanmohammad R, Eslamian M, Rostami M, Faghih-Jouibari M. Comparison of surgical outcome between diabetic versus nondiabetic patients after lumbar fusion. *Int J Spine Surg.* (2018) 12:528–32. doi: 10.14444/5064
32. Johnstone PAS, Alla R, Yu HM, Portman D, Cheng H, Mitchell R, et al. Patient-reported outcomes: using ESAS to screen for anemia. *Support Care Cancer.* (2020) 28:4141–5. doi: 10.1007/s00520-019-05238-6
33. Baron DM, Hochrieser H, Posch M, Metnitz B, Rhodes A, Moreno RP, et al. Preoperative anaemia is associated with poor clinical outcome in non-cardiac surgery patients. *Br J Anaesth.* (2014) 113:416–23. doi: 10.1093/bja/aeu098
34. Lin J, Wang C, Liu J, Yu Y, Wang S, Wen A, et al. Prevalence and intervention of preoperative anemia in Chinese adults: a retrospective cross-sectional study based on national preoperative anemia database. *EClinicalMedicine.* (2021) 36:100894. doi: 10.1016/j.eclinm.2021.100894
35. Austevoll IM, Gjestad R, Grotle M, Solberg T, Brox JI, Hermansen E, et al. Follow-up score, change score or percentage change score for determining clinical important outcome following surgery? An observational study from the Norwegian registry for Spine surgery evaluating patient reported outcome measures in lumbar spinal stenosis and lumbar degenerative spondylolisthesis. *BMC Musculoskelet Disord.* (2019) 20:31. doi: 10.1186/s12891-018-2386-y
36. Goyal A, Elminawy M, Kerezoudis P, Lu VM, Yolcu Y, Alvi MA, et al. Impact of obesity on outcomes following lumbar spine surgery: a systematic review and meta-analysis. *Clin Neurol Neurosurg.* (2019) 177:27–36. doi: 10.1016/j.clineuro.2018.12.012
37. Sivaganesan A, Khan I, Pennings JS, Roth SG, Nolan ER, Oleisky ER, et al. Why are patients dissatisfied after spine surgery when improvements in disability and pain are clinically meaningful? *Spine J.* (2020) 20:1535–43. doi: 10.1016/j.spinee.2020.06.008
38. Archer KR, Seebach CL, Mathis SL, Riley LH III, Wegener ST. Early postoperative fear of movement predicts pain, disability, and physical health six months after spinal surgery for degenerative conditions. *Spine J.* (2014) 14:759–67. doi: 10.1016/j.spinee.2013.06.087
39. Coronado RA, Robinette PE, Henry AL, Pennings JS, Haug CM, Skolasky RL, et al. Bouncing back after lumbar spine surgery: early postoperative resilience is associated with 12-month physical function, pain interference, social participation, and disability. *Spine J.* (2021) 21:55–63. doi: 10.1016/j.spinee.2020.07.013
40. Briguglio M, Gianturco L, Stella D, Colombo C, Bonadies M, Sala O, et al. Correction of hypovitaminosis D improved global longitudinal strain earlier than left ventricular ejection fraction in cardiovascular older adults after orthopaedic surgery. *J Geriatr Cardiol.* (2018) 15:519–22. doi: 10.11909/j.issn.1671-5411.2018.08.005

41. Briguglio M, Wainwright T. Nutritional and physical prehabilitation in elective orthopedic surgery: rationale and proposal for implementation. *Ther Clin Risk Manag*. (2022) 18:21–30. doi: 10.2147/TCRM.S341953

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: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers in Surgery

ORIGINAL RESEARCH
published: 16 March 2022
doi: 10.3389/fsurg.2022.841134

Neurosurgical Management of Interspinous Device Complications: A Case Series

*T. J. Florence[1], Irene Say[2], Kunal S. Patel[1], Ansley Unterberger[3], Azim Laiwalla[1], Andrew C. Vivas[1] and Daniel C. Lu[1]**

[1] UCLA Department of Neurosurgery, Los Angeles, CA, United States, [2] Department of Neurosurgery, University of Massachusetts, Worcester, MA, United States, [3] David Geffen School of Medicine, University of California, Los Angeles, Los Angeles, CA, United States

Background: Best practice guidelines for treating lumbar stenosis include a multidisciplinary approach, ranging from conservative management with physical therapy, medication, and epidural steroid injections to surgical decompression with or without instrumentation. Marketed as an outpatient alternative to a traditional lumbar decompression, interspinous process devices (IPDs) have gained popularity as a minimally invasive stabilization procedure. IPDs have been embraced by non-surgical providers, including physiatrists and anesthesia interventional pain specialists. In the interest of patient safety, it is imperative to formally profile its safety and identify its role in the treatment paradigm for lumbar stenosis.

Case Description: We carried out a retrospective review at our institution of neurosurgical consultations for patients with hardware complications following the interspinous device placement procedure. Eight cases within a 3-year period were identified, and patient characteristics and management are illustrated. The series describes the migration of hardware, spinous process fracture, and worsening post-procedural back pain.

Conclusions: IPD placement carries procedural risk and requires a careful pre-operative evaluation of patient imaging and surgical candidacy. We recommend neurosurgical consultation and supervision for higher-risk IPD cases.

Keywords: lumbar stenosis, interspinous device, decompressive laminectomy, minimally invasive (MIS), complications

OPEN ACCESS

Edited by:
Hengxing Zhou,
Tianjin Medical University General Hospital, China

Reviewed by:
Gregory Fabrice Jost,
University of Basel, Switzerland
Brandon Sherrod,
The University of Utah, United States

****Correspondence:***
Daniel C. Lu
dclu@mednet.ucla.edu

Specialty section:
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

Received: *22 December 2021*
Accepted: *27 January 2022*
Published: *16 March 2022*

Citation:
Florence TJ, Say I, Patel KS, Unterberger A, Laiwalla A, Vivas AC and Lu DC (2022) Neurosurgical Management of Interspinous Device Complications: A Case Series. Front. Surg. 9:841134. doi: 10.3389/fsurg.2022.841134

INTRODUCTION

Degenerative lumbar stenosis is a condition resulting from severe narrowing of the spinal canal and often manifests as neurogenic claudication: back and/or leg pain exacerbated by load-bearing activity and lumbar extension, and improved symptoms with rest or flexion. Standard of care treatment begins with conservative measures such as physical therapy, and anti-inflammatory pain medications. Treatment escalates stepwise to corticosteroid injections and decompressive surgery with or without instrumentation for refractory symptoms and corresponding radiographic pathology. Developed as an alternative to decompressive laminectomy, interspinous process devices (IPDs) are an emerging technology in treating lumbar stenosis. The devices are designed

to limit the extension between two spinal levels, in turn preventing symptomatic exacerbation of lumbar stenosis. Chiefly placed by interventional pain specialists or physiatrists according to 2018 CMS data, patient selection and IPD placement are performed by physicians without dedicated training in spine instrumentation (1).

Several IPD brands are available, including X-STOP (Medtronic, Minneapolis, MN), Coflex (Paradigm Spine, New York, NY), Helifix (Alphatec, Carlsbad, CA), Stenofix (Depuy Synthes, Raynham, MA), FLEXUS (Globus, Audubon, PA), Device for Intervertebral Assisted Motion (DIAM) (Medtronic, Minneapolis, MN), Aperius (Medtronic, Minneapolis, MN), Wallis (Zimmer Biomet, Warsaw, IN), and the Superion (Vertiflex/Boston Scientific, Marlborough, MA) (2–4). Efficacy studies have shown an improvement in back and leg pain, functional outcome scores, and reduced the opioid medication requirement compared to conservative therapy (5–11). However, the optimal role of IPDs relative to surgical decompression remains unclear (12, 13). Heterogeneity in practice patterns reflects a lack of clear clinical evidence for the role of IPDs in the management of lumbar stenosis. We frequently observe device implantation offered without a formal evaluation from a spine surgeon.

In this study, we describe our case series of patients referred to our service for management of complications after undergoing placement of IPD by non-surgical providers. We detail a novel surgical approach for minimally invasive IPD removal and simultaneous definitive decompression. We measured parameters describing stenosis and spinal alignment and then discussed each case as a representative example of an area of concern with IPDs.

MATERIALS AND METHODS

Institutional review board approval was obtained for this study. A database of neurosurgery consultations was reviewed to identify inpatient and outpatient consultations regarding issues with previously placed IPDs. Electronic charts were queried for patient presentation, imaging findings, management decision-making, and short- and long-term outcomes. In cases requiring surgical intervention, intraoperative video footage was collected.

We extracted spinal parameters from available clinical images, covering time points before IPD implantation, post-implantation at the time of neurosurgical evaluation, and post-evaluation images. Within-patient measurements were performed on identical imaging modalities where possible. To minimize errors associated with cross-modality comparisons (e.g., MRI to CT) between patients, we utilized ratiometric measurements. To evaluate stenosis, we define relative canal diameter as the dorsal-ventral canal lumen diameter at the maximally stenotic symptomatic level, divided by the diameter at the immediately rostral pedicle. This measurement borrows from established quantitative methods (14) for measuring stenosis with the added numerical benefit of normalizing for individual anatomy. We define lumbar lordosis as the Cobb angle formed by the L1 and S1 superior vertebral body endplate on standing, neutral-position lumbar radiographs, in keeping with established methods (15, 16). Across patients, we calculate means for defined time points and test for significance *via* Student's *t*-test.

SUMMARY OF CASES

Cases are summarized in brief in **Tables 1–3**. Cases 1–4 describe inpatient consultations; cases 5–8 describe outpatient consultations. A graphical illustration of our minimally invasive surgery (MIS) method for IPD removal and simultaneous definitive laminectomy is shown in **Figure 1**.

Case 1

A 75-year-old man presented with neurogenic claudication for 2 months. MRI showed lumbar spondylosis with severe lumbar stenosis at the L4/5 level (**Figures 2A,B**). He was seen by a pain management physician with an initial trial of conservative management including physical therapy and anti-inflammatory medications. He continued to have severe pain with disability. He had no neurologic weakness, sensory changes, or bowel and/or bladder dysfunction. At this time, he was recommended an interspinous spacer placement and had the Boston Scientific Superion interspinous spacer placed by an outside physician at the L4/5 level.

The patient was evaluated at our institution after this procedure with worsening severe back pain. He did not have a neurologic deficit, or bowel/bladder dysfunction. A CT scan of the lumbar spine was ordered and showed the interspinous spacer device had migrated anterior to the L4/5 interspinous space, leading to further central canal stenosis (**Figures 2C,D**). Neurosurgery was consulted for recommendations on management for migration of the interspinous spacer device. Given the patient's worsening symptoms and imaging findings, the patient was taken to the operating room within 24 h of presentation to remove the device.

The patient was positioned prone, and the previous incision was located and opened. Subperiosteal dissection was completed to identify the L4 and L5 spinous processes. Soft tissue was removed in the interspinous space until the dorsal side of the interspinous spacer device was identified. The device had migrated anteriorly to the lamina. A laminotomy at L4 was completed to retrieve the device. The dura was examined after removal of the device with no evidence of a cerebrospinal fluid leak. A decompression at L4/5 was completed, given the patient's degenerative lumbar stenosis with identified hypertrophied facet joints and thickened ligaments (**Supplementary Video 1**).

Post-operatively the patient's back pain and neurogenic claudication were significantly improved. The patient was discharged on post-operative day 1 with oral pain medications. There were no long-term issues with pain or neurologic function.

Case 2

An 84-year-old gentleman with coronary artery disease with recent placement of drug-eluting stents and congestive heart failure with an ejection fraction of 20% presented with chronic back pain, neurogenic claudication, and right-sided radicular pain in the L5 distribution. The patient had no weakness

TABLE 1 | Patient demographics.

Patient	Age	Sex	Comorbidities	Presenting Sx	Presenting pathology	Initial pain regimen	ESI	PT	Preop nsg consult
1	75	M	Locally invasive prostate CA	cLBP, Neurogenic Claudication, BLE L5 Radiculopathy	Severe L4/5 stenosis	Percocet, gabapentin	No	Yes	No
2	84	M	CAD s/p CABG, HFrEF, Aflb, pHTN, CVA	cLBP	Severe L4/5 stenosis	Oxycodone	Yes	Yes	No
3	58	M	Afib, poorly controlled T2DM	cLBP	Baastrup's disease, spondylosis without canal stenosis	Meloxicam, flexeril, gabapentin	Yes	Yes	No
4	91	F	CAD s/p CABG, pHTN, COPD	R L5 radiculopathy	Moderate L4/5 and L5/S1 stenosis, RL5 synovial cyst w/severe foraminal stenosis	Norco and pregabalin	Yes	Yes	Yes
5	78	M	HCM, pAfib	Neurogenic claudication	Moderate L3/4 and L4/5 stenosis	Norco	Yes	Yes	No
6	73	F	Osteoporosis, HCV	cLBP, BLE L5 radiculopathy	Severe L4/5 stenosis, degenerative levoscoliosis	Meloxicam, robaxin, nortriptyline	Yes	Yes	No
7	77	F	None	L5 radiculopathy	Severe L3/4 and L4/5 stenosis	Ibuprofen	Yes	No	No
8	74	F	RA, coronary aneurysm, pHTN, COPD, emphysema	Rheumatic joint pain, BLE L5 radiculopathy	Severe L4/5 stenosis	Tramadol, meloxicam, gabapentin, duloxetine	Yes	Yes	No

Afib, atrial fibrillation; BLE, bilateral lower extremity; CA, cancer; CAD, coronary artery disease; CABG, coronary artery bypass graft; cLBP, chronic low back pain; CVA, cerebrovascular accident (stroke); ESI, epidural steroid injections; HCM, hypertrophic cardiomyopathy; HCV, hepatitis C; nsg, neurosurgery; pHTN, pulmonary hypertension; PT, physical therapy; Sx, symptoms; T2DM, type 2 diabetes mellitus.

TABLE 2 | Perioperative considerations.

Patient	Off-label	Implant level	Complication	Prompting Sx	Surgery	Outcome
1	Yes	L4/5	Ventral migration	Immediate post-operative pain exacerbation	MIS L4/5 laminectomy, IPD removal	Pain exacerbation resolved
2	Yes	L4/5	L4 spinous process fracture, ventral migration	Acute LBP, L4/5 radiculopathy	Bone fragment and IPD removal (performed by pain team)	BLE L4 radiculopathy
3	Yes	L3/4	None	Acute pain exacerbation	None	Requires frequent RFA ablations
4	Yes	L4/5	Inferior and ventral migration, S1 stenosis	Extreme BLE L5/S1 radiculopathy urinary retention	MIS L4/5 laminectomy IPD removal	Resolved radiculopathy and urinary retention
5	No	L3/4 and L4/5	None	Progressive R L4/5 radiculopathy	L3/4 4/5 laminectomy IPD removal x 2	Radiculopathy resolved
6	Yes	L4/5	None	Neurogenic claudication, worsening BLE L5 radiculopathy	MIS L4/5 laminectomy, IPD removal	R thigh pain resolved, L persistent
7	Yes	L3/4 and L4/5	None	Nonrelief of symptoms	L3/4 4/5 laminectomy IPD removal x 2	Resolved radiculopathy
8	Yes	L4/5	None	Nonrelief of symptoms	MIS L4/5 laminectomy, IPD removal	Resolved radiculopathy

BLE, bilateral lower extremity; IPD, interspinous process device; LBP, low back pain; MIS, minimally invasive surgery; RFA, radiofrequency ablation; Sx, symptoms.

or bowel and bladder dysfunction. The patient's MRI showed severe lumbar stenosis at the L4/5 level and mild stenosis at the L3/4 level (**Figures 3A,B**). He was followed by a pain management team outside our department who recommended IPD placement after finding no relief with conservative measures. The patient's anticoagulation was held for the procedure, and

TABLE 3 | Symptomatology and temporal characteristics.

Patient	Pain at consultation (VAS)	Pain at follow up (VAS)	Implant to consultation (days)	Implant to surgical intervention (days)	Follow-up (days)
1	10/10	8/10	3	4	894
2	6/10	8/10	11	21	211
3	7/10	7/10	17	n/a	949
4	10/10	2/10	7	9	378
5	8/10	3/10	874	905	68
6	8/10	6/10	266	290	147
7	10/10	4/10	115	173	330
8	8/10	8/10	359	383	108

VAS, visual analog scale.

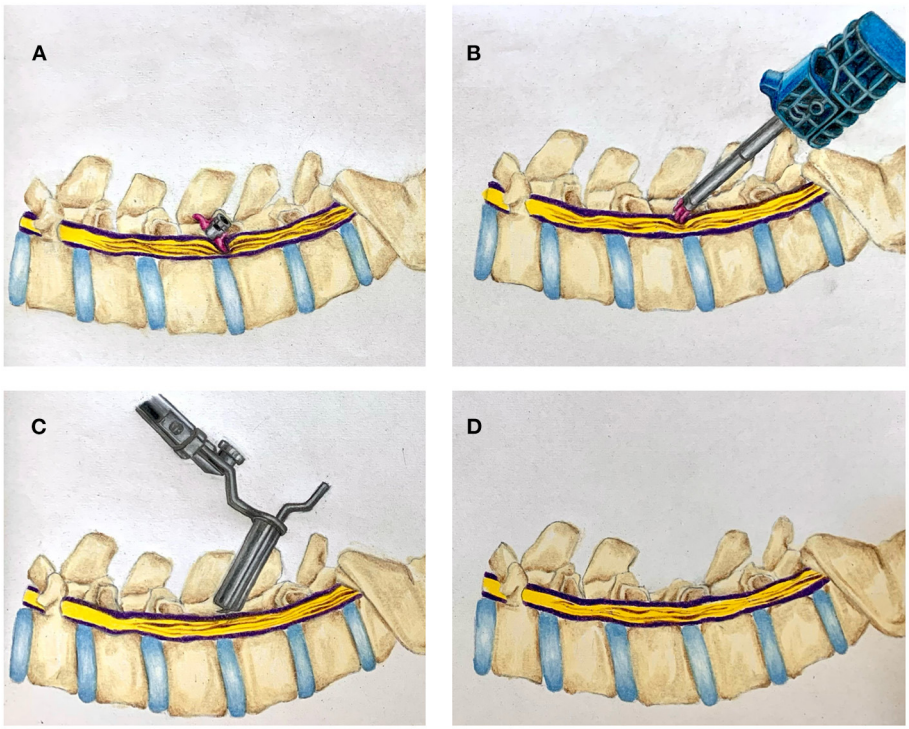


FIGURE 1 | Illustration of combined interspinous process device (IPD) retrieval and MIS lumbar decompression. **(A)** Migrated interspinous process device *in situ*. **(B)** Retrieval of migrated IPD. **(C)** Tubular MIS laminectomy. **(D)** Completed laminectomy.

a Superion interspinous spacer device was implanted at the L4/5 level.

The patient presented to our emergency department 1 week after this procedure with worsening back pain and no improvement in pre-operative radicular leg pain and paresthesia. There was no change in strength or bowel/bladder function. A plain X-ray in the emergency department showed a L4 spinous process fracture (**Figures 3C,D**). At this time, neurosurgery was consulted. Removal of the IPD was recommended because of new worsening back pain and instability of the IPD.

The patient was positioned prone, and the previous incision was opened. The interspinous spacer device was removed along with the fracture fragment of the L4 spinous process. Post-operatively, the patient's pain improved, and the patient was discharged on the same day of the procedure.

Case 3

A 58-year-old man with atrial fibrillation initially presented with chronic low back pain without neurogenic claudication or radicular pain. He was initially managed by an outside clinical team who diagnosed L4/5 Baastrup's disease and performed a partial removal of the L4 spinous process and lamina. After this procedure, the patient had persistent lower back pain. The patient had no neurologic weakness or bowel and/or bladder symptoms. An MRI showed lumbar spondylosis without significant central

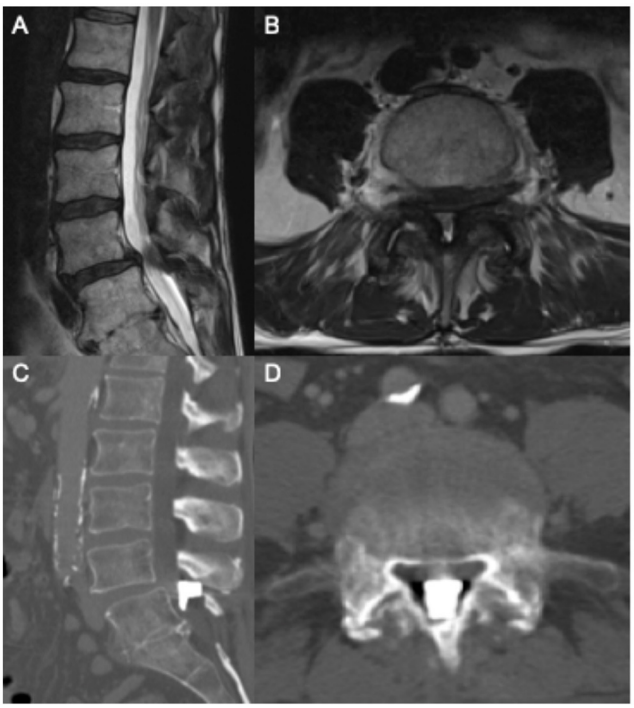


FIGURE 2 | Pre-operative sagittal **(A)** and axial **(B)** T2 MRI showing L4/5 severe central canal stenosis. Following interspinous spacer placement, sagittal **(C)** and axial **(D)** CT scan showing spacer migration into central canal.

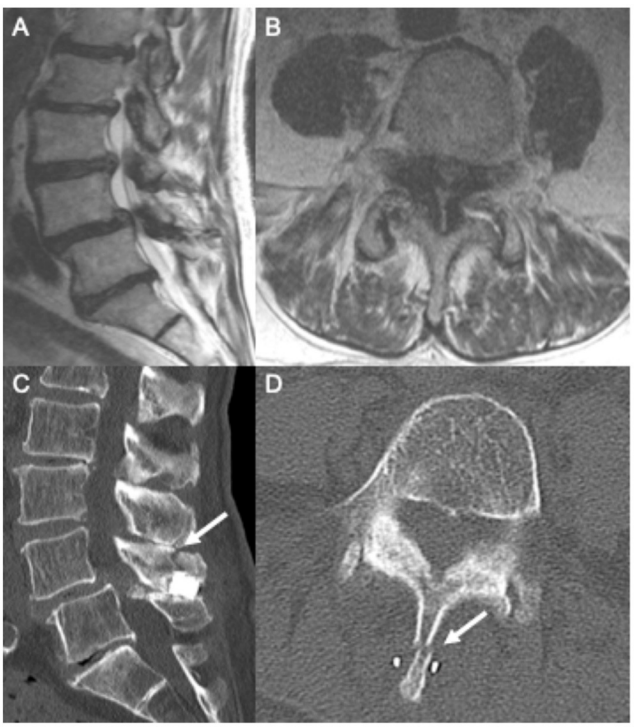


FIGURE 3 | Pre-operative sagittal **(A)** and axial **(B)** T2 MRI showing grade 1 spondylolisthesis and L4/5 severe central canal stenosis. Following interspinous spacer placement, sagittal **(C)** and axial **(D)** CT imaging showing L4 spinous process fracture.

canal stenosis. A Superion interspinous spacer device was placed at the L3/4 level. His anticoagulation was held for this procedure.

The patient presented to our emergency department of our institution with worsening pain over the incision site used to place the interspinous spacer device. Neurosurgery was consulted for recommendations on management. Imaging completed in the emergency department showed no fracture or migration of the device. The patient's pain was able to be controlled with pain medications, and he was scheduled for facet injections at this level.

Case 4

A 91-year-old female with coronary artery disease status post three-vessel bypass, pulmonary hypertension, and chronic obstructive pulmonary disease presented with debilitating right lower extremity radiculopathy. Imaging revealed a synovial cyst at the right L5/S1 facet resulting in severe foraminal stenosis and moderate L4/5 and L5/S1 canal stenosis. She was evaluated by both neurosurgical and orthopedic specialists who did not recommend surgical intervention given her age and serious comorbidities. She established care with a pain specialist who first managed her conservatively with oral pain medication and epidural and foraminal steroid injections. Ultimately, she underwent implantation of an L4/5 IPD by an interventional pain specialist.

Upon awakening in the recovery unit, the patient developed severe surgical site pain and new bilateral lower extremity radiculopathy. She required admission for the pain control. Our neurosurgical service was consulted after several days of unremitting pain and urinary retention. CT lumbar spine revealed ventral migration of the IPD into the canal with severe stenosis. The patient underwent an urgent MIS L4/5 laminectomy and IPD removal with subsequent resolution of pain and urinary retention. Due to deconditioning, the patient was discharged to a skilled nursing facility.

Case 5

A 78-year-old male with hypertrophic cardiomyopathy and paroxysmal atrial fibrillation presented with chronic low back pain and neurogenic claudication. After no response to physical therapy, oral pain medications, and epidural steroid injections, he underwent implantation of IPD at L3/4 and L4/5 for moderate stenosis by an interventional pain specialist.

The patient presented to our clinic with persistent back pain and new right L5 radiculopathy. Workup revealed subtle progression of stenosis, including the right L4 lateral recess. We performed a minimally invasive removal of both IPDs and simultaneous L3/4 and L4/5 laminectomy with a partial right L4 medial facetectomy. The patient's right L5 radiculopathy and neurogenic claudication symptoms were resolved.

Case 6

A 73-year-old female with osteoporosis, hepatitis C, and lumbar spondylosis presented with symptomatic severe stenosis at L4/5 and mild degenerative levoscoliosis. She

suffered from debilitating low back pain and severe bilateral radiculopathy in an L5 distribution. These symptoms were managed conservatively by an interventional pain specialist with NSAIDs, antidepressants, muscle relaxants in addition to steroid injections and physical therapy. Eventually this provider implanted an IPD at the L4/5 level.

Following implantation, the patient experienced worsening bilateral L5 radiculopathy. She sought outpatient neurosurgical consultation at our institution. We performed an MIS removal of the IPD with simultaneous decompression of L4/5. She had complete resolution of right thigh pain and significant improvement in her left thigh pain.

Case 7

A 77-year-old female with no significant past medical history presented with severe bilateral L5 radiculopathy. Imaging demonstrated severe lumbar stenosis at L3/4 and L4/5. Her pain became refractory to epidural steroid injections, and an outpatient pain specialist implanted IPDs at L3/4 and L4/5.

After 6 months of persistent symptoms, the patient presented for outpatient neurosurgical consultation. Imaging demonstrated bilateral nerve root compression, and we removed the IPD and performed laminectomies at L3/4 and L4/5. On outpatient follow-up, the patient's bilateral radicular leg symptoms were resolved.

Case 8

A 74-year-old female with rheumatoid arthritis, coronary aneurysm, pulmonary hypertension, chronic obstructive pulmonary disease, and emphysema presented to our outpatient clinic for neurosurgical consultation. She suffered from chronic low back pain, neurogenic claudication, and bilateral L5 radiculopathy. A previous MRI demonstrated severe stenosis at L4/5. Her symptoms had been managed by an outpatient pain specialist with oral pain medication, antidepressants, physical therapy, and steroid injections. One year prior to the presentation, she underwent L4/5 IPD placement at an out-of-state medical center.

On presentation to our spine clinic, she had experienced no significant improvement in any of her symptoms referable to lumbar stenosis in the intervening year. Repeat lumbar X-ray demonstrated an L4/5 IPD in stable position; a new MRI redemonstrated severe L4/5 stenosis without significant progression. We therefore felt the IPD had failed to address the symptomatic stenosis and that the patient would benefit from surgical decompression. Simultaneous IPD removal and MIS laminectomy were performed *via* the technique described above. At follow-up the patient reported a significant reduction in back pain, claudication symptoms, and radiculopathy.

RESULTS

For each patient, we examined the timing of surgical consultation and its effect. Mean time from the IPD placement to the neurosurgical consultation was 206 days (SD 301 days); mean time from the IPD placement to the surgical intervention was 255 days (SD 322 days). Mean follow-up duration for patients in this series was 386 days (SD 347 days). Visual analog scale (VAS) pain scores decreased from a mean of 8.4 on initial consultation to 5.6 at last follow-up.

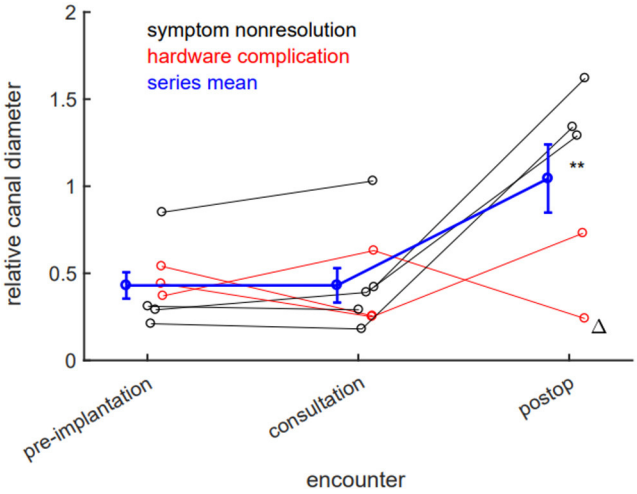


FIGURE 4 | Laminectomy, but not interspinous process device (IPD) implantation, reduces lumbar stenosis. There is no significant radiographic evidence of canal stenosis reduction between implantation and neurosurgical consultation. Canal stenosis only improves in a statistically significant manner after laminectomy. Black datapoints represent patients seen for symptom nonresolution; red datapoints represent patients seen for hardware complications; blue data represent population mean; error bars ±SEM. $^{**}p < 0.05$ (0.02, post-op compared to either pre-implantation or consultation stenosis). Delta (Δ) denotes patient whose IPD was explanted by interventional pain team.

We sought to systematically study imaging parameters better to understand the effects of IPD placement and its removal. First, we examined the effect of IPD placement on lumbar canal stenosis. We define a dimensionless measure, "relative canal diameter," as the dorsal-ventral canal lumen diameter at the maximally stenotic symptomatic level, divided by the diameter at the immediately rostral pedicle. We found no measurable improvement in canal stenosis from IPD placement at the time of neurosurgical consultation (pre-implantation 0.430, consultation 0.431, $p = 0.99$). Statistically significant improvement in canal stenosis in our case series was observed only after definitive surgical decompression (post-op 1.044, $p = 0.02$ when compared both with pre-implantation and consultation stenosis; **Figure 4**).

We next examined if IPD implantation affects spinal alignment. Specifically, we hypothesized that implantation might reduce lumbar lordosis by holding two lumbar levels in relative flexion. Across all eight patients, we did not observe a statistically significant absolute reduction in lumbar lordosis, likely due to intrinsic variability (pre-implantation mean 56.92 degrees, consultation mean 52.51 degrees, $p = 0.60$). When this variability was controlled by baseline normalization, we observed a significant 4.1% relative reduction in lumbar lordosis after IPD implantation ($p = 0.0075$; **Figure 5**).

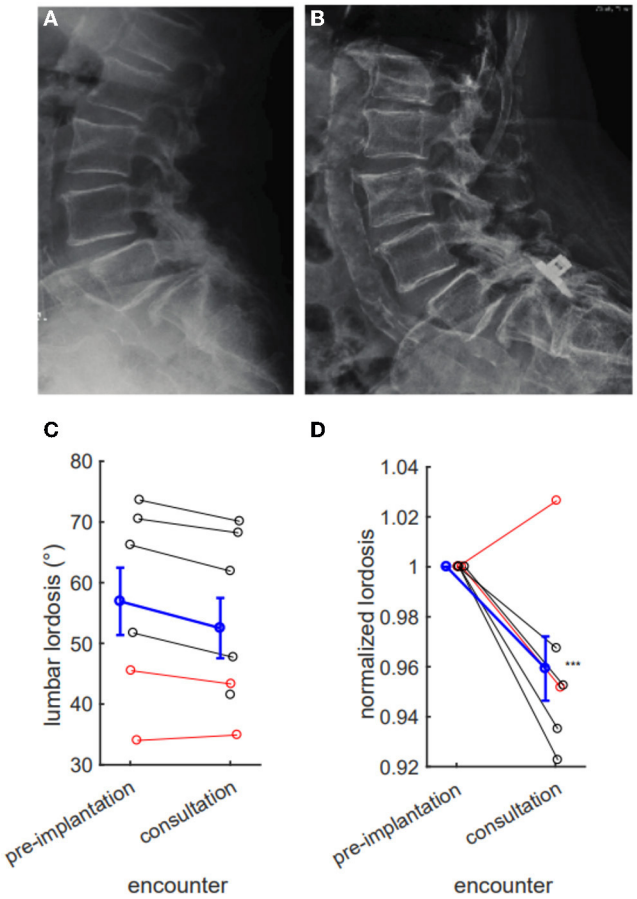


FIGURE 5 | Interspinous process device (IPD) implantation results in a measurable reduction in lumbar lordosis. Pre- **(A)** and post- **(B)** placement X-rays with ventral migration of device into L5/S1 interspace, with evident reduction in lumbar lordosis. **(C)** IPD implantation tends to reduce lumbar lordosis (pre-implantation mean 56.92 degrees, consultation 52.51 degrees, $p = 0.60$), but this difference fails to reach statistical significance. **(D)** This reduction reaches significance when normalizing for pre-implantation lordosis (consultation 95.9% of baseline, difference 4.1%, $p = 0.0075$). **(C,D)** Red denotes hardware complications; black denotes nonresolution of symptoms; blue denotes series mean. Error bars mean ± SEM $^{***}p < 0.01$.

DISCUSSION

Interspinous process devices were placed without a formal neurosurgical consultation in all, except one case. While patient stated upon interview that he was not initially interested in surgery, the other patients answered that they would have considered surgery as a treatment option. This patient cohort skews elderly with multiple severe medical comorbidities. We surmise that prior treating physicians may have assumed that these patients were not candidates for surgery, discouraging referrals. We wish to emphasize that the final assessment of surgical candidacy is a joint risk–benefit analysis between the operating surgeon, the patient, anesthesiologist, and consultant physicians for perioperative risk stratification. In this cohort, we observed a delay in definitive treatment, associated with a delay in neurosurgical consultation. Furthermore, we were not aware that any of these patients were assessed pre-operative to their index surgery for risk assessment and optimization for anesthesia.

Furthermore, there is a logical contradiction in deeming a patient not a surgical candidate for one procedure while recommending another. This practice pattern arises from the assumption that IPD placement is significantly less invasive than a laminectomy and could be performed under conscious sedation. On the contrary, published data suggest that minimally invasive lumbar decompression compares favorably to interspinous device implantation in terms of operative time, estimated blood loss, and recovery (17); additionally, MIS procedures, including advanced instrumentation procedures such as transforaminal lumber interbody fusion (TLIF), are now performed routinely under conscious sedation (18). Therefore, we expect differences in perioperative risks to be minimal (19). Minimally invasive decompressive surgery is well established as a short, safe procedure with high satisfaction rates (20). There is no data demonstrating reduced perioperative morbidity with IPD placement vs. surgical decompression.

In fact, recent research on IPD has been largely promising, with several studies reporting long-term, cost-effective benefit in large cohorts (7–10). Registry data of high patient satisfaction, decreased opioid consumption, and even randomized controlled trials support its use (6, 21–23). However, the majority of these studies were industry sponsored. While industry partnerships remain integral to technological innovation, it is clear that further objective study is needed.

Our study observed a high rate of ventral and intracanalicular hardware migration, which all risk permanent nerve injury, leading to weakness, bowel/bladder dysfunction—all device-related complications beyond the purview of physiatry and pain medicine. Spinal instrumentation failure and misplacement fall well outside their scope of practice, and several interventional pain specialists have recognized their shortcomings in surgical training (22, 24, 25). Yet, the CPT code for the IPD placement, 22,869 is frequently billed by non-surgical spine providers as a "stabilization/distraction device," and a recent investigation suggests that its lucrative fee scheduling may influence practice patterns (26). In the interest of patient safety and full transparency, we emphasize a neurosurgical spine consultation prior to IPD placement.

Furthermore, we observed a seemingly arbitrary, unsubstantiated expansion of indications for IPD placement beyond what is supported by clinical data. Outcome analysis spanning up to 5 years after implantation concluded that patients with moderate lumbar stenosis are the best candidates for IPD (7, 8). However, 75% (6 out of 8) patients in our series demonstrated severe lumbar stenosis. Patient 4 in our case series is particularly illustrative. Her radiculopathy stemmed from a synovial cyst causing foraminal stenosis. Rather than undergoing a foraminal decompression, she was recommended for IPD placement by an interventional pain specialist. Spinal instrumentation requires a nuanced, comprehensive understanding of biomechanics and pathophysiology, and recognition of these subtleties hold real-world consequences for patients.

Despite its minimally invasive deployment, IPD is hardware instrumentation of the lumbar spine. We show that distraction of posterior spinal elements from an IPD reduces lumbar lordosis. Despite its minimally invasive deployment, IPD is hardware instrumentation of the lumbar spine. We show distraction of posterior spinal elements from an IPD reduces lumbar lordosis. We observe a roughly 4% reduction in lumbar lordosis across patients in this series. This is a relatively large change surprisingly uncompensated by increased lordosis at other lumbar levels. The clinical significance of this change is indeterminate; our sample is biased to include only patients with post-implantation complications. Furthermore, it is not clear if this change is transient or permanent. A simple hypothesis is that patients with device-associated pain exaggerate lumbar flexion away from instrumented levels. To evaluate this hypothesis, lumbar lordosis should be measured in cohorts with and without post-placement complications. The data do, however, highlight the ability of IPD placement to alter sagittal parameters.

Interventional pain medicine provides physicians with robust procedural exposure, ranging from image-guided injections, ablations, and blocks, but implantation of spinal instrumentation represents an unprecedented foray into spine surgery. What is most concerning is not simply the procedure itself, but the absence of careful consideration of and deliberation on spinal biomechanics. Spinal instrumentation is typically placed by fellowship-trained orthopedic and neurological surgeons with several years of advanced education, careful apprenticeship, and supervised surgical training in spine pathology. Pain specialists performing IPD implantation simply lack formal training in basic surgical technique, let alone minimally invasive spine surgery.

In August 2021, the AANS–CNS Joint Section on Disorders of the Spine and Peripheral Nerves released a position statement on spinal instrumentation by non-surgeon spine practitioners (27). Naming IPD devices specifically, the document cites concerns about the lack of standardized, formal training in pathology recognition and treatment formulation, inability to address potential complications, and unintentional alterations in spinal balance parameters and biomechanics. In our case series, we document patient examples of each of these areas of concern. Multidisciplinary collaboration with pain specialists and physiatrists is essential. However, we remain firm in our conclusion that spinal instrumentation, however minimally invasive, should be performed by fellowship-trained spine surgeons.

Complications of IPD placement have been explored previously in patient series large and small (28–38). The present study is novel in several ways. First, we are the first to measure alterations in sagittal parameters and lumbar stenosis as a function of IPD placement and MIS decompression. Second, although dorsal device migration and spinous process fracture have been previously reported, ventral device migration into the lumbar central canal has not. We report two such cases resulting in severe iatrogenic in the short series presented here. For both patient counseling and expert consultation, awareness of the totality of device complications is critical.

The major limitation of our study is that it is an uncontrolled case series, constituting a low level of clinical evidence. Furthermore, our case series of referred patients are biased toward complication and treatment failure. Yet, our series supports that (1) IPD is subject to hardware complications and treatment failure and (2) spine consultation should be sought before placement. Given the proliferation of IPD devices, we firmly believe in spreading awareness and promoting patient safety for all spine patients and the neurosurgical community.

CONCLUSIONS

In this study, we illustrate eight cases of patient complications after IPD placement. We describe hardware migration, hardware-related fracture, and a lack of post-procedural improvement. Therefore, we recommend consultation with a fellowship-trained spine surgeon for any patient considering IPD placement.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by UCLA IRB. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements. Written informed consent was not obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

TF conceived study, performed data analysis, and authored manuscript. IS authored manuscript. KP conceived study, authored manuscript, and edited operative video. AU provided illustration. AV contributed data and edited manuscript. DCL conceived the study, guided data analysis, and authored manuscript. All authors contributed to the article and approved the submitted version.

ACKNOWLEDGMENTS

This study was made possible by the generous support of the Henry & Jessica Chen Foundation.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsurg.2022.841134/full#supplementary-material

Supplementary Video 1 | Video recording of removal of interspinous device that has migrated into the central canal. The previous incision was opened, and monopolar electrocautery was used to expose the dorsal surface of the device between the L4 and L5 spinous processes. A high-speed drill and Kerrison Rongeurs were used to remove part of the L4 and L5 spinous processes to free

the interspinous spacer device. A tool designed to place the device is used in reverse (in this case, the Boston Scientific Superion "Inserter"). Briefly, the insertion tool is docked onto the dorsal aspect of the implant. A drive screw mechanism in the handle of the insertion tool is used to retract the IPD interspinous blades. The device was removed en bloc, and a microsurgical lumbar decompression was completed.

REFERENCES

1. Wang MC, AlGhamdi MYT. Editorial. Interspinous spacers for lumbar stenosis: time for obsolescence? *J Neurosurg.* (2021) 34:541–2. doi: 10.3171/2020.8.SPINE201205
2. Chiu JC. Interspinous process decompression (IPD) system (X-STOP) for the treatment of lumbar spinal stenosis. *Surg Technol Int.* (2006) 15:265–75.
3. Lee J, Hida K, Seki T, Iwasaki Y, Minoru A. An interspinous process distractor (X STOP) for lumbar spinal stenosis in elderly patients. *J Spinal Disord Techn.* (2004) 17:72–77. doi: 10.1097/00024720-200402000-00013
4. Talwar V, Lindsey DP, Fredrick A, Hsu KY, Zucherman JF, Yerby SA. Insertion loads of the X STOP interspinous process distraction system designed to treat neurogenic intermittent claudication. *Eur Spine J.* (2006) 15:908–12. doi: 10.1007/s00586-005-0891-9
5. Bini W, Miller LE, Block JE. Minimally invasive treatment of moderate lumbar spinal stenosis with the superion interspinous spacer. *Open Orthop J.* (2011) 5:361–7. doi: 10.2174/1874325001105010361
6. Nunley PD, Deer TR, Benyamin RM, Staats PS, Block JE. Interspinous process decompression is associated with a reduction in opioid analgesia in patients with lumbar spinal stenosis. *J Pain Res.* (2018) 11:2943–8. doi: 10.2147/JPR.S182322
7. Nunley PD, Patel VV, Orndorff DG, Lavelle WF, Block JE, Geisler FH. Five-year durability of stand-alone interspinous process decompression for lumbar spinal stenosis. *Clin Interv Aging.* (2017) 12:1409–17. doi: 10.2147/CIA.S143503
8. Nunley PD, Patel VV, Orndorff DG, Lavelle WF, Block JE, Geisler FH. Superion interspinous spacer treatment of moderate spinal stenosis: 4-year results. *World Neurosurg.* (2017) 104:279–83. doi: 10.1016/j.wneu.2017.04.163
9. Parker SL, Anderson LH, Nelson T, Patel VV. Cost-effectiveness of three treatment strategies for lumbar spinal stenosis: conservative care, laminectomy, and the Superion interspinous spacer. *Int J Spine Surg.* (2015) 9:28. doi: 10.14444/2028
10. Patel VV, Nunley PD, Whang PG, Haley TR, Bradley WD, Davis RP, et al. Superion(®) InterSpinous Spacer for treatment of moderate degenerative lumbar spinal stenosis: durable three-year results of a randomized controlled trial. *J Pain Res.* (2015) 8:657–62. doi: 10.2147/JPR.S92633
11. Shabat S, Miller LE, Block JE, Gepstein R. Minimally invasive treatment of lumbar spinal stenosis with a novel interspinous spacer. *Clin Interv Aging.* (2011) 6:227–33. doi: 10.2147/CIA.S23656
12. Lauryssen C, Jackson RJ, Baron JM, Tallarico RA, Lavelle WF, Deutsch H, et al. Stand-alone interspinous spacer versus decompressive laminectomy for treatment of lumbar spinal stenosis. *Expert Rev Med Devices.* (2015) 12:763–9. doi: 10.1586/17434440.2015.1100071
13. Phan K, Rao PJ, Ball JR, Mobbs RJ. Interspinous process spacers versus traditional decompression for lumbar spinal stenosis: systematic review and meta-analysis. *J Spine Surg.* (2016) 2:31–40. doi: 10.21037/jss.2016.01.07
14. Wildermuth S, Zanetti M, Duewell S, Schmid MR, Romanowski B, Benini A, et al. Lumbar spine: quantitative and qualitative assessment of positional (upright flexion and extension) MR imaging and myelography. *Radiology.* (1998) 207:391–8. doi: 10.1148/radiology.207.2.9577486
15. 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
16. Polly DW Jr, Kilkelly FX, McHale KA, Asplund LM, Mulligan M, Chang AS. Measurement of lumbar lordosis. Evaluation of intraobserver, interobserver, and technique variability. *Spine.* (1996) 21:1530–5; discussion 1535–6. doi: 10.1097/00007632-199607010-00008
17. Johans SJ, Amin BY, Mummaneni PV. Minimally invasive lumbar decompression for lumbar stenosis: review of clinical outcomes and cost effectiveness. *J Neurosurg Sci.* (2015) 59:37–45.
18. Chan AK-H, Choy W, Miller CA, Robinson LC, Mummaneni PV. A novel technique for awake, minimally invasive transforaminal lumbar interbody fusion. *Neurosurg Focus.* (2019) 46:E16. doi: 10.3171/2019.1.FOCUS18510
19. Peng K, Liu H-Y, Liu S-L, Ji F-H. Dexmedetomidine-fentanyl compared with midazolam-fentanyl for conscious sedation in patients undergoing lumbar disc surgery. *Clin Ther.* (2016) 38:192–201.e2. doi: 10.1016/j.clinthera.2015.11.016
20. Phan K, Mobbs RJ. Minimally invasive versus open laminectomy for lumbar stenosis: a systematic review and meta-analysis. *Spine.* (2016) 41:E91–E100. doi: 10.1097/BRS.0000000000001161
21. Tekmyster G, Sayed D, Cairns KD, Raso LJ, Kim C, Block JE. Interspinous process decompression with the superion spacer for lumbar spinal stenosis: real-world experience from a device registry. *Med Devices.* (2019) 12:423–7. doi: 10.2147/MDER.S220431
22. Hartman J, Granville M, Jacobson RE. The use of Vertiflex® interspinous spacer device in patients with lumbar spinal stenosis and concurrent medical comorbidities. *Cureus.* (2019) 11:e5374. doi: 10.7759/cureus.5374
23. Weisbein J. How I do it: the Vertiflex® procedure for lumbar spinal stenosis. *ASRA News.* (2020) 45:1–4. doi: 10.52211/asra110120.073
24. Hagedorn JM, Deer T, Sayed D, Lamer T. Pain medicine: if we want to be surgeons, we must have surgical training. *Reg Anesth Pain Med.* (2020) 45:561–2. doi: 10.1136/rapm-2019-101105
25. Naidu RK, Chaturvedi R, Engle AM, Mehta P, Su B, Chakravarthy K, et al. Interventional spine and pain procedure credentialing: guidelines from the american society of pain & neuroscience. *J Pain Res.* (2021) 14:2777–91. doi: 10.2147/JPR.S309705
26. Lorio D, Twetten M, Golish SR, Lorio MP. Determination of work relative value units for management of lumbar spinal stenosis by open decompression and interlaminar stabilization. *Int J Spine Surg.* (2021) 15:1–11. doi: 10.14444/8026
27. AANS Board of Directors and CNS Executive committee. *Position Statement on Arthrodesis of the Spine by the Non-spine Surgeon.* (2021). Available online at: https://www.aans.org/-/media/Files/AANS/Advocacy/PDFS/AANS_and_CNS_Position_Statement_on_Arthrodesis_of_the_Spine_FINAL-APPROVED_082121.ashx?la=en&hash=FBCCC7E584BED8F2797D62B79214DDAB59911D99
28. Kim DH, Shanti N, Tantorski ME, Shaw JD, Li L, Martha JF, et al. Association between degenerative spondylolisthesis and spinous process fracture after interspinous process spacer surgery. *Spine J.* (2012) 12:466–72. doi: 10.1016/j.spinee.2012.03.034
29. Lee HG, Kang MS, Na YC, Jin BH. Spinal intradural arachnoid cyst as a complication of insertion of an interspinous device. *Br J Neurosurg.* (2019) 36:1–5. doi: 10.1080/02688697.2019.1668541
30. Wu A-M, Zhou Y, Li Q-L, Wu X-L, Jin Y-L, Luo P, et al. Interspinous spacer versus traditional decompressive surgery for lumbar spinal stenosis: a systematic review and meta-analysis. *PLoS ONE.* (2014) 9:e97142. doi: 10.1371/journal.pone.0097142
31. Welton L, Krieg B, Trivedi D, Netsanet R, Wessell N, Noshchenko A, et al. Comparison of adverse outcomes following placement of superion interspinous spacer device versus laminectomy and laminotomy. *Int J Spine Surg.* (2021) 15:153–60. doi: 10.14444/8020
32. Kim DH, Tantorski M, Shaw J, Martha J, Li L, Shanti N, et al. Occult spinous process fractures associated with interspinous process spacers. *Spine.* (2011) 36:E1080–5. doi: 10.1097/BRS.0b013e318204066a
33. Barbagallo GMV, Olindo G, Corbino L, Albanese V. Analysis of complications in patients treated with the X-Stop Interspinous Process Decompression System: proposal for a novel anatomic scoring system for patient selection and review of the literature. *Neurosurgery.* (2009) 65:111–19; discussion 119–20. doi: 10.1227/01.NEU.0000346254.07116.31
34. Epstein NE. A review of interspinous fusion devices: high complication, reoperation rates, and costs with poor outcomes. *Surg Neurol Int.* (2012) 3:7. doi: 10.4103/2152-7806.92172

35. Deyo RA, Martin BI, Ching A, Tosteson ANA, Jarvik JG, Kreuter W, et al. Interspinous spacers compared with decompression or fusion for lumbar stenosis: complications and repeat operations in the Medicare population. *Spine.* (2013) 38:865–72. doi: 10.1097/BRS.0b013e31828631b8
36. Gazzeri R, Galarza M, Neroni M, Fiore C, Faiola A, Puzzilli F, et al. Failure rates and complications of interspinous process decompression devices: a European multicenter study. *Neurosurg Focus.* (2015) 39:E14. doi: 10.3171/2015.7.FOCUS15244
37. Bowers C, Amini A, Dailey AT, Schmidt MH. Dynamic interspinous process stabilization: review of complications associated with the X-Stop device. *Neurosurg Focus.* (2010) 28:E8. doi: 10.3171/2010.3.FOCUS1047
38. Xu C, Ni W-F, Tian N-F, Hu X-Q, Li F, Xu H-Z. Complications in degenerative lumbar disease treated with a dynamic interspinous spacer (Coflex). *Int Orthop.* (2013) 37:2199–204. doi: 10.1007/s00264-013-2006-2

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.

frontiers in Surgery

REVIEW
published: 22 March 2022
doi: 10.3389/fsurg.2022.834551

Research Progress of Ponticulus Posticus: A Narrative Literature Review

Xiaoyan Xu[1†], *Yuefeng Zhu*[1,2†], *Xing Ding*[1,3†], *Mengchen Yin*[1,3*], *Wen Mo*[1,3*] and *Junming Ma*[1,3*]

[1] Shanghai University of Traditional Chinese Medicine, Shanghai, China, [2] Department of Orthopaedics, Huadong Hospital, Fudan University, Shanghai, China, [3] Department of Orthopaedics, Longhua Hospital, Shanghai University of Traditional Chinese Medicine, Shanghai, China

Study Design: Narrative review.

Objective: The purpose of this review was to consolidate the current literature related to ponticulus posticus (PP) and to improve the systematic understanding of this anatomical variant of atlas among spine surgeons.

Methods: Articles reviewed were searched in PubMed, Ovid MEDLINE, and Embase. All articles of any study design discussing on PP were considered for inclusion. Two independent authors read article titles and abstracts and included appropriate articles. The relevant articles were studied in full text.

Results: A total of 113 literatures were reviewed and consolidated in this narrative review. These articles are roughly divided into the following five subcategories: (1) epidemiology, (2) pathology and anatomy, (3) clinical presentation, (4) surgical significance, and (5) radiographic examination.

Conclusion: The PP is non-negligible with a high prevalence. The PP compresses the V3 segment of the artery, the suboccipital nerve, and the venous plexus, consequently contributing to the incidence of neurological pathologies. When a PP is observed or suspected on a lateral radiograph, we recommend that a computed tomography (CT) scan of a patient who is about to receive a C1 lateral mass screw (C1LMS) should be performed, which could determine a safe entry point and the right trajectory of screw insertion.

Keywords: ponticulus posticus (PP), research progress, narrative review, clinical presentation, surgical significance

OPEN ACCESS

Edited by:
Lingxiao Chen,
The University of Sydney, Australia

Reviewed by:
Konstantinos Markatos,
Salamina Medical Center, Greece
Liu Yi,
China Medical University, China

***Correspondence:**
Mengchen Yin
yinmengchen0513@126.com
Wen Mo
mw2218@126.com
Junming Ma
junming236@126.com

[†]*These authors share first authorship*

Specialty section:
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

Received: *13 December 2021*
Accepted: *17 February 2022*
Published: *22 March 2022*

Citation:
Xu X, Zhu Y, Ding X, Yin M, Mo W and Ma J (2022) Research Progress of Ponticulus Posticus: A Narrative Literature Review. Front. Surg. 9:834551. doi: 10.3389/fsurg.2022.834551

INTRODUCTION

Ponticulus posticus (PP) is the meaning of "little posterior bridge" in Latin, which was a variation occurring on the atlas vertebra. It was defined as a bony bridge formed between the posterior portion of the superior articular process and the lateral portion of the upper margin of the posterior arch of the atlas, surrounding all or part of the vertebral artery (VA) (1). It was first detected on imaging incidentally and was reported in the dentistry, neurosurgery, and orthopedic spinal surgery literature (2).

Ponticulus posticus has not been a matter of concern for spine surgeons until an increasing number of epidemiology studies indicated its non-negligible morbidity. More published studies showed a close connection between PP and cervicogenic headache (CGH) (3). Surgical significance of PP in the insertion of screws into the lateral mass of the atlas was also reported (4). A practical, narrative review of PP was undertaken to address the following areas: (1) epidemiology, (2) pathology and anatomy, (3) clinical presentation, (4) surgical significance, and (5) radiographic examination. Not only did it provide an extensive systematic review of all recent studies, we would rather aim to provide an updated comprehensive synthesis of the current evidence to facilitate a cogent clinical understanding of PP, which could guide spine surgeons in the condition of cervical spine disorders combined with PP.

METHODS

A comprehensive literature search was performed on November 01, 2021 according to the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines. Studies published from 1950 to 2021 were chosen through relevant PubMed, Ovid MEDLINE, and Embase searches to prioritize the largest and most recent studies. The Medical Subject headings and Boolean operators employed for this search were: "ponticulus posticus" or "posticus ponticus" or "foramen arcuate" or "foramen arcuale" or "foramen sagittale" or "foramen atlantoideum posterior" or "Kimmerle's anomaly" or "foramen retroarticulare superior" or "canalis vertebralis" or "retroarticular vertebral artery ring" or "retroarticular canal" or "retrocondylar vertebral artery". Though no strict inclusion/exclusion criteria were used, preference was given to well-known, large, multi-institution databases that represented care across many centers, in addition to larger single-center studies. All articles about study design discussing about PP were considered for inclusion. Experimental or animal studies, non-English language studies, non-peer-reviewed studies, conference abstracts, paper, letter, and unpublished manuscripts were excluded. After an initial screen of abstracts and article titles, we obtained full-text articles of all potential studies. To perfect the research, two independent researchers reviewed and evaluated the included articles, respectively. Any different opinions were discussed until a consensus was reached. Since no human subjects were directly involved in this article; hence, an IRB statement was not needed.

RESULTS

Literature Search

A total of 172 studies were identified from the initial search, of which 28 duplicates and 11 non-English language articles were removed. Titles and abstracts of the rest 133 studies were screened according to the predefined inclusion criteria, and 20 studies were excluded. In total, 113 articles were critically reviewed and consolidated for this literature review (**Figure 1**).

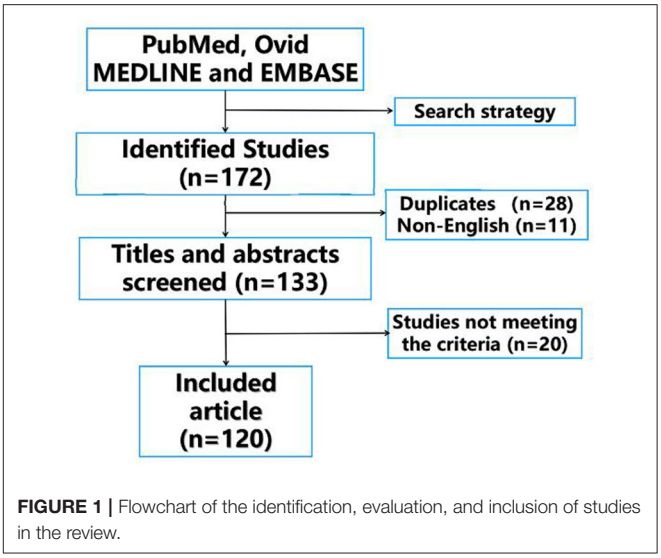


FIGURE 1 | Flowchart of the identification, evaluation, and inclusion of studies in the review.

Epidemiology

Ponticulus posticus is a normal anatomical variant of atlas vertebrae (C1), and its prevalence in population has been the focus in PP studies. In the current study, we updated the studies on the prevalence of PP in various areas of the world, and a total of 58 published studies were included in the narrative review (**Table 1**). According to the review, we found that the total prevalence of these studies was 5–55.7%, and there were some regional differences in the prevalence. The prevalence in East Asia was 6.2–19.0%, Europe was 14.3–34.7%, North America was 5–45.5%, and India was 10.9–37.8%, of which East Asia had the lowest incidence. These differences could be attributed to the differences in the different ethnic groups all over the world. Some scholars argued that the degenerative changes may be the cause of PP, and prevalence increases with age due to calcification, but there was no definitive evidence for association between the age and the prevalence of PP. Several recent studies did not find a statistically significant association between the age and the presence of PP (7–9). With regard to sex bias, scholars hold different views. In studies conducted by Takaaki, Paraskevas, Hong, and Saleh, the frequency of PP was higher in men (9–12). In contrast, the studies conducted by Schilling et al. (2010) and Tambawala et al. reported female predilection for this anomaly (13, 14). More studies showed that there was no statistically significant association between gender of the patient and the presence of PP (7, 8, 15, 16). The currently available literature was inconclusive in this aspect. According to Pekala's meta-analysis of 55,985 subjects, the total prevalence of the incomplete PP was 13.6%, which was higher than the complete one (9.1%) (3). However, the meta-analysis performed by Elliott and Tanweer (17) found complete PP in 9.3% of patients and incomplete PP in 8.7% of patients. The difference of study results may be attributed to the methods employed, and we could not reach a

Abbreviations: PP, ponticulus posticus; C1LMS, C1 lateral mass screw; CGH, cervicogenic headache; PDC, palatally displaced canines; PL, ponticulus lateralis; VAG, vertebral artery groove.

TABLE 1 | Review of the literatures on prevalence of PP.

	Author	Year	Sample	Population	PP (%)
1	S Selby	1955	306	USA	27.1%
2	Pyo J	1959	300	USA	12.7%
3	Kendrick GS	1963	353	USA	15.8%
4	Radojevic S	1964	105	Sweden	14.3%
5	Saunders SR	1978	592	Canada	29.2%
6	Farman AG	1979	220	South Africa	8.0%
7	Gupta SC	1979	123	India	18.7%
8	Takaaki M	1979	307	Japan	9.1%
9	Taitz C	1986	672	Multiple continents	33.8%
10	Ruprecht A	1988	419	Saudi Arabia	32.9%
11	Sun JY	1990	923	China	7.4%
12	Le Mino	1992	500	France	14.2%
13	Stubbs	1992	1,000	USA	18.7%
14	Dhall U	1993	148	India	37.8%
15	Mitchell J	1998	1,354	South Africa	9.8%
16	Wight S	1999	895	Scotland	18.0%
17	Cederberg RA	2000	255	North America	11.0%
18	Hasan M	2001	350	North India	6.6%
19	Manjunath KY	2001	60	South India	11.7%
20	Wysocki J	2003	95	Poland	31.6%
21	Kavakli A	2004	86	Turkey	22.1%
22	Unur E	2004	351	Turkey	5.1%
23	Beck RW	2004	847	New Zeland	13.6%
24	Cakmak O	2005	476	Turkey	13.7%
25	Young JP	2005	464	USA	15.5%
26	Paraskevas G	2005	176	Greece	34.7%
27	Senoglu M	2006	338	Turkey	15.2%
28	Lee MJ	2006	709	USA	26.9%
27	Krishnamurthy A	2007	1044	India	13.8%
28	Tubbs RS	2007	60	USA	5.0%
29	Kim KH	2007	537	Korea	19.0%
30	Gupta T	2008	55	India	10.9%
31	Kobayashi Y	2008	50	Japan	10.0%
32	Simsek S	2008	158	Turkey	9.5%
33	Hong JT	2008	1013	Korea	15.6%
34	Cho	2009	355	Korea	11.8%
35	Karau PB	2010	102	Kenya	28.4%
36	Kuhta P	2010	246	USA	45.5%
37	Schilling J	2010	436	USA	19.3%
38	Yeom JS	2012	52	Korea	17.3%
39	Carvalho MF	2012	30	Brasil	40%
40	Baeesa SS	2012	453	Saudi Arabia	47.9%
41	Bayrakdar IS	2014	730	Turkey	17.4%
42	Perez IE	2014	1056	Peruvia	19.8%
43	Geist JR	2014	576	USA	26.2%
44	Wakao N	2014	387	Japan	6.2%
45	Chen CH	2015	500	Taiwan	7.0%
46	Gibelli D	2015	221	Italy	16.7%
47	Sekerci AE	2015	698	Turkey	36.8%
48	Tambawala SS	2017	500	Indian	15.8%
49	Giri J	2017	414	Nepal	35.7%
50	Cirpan S	2017	81	Turkey	16.1%
51	Buyuk SK	2017	374	Nepal	43.0%
52	Song MS	2017	2628	Korea	7.1%
53	Sanchis-Gimeno JA	2018	300	Spain	20.3%
54	Bayrakdar IS	2018	181	Turkey	36.5%
55	Saleh A	2018	2917	USA	22.5%
56	Tripodi D	2019	524	Italy	28.2%
57	Evirgen S	2020	440	Turkey	55.7%
58	Arada CY	2021	108	Thailand	10.3%

definitive conclusion in this aspect. In terms of laterality, the study conducted by Saleh et al. (9) indicated that the left sided arch has a higher rate of PP than the right one (84.7 vs. 89.2%), which was consistent with the findings made in the study of Elliott and Tanweer (17).

Pathology and Anatomy

Ponticulus posticus is an osseous prominence formed in place of a sulcus for the VA on the posterior arch of the atlas. The atlas with a particular anatomy is composed with a short anterior arch and a longer posterior arch, which is a ring-shaped structure without vertebral body. The vertebral artery groove (VAG) is on the superior surface of the posterior arch (18, 19). PP is an aperture formed by the presence of a bony bridge on the VAG, which is placed posteriorly in relation to the anterior surface, and when the bridge is placed laterally, it is called ponticulus lateralis (PL) – a rare type of PP.

The prevalence of PL was reported to be 1.8–3.8% lower than PP (20–23). PL is difficult to be identified from anteroposterior and lateral radiographs and was rarely reported in previous literature as a result. The V3 segment of the VA travels in the VAG, which is covered by a bony ridge with the presence of PP. According to our literature review, the prevailing view was that PP compresses the V3 segment of the VA and causes alternations of the blood flow within the VAs that are ultimately responsible for a range of symptoms such as migraine and CGH. More than 50% of head rotation occurred at the atlantoaxial joint. With additional compression caused by PP, VA is more susceptible to injury when subjected to compression and extension (24). According to the study of atlas vertebrae from the population of northern Greece by Paraskevas et al., there was a high incidence of the coexistence of PP with retrotransverse forame. (11). It reported that the blood flow was directed into the small vein connecting the atlanto-occipital and the atlanto-axoidian venous sinus due to the compression of the vertebral veins in PP. This study also found that 93.5% cases of PP were accompanied by deeply excavated contralateral groove of the VA, which could be interpreted as evidence that, due to VA compression in the canal,

the contralateral VA was dilated, causing an increase in the depth of the corresponding groove. In the study of cadaver conducted by Tubbs et al., all specimens with PP were also found to have gross compression of the VA as it traveled through the PP (25).

Clinical Presentation

From an anatomical point of view, PP compresses the V3 segment of the artery, the suboccipital nerve, and the venous plexus, consequently contributing to the incidence of neurological pathologies such as vertigo and migraine (26). Pekala conducted a meta-analysis in 2018, finding a significant association between PP and headaches (3). Besides, the probability of complete PP resulting in headaches was higher than the incomplete ones, which in turn had a higher probability of headache compared to patients without PP. This result indicated the importance of PP in the etiology of headaches, which was supported by multiple prior studies (14, 27–29). Except for headaches, PP could cause a range of symptoms including retro-orbital pain, vasomotor disturbance of the face and recurrent disturbances of vision, swallowing, and phonation—the Barre–Lieou syndrome caused by alteration of the blood flow within the vertebral arteries, and an associated disturbance of the periarterial nerve plexus (30).

The study by Pearce (2004) introduced the ponticulus resection to treat the Barre–Lieou syndrome caused by PP (30). The patients who had surgical resection of PP during the last 10 years were reviewed and satisfactory surgical outcomes were found. However, we could not find any studies on this topic in recent years. We conjectured that few patients with the Barre–Lieou syndrome were serious enough to require surgical resection.

In addition to neurological pathologies, PP is associated with oral and maxillofacial disorders. This may be attributed to the activity of the neural crest as the common embryonic origin of the neck and shoulder skeletal development and the origin of development of tooth and midface skeletal fields (31, 32). According to the study conducted by Dadgar et al., the presence of the PP correlated with the presence of palatally displaced canines (PDC) significantly and positively (33). The study by Leonardi et al. (31) reached a converging conclusion in which 34.2% of patients with PDC showed PP as opposed to the group of normal population (20%) (34). Bayrakdar et al. found that there was a significant association between PP and cleft lip (35). In this study, the incidence of PP in the cleft-palate group was 22.2% compared to 9% in normal group.

Radiographic Examination

We noticed that there were several methodologies to identify the PP in previous studies including cadaveric studies, lateral radiographs, and computed tomography (CT) scans. In our study, we found that the prevalence of PP in different studies was different, which may be contributed to the methodologies. In the radiographic examination, lateral radiographs could not identify the laterality, completeness, and sometimes even the presence of PP. In the study by Kim et al., the prevalence of PP was 26% based on the CT scans, which was only 14% in lateral radiographs (36). The difference was significant and meant that a substantial proportion of patients with PP were missed on lateral radiographs. The CT scan was still a reliable method when PP was combined with other anatomical variant. **Figure 2** shows a typical case. Elgafy et al. reported a special CT finding of ipsilateral PP and high-riding VA, which were found only in 5 patients out of 100 cases (37).

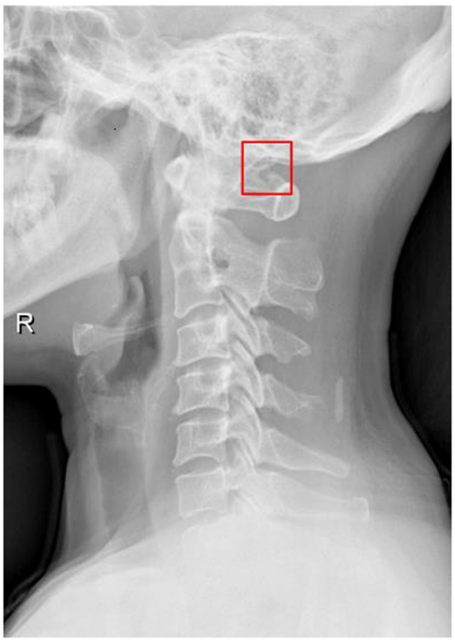


FIGURE 2 | A 44-year-old female with migraine and normal neurologic examination. Lateral radiograph showed the right-sided partial ponticulus posticus, an anomalous bony bridge formed from the superior articulating surface of the atlas but not fused to the posterior arch of the atlas.

Radiographically, the most common classification of PP was based on the completeness of the bony bridge: none, complete, and incomplete. None type: there was no formed bony bridge; complete type: a complete bony ring was formed; and incomplete type: some portions of the bony ring were defective. However, this traditional classification neglected the laterality of PP, and there was a novel classification system introduced by Saleh et al. (9). This classification consisted of a two-letter designation for each patient, including either A, B, or C (A means no PP; B means incomplete PP; and C means complete PP). The first letter described the right-sided posterior arch, and the second letter described the left one. This classification system included 9 potential subtypes for all patients: AA, BB, CC, AB, AC, BA, BC, CA, and CB. However, we could not find a classification that combines clinical symptoms with imaging findings.

Surgical Significance

The C1 lateral mass screw (C1LMS) insertion was firstly reported by Goel and Laheri in 1994, which revolutionized the treatment of atlantoaxial instability (38). PP has gained increasing attention in recent years, and the literature has increased correspondingly as C1LMS has become increasingly popular. When the methods of inserting the C1LMS is

through the posterior arch into the lateral mass, PP may be mistaken for a thickened posterior arch and may mislead the surgeon to drill the borehole too superiorly, which could cause iatrogenic injury to the V3 segment of the artery. Zhang et al. successfully inserted C1LMS in 11 patients with PP by performing preoperative three-dimensional CT reconstructive imaging, which contributed to choose an appropriate entry point and a right trajectory of screw insertion (39). Arslan et al. developed cervical column 3D models for 200 patients, of which 29 were with PP, and evaluated 3D models of both normal and PP cases (6). They found that the VA in PP cases was clearly narrower than that in normal cases, and the safe distance between lateral mass screw fixation and the bony bridge was 4 mm.

The conventional C1LMSs have been accepted as more stable approaches to avoid VA injury compared with C1LMSs inserted *via* the posterior arch because the screws are placed farther from the VAG. However, the study by Song et al. indicated that the latter had some anatomical feasibility and advantage with the relatively sufficient VAG height (40). In addition, the lower margin of the C1 arch could determine an appropriate entry point. The disadvantage of the conventional C1LMSs included more venous bleeding, less biomechanical stability, and postoperative C2 nerve dysfunction.

In the study conducted by Yeom et al., 9 patients with PP received C1LMS, and 3 of whom received resection of the ponticulus before the screw insertion due to wide PP and deep VAG (41). Although VA injury was not reported in this study, we did not advocate this radical surgery strategy. Notably, Lee et al. reported the notching technique (lateral mass screws inserted partially through the posterior arch), which modified the entry point to make the screw remote from the greater occipital nerve and was possible in the vast majority of patients (42).

CONCLUSION

Considering different methodologies and regional differences, the prevalence of PP is inconsistent. However, one point is certain, PP is non-negligible with a high prevalence. PP compresses the V3 segment of the artery, the suboccipital nerve, and the venous plexus, consequently contributing to the incidence of neurological pathologies. When a PP is observed or suspected on a lateral radiograph, we recommend that a CT scan of a patient who is about to receive a C1LMS should be performed, which could determine a safe entry point and a right trajectory of screw insertion. The insertion of C1LMSs *via* the posterior arch was applicable in the majority of cases, and the notching technique might be considered as necessary. Conventional C1LMSs should not be recommended due to the surgical risk and the postoperative complications.

AUTHOR CONTRIBUTIONS

MY, XX, and YZ: conceptualization, methodology, formal analysis, and writing-original draft. WM: resources and data curation. XD and JM: supervision and writing-reviewing and editing. All authors read and approved the final manuscript.

ACKNOWLEDGMENTS

We would like to thank the reviewers for their thorough review of our manuscript, especially under the severe circumstance of worldwide epidemic COVID-19, and we wish that everybody pulls through safe and sound.

REFERENCES

1. Dugdale LM. The ponticulus posterior of the atlas. *Australas Radiol.* (1981) 25:237–8. doi: 10.1111/j.1440-1673.1981.tb02254.x
2. Ahn J, Duran M, Syldort S, Rizvi A, D'Antoni AV, Johal J, et al. Arcuate foramen: anatomy, embryology, nomenclature, pathology, and surgical considerations. *World Neurosurg.* (2018) 118:197–202. doi: 10.1016/j.wneu.2018.07.038
3. Pekala PA, Henry BM, Phan K, Pekala JR, Taterra D, Walocha JA, et al. Presence of a foramen arcuale as a possible cause for headaches and migraine: systematic review and meta-analysis. *J Clin Neurosci.* (2018) 54:113–8. doi: 10.1016/j.jocn.2018.05.008
4. Young JP, Young PH, Ackermann MJ, Anderson PA, Riew KD. The ponticulus posticus: implications for screw insertion into the first cervical lateral mass. *J Bone Joint Surg Am.* (2005) 87:2495–8. doi: 10.2106/00004623-200511000-00017
5. Stubbs DM. The arcuate foramen. Variability in distribution related to race and sex. *Spine.* (1992) 17:1502–4. doi: 10.1097/00007632-199212000-00010
6. Arslan D, Ozer MA, Govsa F, Kitis O. The Ponticulus Posticus as Risk Factor for Screw Insertion into the First Cervical Lateral Mass. *World Neurosurg.* (2018) 113:e579–85. doi: 10.1016/j.wneu.2018.02.100
7. Chen CH, Chen YK, Wang CK. Prevalence of ponticuli posticus among patients referred for dental examinations by cone-beam CT. *Spine J.* (2015) 15:1270–6. doi: 10.1016/j.spinee.2015.02.031
8. Giri J, Pokharel PR, Gyawali R. How common is ponticulus posticus on lateral cephalograms? *BMC Res Notes.* (2017) 10:172. doi: 10.1186/s13104-017-2494-z
9. Saleh A, Gruber J, Bakhsh W, Rubery PT, Mesfin A. How Common Is the Ponticulus Posticus?: A Computed Tomography Based Analysis of 2917 Patients. *Spine.* (2018) 43:E436–41. doi: 10.1097/BRS.0000000000002400
10. Najmuddin M. Prevalence of ponticulus posticus on the posterior arch of the atlas in symptomatic and asymptomatic patients. *Oral Radiol.* (2022) 1–4. doi: 10.1007/s11282-021-00583-x
11. Paraskevas G, Papaziogas B, Tsonidis C, Kapetanos G. Gross morphology of the bridges over the vertebral artery groove on the atlas. *Surg Radiol Anat.* (2005) 27:129–36. doi: 10.1007/s00276-004-0300-9
12. Hong JT, Lee SW, Son BC, Sung JH, Yang SH, Kim IS, et al. Analysis of anatomical variations of bone and vascular structures around the posterior atlantal arch using three-dimensional computed tomography angiography. *J Neurosurg Spine.* (2008) 8:230–6. doi: 10.3171/SPI/2008/8/3/230
13. Tambawala SS, Karjodkar FR, Sansare K, Motghare D, Mishra I, Gaikwad S, et al. Prevalence of Ponticulus Posticus on Lateral Cephalometric Radiographs, its Association with Cervicogenic Headache and a Review of Literature. *World Neurosurg.* (2017) 103:566–75. doi: 10.1016/j.wneu.2017.04.030
14. Chitroda PK, Katti G, Baba IA, Najmudin M, Ghali SR, Kalmath B. Ponticulus posticus on the posterior arch of atlas, prevalence analysis in symptomatic and asymptomatic patients of gulbarga population. *J Clin Diagn Res.* (2013) 7:3044–7. doi: 10.7860/JCDR/2013/6795.3847

15. Cho YJ. Radiological analysis of ponticulus posticus in Koreans. *Yonsei Med J.* (2009) 50:45–9. doi: 10.3349/ymj.2009.50.1.45
16. Gibelli D, Cappella A, Cerutti E, Spagnoli L, Dolci C, Sforza C. Prevalence of ponticulus posticus in a Northern Italian orthodontic population: a lateral cephalometric study. *Surg Radiol Anat.* (2016) 38:309–12. doi: 10.1007/s00276-015-1554-0
17. Elliott RE, Tanweer O. The prevalence of the ponticulus posticus (arcuate foramen) and its importance in the Goel-Harms procedure: meta-analysis and review of the literature. *World Neurosurg.* (2014) 82:e335–343. doi: 10.1016/j.wneu.2013.09.014
18. Aksoy S, Yalcin B. Morphometric anatomy of the posterior aspect of the atlas and the vertebral artery groove in relation to lateral mass screw placement. *J Neurol Surg A Cent Eur Neurosurg.* (2021). doi: 10.1055/s-0041-1739214
19. Yeom JS, Buchowski JM, Park KW, Chang BS, Lee CK, Riew KD. Undetected vertebral artery groove and foramen violations during C1 lateral mass and C2 pedicle screw placement. *Spine.* (2008) 33:E942–9. doi: 10.1097/BRS.0b013e3181870441
20. Ozdemir B, Kanat A, Durmaz S, Ersegun Batcik O, Gundogdu H. Introducing a new possible predisposing risk factor for odontoid type 2 fractures after cervical trauma; Ponticulus posticus anomaly of C1 vertebra. *J Clin Neurosci.* (2022) 96:194–8. doi: 10.1016/j.jocn.2021.11.013
21. Le Minor JM, Trost O. Bony ponticles of the atlas (C1) over the groove for the vertebral artery in humans and primates: polymorphism and evolutionary trends. *Am J Phys Anthropol.* (2004) 125:16–29. doi: 10.1002/ajpa.10270
22. Kazan S, Yildirim F, Sindel M, Tuncer R. Anatomical evaluation of the groove for the vertebral artery in the axis vertebrae for atlanto-axial transarticular screw fixation technique. *Clin Anat.* (2000) 13:237–43. doi: 10.1002/1098-2353(2000)13:4<237::AID-CA2>3.0.CO;2-K
23. Radojevic S, Negovanovic B. The Vertebral Groove and Bone Rings of the Vertebral Artery of the Atlas (Anatomical and Radiological Study). *Acta Anat (Basel).* (1963) 55:186–94.
24. Isaji T, Yasuda M, Kawaguchi R, et al. Posterior inferior cerebellar artery with an extradural origin from the V3 segment: higher incidence on the nondominant vertebral artery. *J Neurosurg Spine.* (2018) 28:154–9. doi: 10.3171/2017.5.SPINE161286
25. Tubbs RS, Johnson PC, Shoja MM, Loukas M, Oakes WJ. Foramen arcuale: anatomical study and review of the literature. *J Neurosurg Spine.* (2007) 6:31–4. doi: 10.3171/spi.2007.6.1.6
26. Natsis K, Piperaki ET, Fratzoglou M, Lazaridis N, Tsitsopoulos PP, Samolis, et al. Atlas posterior arch and vertebral artery's groove variants: a classification, morphometric study, clinical and surgical implications. *Surg Radiol Anat.* (2019) 41:985–1001. doi: 10.1007/s00276-019-02256-1
27. Donald PM, Nagraj SK, Pallivathukkal RG, Ismail ARB. Ponticulus posticus of atlas vertebrae: an incidental finding in Malaysian orthodontic patients. *BMJ Case Rep.* (2017) 1–3. doi: 10.1136/bcr-2017-220851
28. Haji Ghadimi M, Amini F, Hamedi S, Rakhshan V. Associations among sella turcica bridging, atlas arcuate foramen (ponticulus posticus) development, atlas posterior arch deficiency, and the occurrence of palatally displaced canine impaction. *Am J Orthod Dentofacial Orthop.* (2017) 151:513–20. doi: 10.1016/j.ajodo.2016.08.024
29. Rios L, Mata-Escolano F, Blanco-Perez E, Llido S, Bastir M, Sanchis-Gimeno JA. Acute headache attributed to whiplash in arcuate foramen and non-arcuate foramen subjects. *Eur Spine J.* (2017) 26:1262–5. doi: 10.1007/s00586-016-4856-y
30. Pearce JM. Barre-Lieou "syndrome". *J Neurol Neurosurg Psychiatry.* (2004) 75:319.
31. Putrino A, Leonardi RM, Barbato E, Galluccio G. The association between ponticulus posticus and dental agenesis: a retrospective study. *Open Dent J.* (2018) 12:510–9. doi: 10.2174/1874210601812010510
32. Kaya Y, Oztas E, Goymen M, Keskin S. Sella turcica bridging and ponticulus posticus calcification in subjects with different dental anomalies. *Am J Orthod Dentofacial Orthop.* (2021) 159:627–34. doi: 10.1016/j.ajodo.2019.11.024
33. Dadgar S, Alimohamadi M, Rajabi N, Rakhshan V, Sobouti F. Associations among palatal impaction of canine, sella turcica bridging, and ponticulus posticus (atlas arcuate foramen). *Surg Radiol Anat.* (2021) 43:93–9. doi: 10.1007/s00276-020-02548-x
34. Leonardi R, Barbato E, Vichi M, Caltabiano M. Skeletal anomalies and normal variants in patients with palatally displaced canines. *Angle Orthod.* (2009) 79:727–32. doi: 10.2319/082408-448.1
35. Bayrakdar IS, Yasa Y, Duman SB, Karaturgut UE, Ocak A, Gunen Yilmaz S. Cone beam computed tomography evaluation of ponticulus posticus in patients with cleft lip and palate: a retrospective radio-anatomic study. *Folia Morphol (Warsz).* (2018) 77:72–8. doi: 10.5603/FM.a2017.0076
36. Kim KH, Park KW, Manh TH, Yeom JS, Chang BS, Lee CK. Prevalence and morphologic features of ponticulus posticus in Koreans: analysis of 312 radiographs and 225 three-dimensional CT scans. *Asian Spine J.* (2007) 1:27–31. doi: 10.4184/asj.2007.1.1.27
37. Elgafy H, Pompo F, Vela R, Elsamaloty HM. Ipsilateral arcuate foramen and high-riding vertebral artery: implication on C1-C2 instrumentation. *Spine J.* (2014) 14:1351–5. doi: 10.1016/j.spinee.2014.01.054
38. Goel A, Laheri V. Plate and screw fixation for atlanto-axial subluxation. *Acta Neurochir (Wien).* (1994) 129:47–53. doi: 10.1007/BF01400872
39. Zhang XL, Huang DG, Wang XD, Zhu JW, Li YB, He BR, et al. The feasibility of inserting a C1 pedicle screw in patients with ponticulus posticus: a retrospective analysis of eleven patients. *Eur Spine J.* (2017) 26:1058–63. doi: 10.1007/s00586-016-4589-y
40. Song MS, Lee HJ, Kim JT, Kim JH, Hong JT. Ponticulus posticus: Morphometric analysis and Its anatomical Implications for occipito-cervical fusion. *Clin Neurol Neurosurg.* (2017) 157:76–81. doi: 10.1016/j.clineuro.2017.04.001
41. Yeom JS, Kafle D, Nguyen NQ, Noh W, Park KW, Chang BS, et al. Routine insertion of the lateral mass screw via the posterior arch for C1 fixation: feasibility and related complications. *Spine J.* (2012) 12:476–83. doi: 10.1016/j.spinee.2012.06.010
42. Lee MJ, Cassinelli E, Riew KD. The feasibility of inserting atlas lateral mass screws via the posterior arch. *Spine.* (2006) 31:2798–801. doi: 10.1097/01.brs.0000245902.93084.12

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.

frontiers | Frontiers in Surgery

ORIGINAL RESEARCH
published: 12 April 2022
doi: 10.3389/fsurg.2022.871776

Changes in Thromboelastography to Predict Ecchymosis After Knee Arthroplasty: A Promising Guide for the Use of Anticoagulants

Yuelong Chen[1], Leilei Qin[2], Jianye Yang[3], Jiawei Wang[2], Jiaxing Huang[2], Xuan Gong[4†] and Ning Hu[2*†]*

[1] Department of Respiratory and Critical Care Medicine, The First Affiliated Hospital of Chongqing Medical University, Chongqing, China, [2] Department of Orthopaedics, The First Affiliated Hospital of Chongqing Medical University, Chongqing, China, [3] Department of Orthopaedics, Fuling Central Hospital, Chongqing, China, [4] Department of Outpatient Care, Chongqing General Hospital, Chongqing, China

OPEN ACCESS

Edited by:
Hengxing Zhou,
Tianjin Medical University General Hospital, China

Reviewed by:
Xin Tang,
Sichuan University, China
Jinwei Xie,
Sichuan University, China

****Correspondence:***
Xuan Gong
1113468198@qq.com
Ning Hu
hunicqjoint@yeah.net

† These authors have contributed equally to this work

Specialty section:
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

Received: *08 February 2022*
Accepted: *21 March 2022*
Published: *12 April 2022*

Citation:
Chen Y, Qin L, Yang J, Wang J, Huang J, Gong X and Hu N (2022) Changes in Thromboelastography to Predict Ecchymosis After Knee Arthroplasty: A Promising Guide for the Use of Anticoagulants. Front. Surg. 9:871776. doi: 10.3389/fsurg.2022.871776

Background: Ecchymosis is one of the worrisome complications after total knee arthroplasty (TKA) and interferes with functional rehabilitation. Current clinical guidelines do not provide individualized approaches for patients with ecchymoses.

Methods: In this study, we used thromboelastography (TEG) to determine the coagulation state after TKA and to then explore markers that predict the occurrence of ecchymosis events after TKA. In our cohort, patients were divided into ecchymosis ($n = 55$) and non-ecchymosis ($n = 137$) groups according to whether ecchymosis events occurred after TKA. Rivaroxaban 10 mg/d was taken orally for thromboprophylaxis after surgery. All patients completed TEG testing. Correlation analysis was used to determine the risk factors for ecchymosis after TKA, and receiver operating characteristic (ROC) curves for variables with significant correlation were plotted.

Results: In all, 55 of the 192 patients (28.65%) developed ecchymosis surrounding the surgical site. Multivariate analysis showed that hidden blood loss (OR = 1.003 and $p = 0.005$) and changes in the coagulation index (ΔCI) values (OR = 0.351 and $p = 0.001$) were risk factors for ecchymosis after TKA. Using the Youden index, 0.1805 was determined as the optimal threshold value of ΔCI for predicting the occurrence of ecchymosis, with a sensitivity of 74.55% and specificity of 72.99%. ΔCI is a promising marker as an alarm for the occurrence of ecchymosis after TKA.

Trial Registration: The study was registered in the Chinese Clinical Trial Registry (ChiCTR1800017245). Registered name: The role of thrombelastography in monitoring the changes of coagulation function during perioperative period of arthroplasty. Registered 19 July 2018. http://www.chictr.org.cn/showproj.aspx?proj=29220

Keywords: ecchymosis, total knee arthroplasty (TKA), thromboelastography (TEG), arthroplasty, anticoagulation

INTRODUCTION

Total knee arthroplasty (TKA) is considered the most effective treatment for end-stage knee osteoarthritis (OA) (1). Due to the high prevalence of OA, TKA is a fairly common surgery. In the United States, the number of TKAs is projected to increase by 673% by 2030 (2). Venous thromboembolism (VTE) is a worrisome complication after TKA (3). Perioperative anticoagulant prophylaxis has been shown to reduce the incidence of postoperative VTE-related mortality and complications (4). Evidence-based guidelines recommend that patients undergoing TKA receive oral rivaroxaban for anticoagulant prophylaxis for 14 days (5, 6). However, postoperative bleeding complications associated with anticoagulation are not uncommon, especially with the widespread use of factor Xa inhibitors, in which the incidence of ecchymosis around the wound is as high as 13% (7).

The formation of postoperative ecchymosis around the wound is related to the use of anticoagulants (3). Ecchymosis around the surgical site can prolong the recovery time after TKA and may even lead to reoperation due to periprosthetic infection (8, 9). At present, there are still no clear guidelines for the balance between postoperative anticoagulation and bleeding (10). The use of anticoagulants should prevent VTE and avoid the occurrence of bleeding events. The monitoring of coagulation function has guiding value for the use of anticoagulants (11). Routine coagulation tests provide limited information about the quality of coagulation status (12, 13). Therefore, we need an alarm to predict the occurrence of ecchymosis events around the wound after TKA.

Thrombelastography (TEG) provides a comprehensive evaluation of blood viscoelastic properties and has potential value in predicting postoperative bleeding and thrombotic events (12, 14). Moreover, previous studies have shown that the change of coagulation index (ΔCI) value was a risk factor for patients with ecchymosis after TKA and was expected to guide personalized anticoagulant therapy (6). Thus, in this study, we sought to (1) explore whether the change in ΔCI can predict ecchymosis after TKA and (2) to calculate the threshold for predicting patients with ecchymosis based on ΔCI.

MATERIALS AND METHODS

From October 2018 to October 2020, we prospectively enrolled patients who were scheduled to undergo primary unilateral total knee arthroplasty (TKA) for knee OA. We excluded patients who (1) underwent bilateral TKA; (2) did not undergo TEG testing; (3) had a history of cardiovascular surgery, VTE or prior anticoagulant therapy; (4) were concomitant with coagulation disorders; (5) were treated with anticoagulation agents other than rivaroxaban; or (6) had incomplete medical records. According to the occurrence of ecchymosis after TKA, the patients were divided into ecchymosis and non-ecchymosis groups, ecchymosis was defined as subcutaneous extravasation of blood, without pain, swelling, or limited movement of the knee joint (6).

A tourniquet was used intraoperatively, and the tourniquet was loosened before the incision was closed. The anesthesiologist recorded the blood loss during the operation, mainly involving attracting blood from bottles and gauze. No drainage was used. All patients received standard physical therapy and rivaroxaban anticoagulant therapy for 14 days. Rivaroxaban (10 mg) was administered once daily starting 12 h after surgery, monitoring the occurrence of ecchymosis closely and discontinuing rivaroxaban once ecchymosis was observed. Venous blood was collected 1 day before surgery to obtain baseline hematocrit (HCT) and TEG values. The HCT and TEG values were monitored daily postoperatively until the patient was discharged. For discharged patients, investigators followed them up daily to see if there were any ecchymosis events. Once there were ecchymosis events, HCT and TEG tests were completed within 24 h, and anticoagulation therapy was stopped. TEG tests were performed by a TEG® Hemostasis Analyzer (Hemonetics Corporation, Braintree, MA, USA).

All indicators of TEG (R-time, α-angle, maximum amplitude, and K-time) were recorded, and the CI was calculated using the formula $CI = 0.1227(R) + 0.0092(K) + 0.1655(MA) - 0.0241(\alpha) - 5.0220$. We analyzed the ΔCI values (ΔCI = the postoperative CI value – the preoperative baseline CI value) for all patients. For patients without ecchymosis after TKA, we analyzed the maximum variation in CI relative to preoperative values; for patients with ecchymosis, we analyzed the ΔCI values between the day of ecchymosis occurrence and preoperatively. The gross (15) equation was used to calculate the volume of human erythrocytes and total blood loss. Then, hidden blood loss was the residual value of the total blood loss during the removal of intraoperative blood loss.

Statistical Analysis

Statistical analysis was carried out with SPSS 24.0. Comparisons were made between the patients with and without ecchymosis. To clarify the values of factors related to ecchymosis in predicting the occurrence of ecchymosis events, the receiver operating characteristic (ROC) curve was established by MedCalc; the area under the ROC curve (AUC) was also calculated. The optimal cutoff values of each index for predicting the occurrence of ecchymosis events and the corresponding specificity and sensitivity were determined by Youden's J statistic. $P < 0.05$ was considered statistically significant.

RESULTS

A total of 192 patients who received a unilateral primary TKA were eligible for the study. In all, 55 of 192 patients (28.65%) developed ecchymosis surrounding the surgical site. There were no statistically significant differences between the two groups in terms of age ($p = 0.125$), sex ($p = 0.480$), or BMI ($P = 0.085$) (**Table 1**). During the follow-up, only three patients developed ecchymosis around the wound, which improved after anticoagulant treatment was stopped, and blood samples of these patients were obtained on the day that ecchymosis was observed.

Total blood loss and hidden blood loss were significantly higher in the ecchymosis group compared to those in the

TABLE 1 | Demographic data for the study population.

Variables	Non-ecchymosis group ($n = 137$)	Ecchymosis group ($n = 55$)	*P*-value
Age (years)	67.80 ± 10.787	65.16 ± 10.445	0.125
Gender (male/female)	40/97	13/42	0.480
Height	157.82 ± 7.026	157.48 ± 6.523	0.764
Weight	58.242 ± 9.6932	60.694 ± 10.1908	0.139
BMI (kg/m^2)	23.355 ± 3.6025	24.4537 ± 4.0201	0.085

BMI, body mass index. Variables are expressed as mean ± SD (standard deviation).

TABLE 2 | Comparisons of variables of the ecchymosis group and non-ecchymosis group.

Variables	Non-ecchymosis group	Ecchymosis group	*P*-value
ΔCI	0.8490 ± 1.3344	−0.5332 ± 1.1554	0.001
Operation time (min)	91.06 ± 10.406	94.69 ± 16.487	0.134
Total blood loss (mL)	287.8376 ± 109.4661	334.0836 ± 125.7136	0.012
Intraoperative blood loss (mL)	31.53 ± 12.059	32.91 ± 12.045	0.475
Hidden blood loss (mL)	137.3048 ± 107.5984	319.3564 ± 110.8418	<0.001

ΔCI, change of coagulation index. Variables are expressed as mean ± SD (standard deviation).

non-ecchymosis group (**Table 2**). Compared to preoperative TKA, the average change in ΔCI in the ecchymosis group reached −0.5332 ± 1.1554, while the average change in ΔCI in the non-ecchymosis group reached 0.8490 ± 1.3344, thereby demonstrating a significant difference between the two groups ($p = 0.001$). The levels of total and hidden blood loss were 334.08 ± 125.71 ml and 319.36 ± 110.84 ml in the ecchymosis group, which were significantly higher than those in the non-ecchymosis group, with 287.8376 ± 109.4661 ml ($p = 0.012$) and 137.3048 ± 107.5984 ml ($p < 0.001$) for total blood loss and hidden blood loss, respectively. There were no significant differences in operative time (91.06 ± 10.406 vs. 94.69 ± 16.487 min) or intraoperative blood loss (31.53 ± 12.059 vs. 32.91 ± 12.045 ml) between the two groups (**Table 2**).

We performed multivariate logistic regression analyses on potential risk factors for ecchymosis formation after TKA, including ΔCI, hidden blood loss, age, and BMI. The data suggested that ΔCI (OR: 0.351, 95% CI: 0.234, 0.526, and $p = 0.001$) and hidden blood loss (OR: 1.003, 95% CI: 1.000, 1.007, and $p = 0.005$) could be independent risk factors for the formation of ecchymosis, in addition to age, BMI, and total blood loss (**Table 3**).

To measure the value of CI and hidden blood loss in predicting the occurrence of ecchymosis, we plotted the ROC curves of the two variables (**Figure 1**). ΔCI discriminated between ecchymosis and non-ecchymosis with an AUC of 0.794 (95% CI: 0.730, 0.849). However, hidden blood loss did not exhibit a superior AUC of 0.681 (95% CI: 0.610, 0.746) (**Figure 1**).

TABLE 3 | Risk factors for ecchymosis after TKA.

Variables	OR (95% Confidence interval)	*P*-value
ΔCI	0.351 (0.234, 0.526)	0.001
Hidden blood loss (mL)	1.003 (1.000, 1.007)	0.005
Total blood loss (mL)		0.259
Age (years)		0.078
Gender (male/female)		0.479
BMI (kg/m^2)		0.067

ΔCI, change of coagulation index. BMI, body mass index. OR, odds ratio. TKA, total knee arthroplasty.

As shown in **Table 4**, the threshold of CI was 0.1805, demonstrating a sensitivity of 74.55% (95% CI: 61.0, 85.3) and a specificity of 72.99% (95% CI: 64.7, 80.2) for predicting ecchymosis events after TKA. When the amount of hidden blood loss reached 311.63 ml the sensitivity and specificity for predicting the occurrence of ecchymosis were 60.00% (95% CI: 45.9, 73.0) and 76.64% (95% CI: 68.7, 83.4), respectively.

DISCUSSION

To our knowledge, this study was the first attempt to use ΔCI to predict ecchymosis events after TKA and demonstrated its reliability. In our cohort, the ΔCI in the ecchymosis group was significantly higher than that in the non-ecchymosis group ($p = 0.001$) and was an independent risk factor (OR = 0.351, $p = 0.001$) for ecchymosis after TKA. The optimal cutoff value of ΔCI (0.1805) reflected maximal sensitivity (74.55%) and specificity (72.99%) to predict ecchymosis events after TKA. This study also found a significant correlation (OR = 1.003, $p = 0.005$) between hidden blood loss and ecchymosis events after TKA. Unfortunately, hidden blood loss showed unsatisfactory sensitivity in predicting the occurrence of ecchymosis events. Hidden blood loss is generally defined as blood deposited in the joint space and blood seeping into the tissue (16, 17). However, when the volume of hidden blood loss was not sufficient, the blood in the tissue may have been absorbed by the body before it penetrated the mucosa of the skin, preventing the formation of ecchymosis.

Damage to the vascular wall at the surgical site provides a possibility for the formation of ecchymosis, but it may not be the only cause (18). The effect of anticoagulants on the formation of ecchymosis cannot be ignored. In the absence of thromboprophylaxis treatment, the incidence of VTE after TKA can be as high as 40–84% (19). However, anticoagulant chemoprophylaxis puts patients at risk for bleeding after TKA. Bleeding complications (including ecchymosis) following total joint arthroplasty are not acceptable, as they can lead to more important complications, such as infection, wound healing problems, dysfunction and loosening of the joints, with a high likelihood of affecting the surgical outcome (20). Rivaroxaban, a direct oral factor Xa inhibitor, is commonly prescribed for the

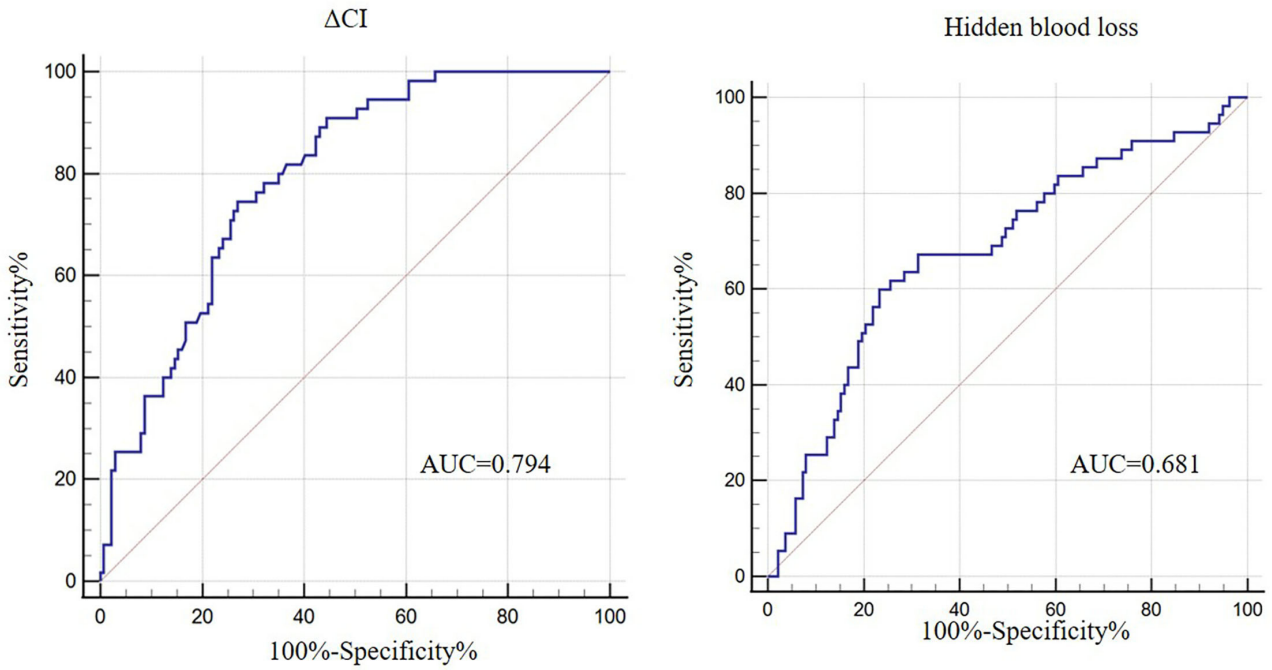


FIGURE 1 | ROC curves of δCI and hidden blood loss in predicting the occurrence of ecchymosis.

TABLE 4 | Sensitivity, specificity, PPV, and NPV of variables for predicting ecchymosis after TKA.

Parameters	AUC (95%CI)	Cut-off	Sensitivity (95%CI)	Specificity (95%CI)	PPV (%)	NPV (%)	LR+	LR–	Accuracy (%)
ΔCI	0.794 (0.730, 0.849)	0.1805	74.55 (61.0, 85.3)	72.99 (64.7, 80.2)	52.6 (44.7, 60.3)	87.7 (81.8, 91.9)	2.76 (2.0, 3.8)	0.35 (0.2, 0.6)	73.4375
Hidden blood loss (mL)	0.681 (0.610, 0.746)	311.63	60.00 (45.9, 73.0)	76.64 (68.7, 83.4)	50.8 (41.5, 59.9)	82.7 (77.3, 87.0)	2.57 (1.8, 3.7)	0.52 (0.4, 0.7)	71.3542

ΔCI, change of coagulation index. CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value. TKA, total knee arthroplasty.

prevention of VTE after TKA due to its effectiveness, high safety and convenience of use (3, 21). However, evidence has shown that rivaroxaban use also increases the risk of postoperative bleeding (7). This poses a challenge to the balance between anticoagulation and bleeding prevention. Therefore, accurate monitoring of coagulation status and early prediction of ecchymosis events are the key links of individual anticoagulation.

TEG is commonly used to evaluate the viscoelastic properties of a patient's whole blood during surgery (22). As early as 2009, Kashuk et al. (14) showed the role of TEG in identifying hypercoagulability and predicting thromboembolic events in surgical patients. Previous studies have attempted to apply ΔR to adjust the use of anticoagulants, but the data showed that ΔR does not have this capability (11). The possible explanation is that the clotting process involved in the formation of a thrombus or fibrinolysis is complex, and it is unreliable to represent the whole process by a single point of the clotting process. Therefore, in this study, we analyzed and compared the preoperative and postoperative changes in the comprehensive evaluation index CI. Through the analysis of two cohorts with or without ecchymosis after TKA, we found a high correlation between ΔCI and ecchymosis, which was consistent with previous research results (6). In addition, we also confirmed that, when the CI was lower than 0.1805, it was a warning that the body was in a hypocoagulable state, and the probability of ecchymosis events was as high as 73.44%.

The patients were prospectively recruited, with each patient followed for at least 2 weeks. The 2-week follow-up covered the entire course of the patient's anticoagulant use, and it was assured that the patient's hemodynamics had stabilized by the end of the follow-up (9).

Some limitations need to be noted in this study. First, this study was performed in a single center, and more regional studies are needed to support our conclusions. We are, in a follow-up study, examining this issue. Second, the patients who underwent TKA were elderly and had different types of underlying diseases. Age and underlying diseases may also be risk factors for the occurrence of ecchymosis (23, 24). In this study, there was no

subgroup analyses on the types of diseases and ages of patients, so the results of the study may be biased. Last, most of the patients were hospitalized for 5 days after surgery. Except for the patients with ecchymosis, blood samples were collected on the day that ecchymosis appeared, and the patients without ecchymosis only had TEG testing during hospitalization. Therefore, it was difficult to ensure that the maximum CI we monitored was the maximum in the non-ecchymosis group.

This study, to our knowledge, is the first to demonstrate that ΔCI in TEG parameters can be used as a predictor of ecchymosis events after TKA, and the optimal cutoff value was 0.1805. On the basis of our findings, we believe that ΔCI is a promising indicator to guide the use of anticoagulants early after TKA. When the ΔCI was lower than 0.1805, it was reasonable to consider stopping the use of rivaroxaban to avoid the occurrence of ecchymosis events. Of course, more research is needed to verify and confirm the reliability of this prediction.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Board and Hospital Ethics Committee of Chongqing Medical University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

NH and XG contributed to the experimental ideas, design of this study, examined, and revised the contents of the manuscript. YC drafted the manuscript. LQ, JY, and JH collected and analyzed the data. JW performed the statistical analysis. All authors approved the final submitted version.

FUNDING

This research was supported by the National Natural Science Foundation of China (82072443) and the Chongqing Technology Innovation and Application Development Special General Project (no: cstc2020jscx-msxmX0094).

REFERENCES

1. Costello CA, Liu M, Furey A, Rahman P, Randell EW, Zhai G. Association between epidemiological factors and nonresponders to total joint replacement surgery in primary osteoarthritis patients. *J Arthroplasty*. (2020) 36:1502–10. doi: 10.1016/j.arth.2020.11.020
2. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. *J Bone Joint Surg Am.* (2007) 89:780–5. doi: 10.2106/00004623-200704000-00012
3. Anderson DR, Dunbar M, Murnaghan J, Kahn SR, Gross P, Forsythe M, et al. Aspirin or rivaroxaban for VTE prophylaxis after hip or knee arthroplasty. *N Engl J Med.* (2018) 378:699–707. doi: 10.1056/NEJMoa1712746
4. Gould MK, Garcia DA, Wren SM, Karanicolas PJ, Arcelus JI, Heit JA, et al. Prevention of VTE in nonorthopedic surgical patients: Antithrombotic Therapy and Prevention of Thrombosis, 9th ed: American College of Chest Physicians Evidence-Based Clinical Practice Guidelines. *Chest.* (2012) 141:e227S–e77S. doi: 10.1378/chest.11-2297
5. Kakkar AK, Brenner B, Dahl OE, Eriksson BI, Mouret P, Muntz J, et al. Extended duration rivaroxaban versus short-term enoxaparin for the prevention of venous thromboembolism after total hip arthroplasty: a double-blind, randomised controlled trial. *Lancet.* (2008) 372:31–9. doi: 10.1016/S0140-6736(08)60880-6
6. Wang J, Zhu HL, Shi ZJ, Zhang Y. The application of thromboelastography in understanding and management of ecchymosis after total knee arthroplasty. *J Arthroplasty.* (2018) 33:3754–8. doi: 10.1016/j.arth.2018.08.024
7. Garfinkel JH, Gladnick BP, Roland N, Romness DW. Increased incidence of bleeding and wound complications with factor-Xa inhibitors after total joint arthroplasty. *J Arthroplasty.* (2018) 33:533–6. doi: 10.1016/j.arth.2017.08.039
8. Parvizi J, Ghanem E, Joshi A, Sharkey PF, Hozack WJ, Rothman RH. Does "excessive" anticoagulation predispose to periprosthetic infection? *J Arthroplasty.* (2007) 22:24–8. doi: 10.1016/j.arth.2007.03.007
9. Kwong LM, Kistler KD, Mills R, Wildgoose P, Klaskala W. Thromboprophylaxis, bleeding and post-operative prosthetic joint infection in total hip and knee arthroplasty: a comprehensive literature review. *Expert Opin Pharmacother.* (2012) 13:333–44. doi: 10.1517/14656566.2012.652087
10. Jacobs JJ, Mont MA, Bozic KJ, Della Valle CJ, Goodman SB, Lewis CG, et al. American Academy of Orthopaedic Surgeons clinical practice guideline on: preventing venous thromboembolic disease in patients undergoing elective hip and knee arthroplasty. *J Bone Joint Surg Am.* (2012) 94:746–7. doi: 10.2106/JBJS.9408.ebo746
11. Connelly CR, Van PY, Hart KD, Louis SG, Fair KA, Erickson AS, et al. Thrombelastography-based dosing of enoxaparin for thromboprophylaxis in trauma and surgical patients: a randomized clinical trial. *JAMA Surg.* (2016) 151:e162069. doi: 10.1001/jamasurg.2016.2069
12. Ågren A, Wikman AT, Holmström M, Östlund A, Edgren G. Thromboelastography (TEG®) compared to conventional coagulation tests in surgical patients–a laboratory evaluation. *Scand J Clin Lab Invest.* (2013) 73:214–220. doi: 10.3109/00365513.2013.765960
13. Tekkesin N, Tekkesin M, Kaso G. Thromboelastography for the monitoring of the antithrombotic effect of low-molecular-weight heparin after major orthopedic surgery. *Anatol J Cardiol.* (2015) 15:932–7. doi: 10.5152/akd.2014.5723
14. Kashuk JL, Moore EE, Sabel A, Barnett C, Haenel J, Le T, et al. Rapid thrombelastography (r-TEG) identifies hypercoagulability and predicts thromboembolic events in surgical patients. *Surgery.* (2009) 146:764–72; discussion 772–64. doi: 10.1016/j.surg.2009.06.054
15. Gross JB. Estimating allowable blood loss: corrected for dilution. *Anesthesiology.* (1983) 58:277–80. doi: 10.1097/00000542-198303000-00016
16. Mylod AG Jr, France MP, Muser DE, Parsons JR. Perioperative blood loss associated with total knee arthroplasty. A comparison of procedures performed with and without cementing. *J Bone Joint Surg Am.* (1990) 72:1010–2. doi: 10.2106/00004623-199072070-00008
17. Li B, Wen Y, Liu D, Tian L. The effect of knee position on blood loss and range of motion following total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc.* (2012) 20:594–9. doi: 10.1007/s00167-011-1628-4
18. Faris PM, Ritter MA, Keating EM, Valeri CR. Unwashed filtered shed blood collected after knee and hip arthroplasties. A source of autologous red blood cells. *J Bone Joint Surg Am.* (1991) 73:1169–78. doi: 10.2106/00004623-199173080-00005
19. He ML, Xiao ZM, Lei M, Li TS, Wu H, Liao J. Continuous passive motion for preventing venous thromboembolism after total knee arthroplasty. *Cochrane Database Syst Rev.* (2014) 7:CD008207. doi: 10.1002/14651858.CD008207.pub3

20. Van Der Veen L, Segers M, Van Raay JJ, Gerritsma-Bleeker CL, Brouwer RW, Veeger NJ, et al. Bleeding complications of thromboprophylaxis with dabigatran, nadroparin or rivaroxaban for 6 weeks after total knee arthroplasty surgery: a randomised pilot study. *BMJ Open.* (2021) 11:e040336. doi: 10.1136/bmjopen-2020-040336
21. Eriksson BI, Borris LC, Friedman RJ, Haas S, Huisman MV, Kakkar AK, et al. Rivaroxaban versus enoxaparin for thromboprophylaxis after hip arthroplasty. *N Engl J Med.* (2008) 358:2765–75. doi: 10.1056/NEJMoa0800374
22. Bai J, Zheng QW, Fu SH, Li XX, Li YR, Zhou Y, et al. Association between thrombelastography system and thromboembolic and bleeding events in Chinese aged people. *Int J Clin Exp Med.* (2013) 6:310–9, Print 2013.
23. Farage MA, Miller KW, Berardesca E, Maibach HI. Clinical implications of aging skin: cutaneous disorders in the elderly. *Am J Clin Dermatol.* (2009) 10:73–86. doi: 10.2165/00128071-200910020-00001
24. Cao YB, Zhang JD, Shen H, Jiang YY. Rivaroxaban versus enoxaparin for thromboprophylaxis after total hip or knee arthroplasty: a meta-analysis of randomized controlled trials. *Eur J Clin Pharmacol.* (2010) 66:1099–108. doi: 10.1007/s00228-010-0889-z

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.

frontiers | Frontiers in Surgery

ORIGINAL RESEARCH
published: 29 April 2022
doi: 10.3389/fsurg.2022.873691

The Learning Curve of Unilateral Biportal Endoscopic (UBE) Spinal Surgery by CUSUM Analysis

Lei Chen, Bin Zhu, Hua-zhang Zhong, Yi-guo Wang, Yi-song Sun, Qi-fei Wang, Jian-jun Liu, Da-sheng Tian and Jue-hua Jing**

Department of Orthopedics, The Second Hospital of Anhui Medical University, Hefei, China

Objective: To assess the learning curve of the unilateral biportal endoscopic (UBE) technique for the treatment of single-level lumbar disc herniation by cumulative summation (CUSUM) method analysis.

Methods: A retrospective analysis was conducted to assess 97 patients' general condition, operation time, complications, and curative effect of single segmental UBE surgery performed by a spinal surgeon in his early stage of this technique. The learning curve of operation time was studied using a CUSUM method, and the cut-off point of the learning curve was obtained.

Results: The operation time was 30 – 241(97.9 ± 34.7) min. The visual analog scale score of lower limb pain decreased from 5.75 ± 0.81 before the operation to 0.39 ± 0.28 at the last follow-up ($P < 0.05$). The Oswestry disability index score decreased from 66.48 ± 4.43 before the operation to 14.57 ± 3.99 at the last follow-up ($P < 0.05$). The CUSUM assessment of operation time revealed the learning curve was the highest in 24 cases. In the learning stage (1–24 cases), the operation time was 120.3 ± 43.8 min. In the skilled stage (25–97 cases), the operation time was 90.5 ± 27.8 min.

Conclusions: About 24 cases of single segmental UBE operation are needed to master the UBE technique.

Keywords: unilateral biportal endoscopic spinal surgery, learning curve, lumbar disc herniation, cumulative summation, operative time

OPEN ACCESS

Edited by:
Hengxing Zhou,
Tianjin Medical University General Hospital, China

Reviewed by:
Pravesh Gadjradj,
NewYork-Presbyterian, United States
Sherwan Hamawandi,
Hawler Medical University, Iraq

****Correspondence:***
Da-sheng Tian
tiands1212@126.com
Jue-hua Jing
jjhhu@sina.com

Specialty section:
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

Received: *11 February 2022*
Accepted: *30 March 2022*
Published: *29 April 2022*

Citation:
Chen L, Zhu B, Zhong H-z, Wang Y-g, Sun Y-s, Wang Q-f, Liu J-j, Tian D-s and Jing J-h (2022) The Learning Curve of Unilateral Biportal Endoscopic (UBE) Spinal Surgery by CUSUM Analysis. Front. Surg. 9:873691. doi: 10.3389/fsurg.2022.873691

INTRODUCTION

Lumbar disc herniation is a common disease that presents as low back pain, lower limb pain, numbness, weakness, or claudication, with a lifetime prevalence of 12.2–43% (1). Conservative treatment can be tried for patients with mild symptoms and without progressive decline (2). However, for patients whose conservative treatment failed, surgery may be the best option (3, 4). In recent years, unilateral biportal endoscopic (UBE) spinal surgery for the treatment of lumbar degenerative diseases and other diseases has gradually increased (5–8). It is generally believed that UBE surgery has the advantages of a wider field of vision, flexible operation, minimally invasive, and contributing to full nerve decompression and faster recovery (9).

Applicable to the most skilled spinal surgeons, there are still some difficulties and risks in the early implementation of UBE technology (10). Navigating the UBE learning curve is a concern for most surgeons who wish to use this technology. At present, there are still few studies on the learning curve of UBE technology. We adopt the cumulative summation (CUSUM) method to analyze the relationship between the number of repeated operations using UBE technology and the possibility of a successful single operation to provide a quantitative basis for determining the optimal number of repetitions in the learning process (11). In addition, the potential methods to shorten the learning curve of UBE were empirically summarized. Through all these, it may provide some references for doctors interested in performing UBE surgery.

METHODS

This retrospective study was conducted in accordance with the guidelines of the Declaration of Helsinki and was approved by the ethics committee of the Second Hospital of Anhui Medical University (No. SL-YX2018-324(F1)). Patients with single segmental lumbar disc herniation treated in the Department of Orthopedics of the second Hospital of Anhui Medical University from November 2018 to May 2020 were studied, and UBE spinal surgery was performed entirely by the same doctor. All patients signed the informed consent form according to the standard of diagnosis and treatment before operation. The inclusion criteria that were used are as follows: (1) patients with single-segment lumbar disc herniation, who have clear surgical indications, (2) American Society of Anesthesiology (ASA) levels I–III, and (3) complete follow-up data can be obtained and the follow-up period is at least 18 months. The exclusion criteria are as follows: (1) patients with extreme lateral, very middle, or bilateral disc herniation, (2) patients with other serious diseases, (3) patients with previous lumbar surgery history, (4) patients with lumbar instability, lumbar infection, or lumbar tumor, (5) patients with the multisegmental lumbar disease need to be treated, (6) a patient whose operation is performed by another doctor. According to the above inclusion and exclusion criteria, a total of 97 patients were enrolled in this study.

Surgical Technique

The patient underwent general anesthesia and was placed in the prone position. With C-arm fluoroscopy, adjustments to the operating bed were made, so that the target intervertebral space is as perpendicular to the ground as possible. Taking the intersection of the upper and lower 1–1.5 cm of the target intervertebral space and the inner edge of the pedicle as the center, a 1–1.5 cm transverse incision was made. The left-hand incision serves as the observation channel (portal), and the right-hand incision serves as the working channel. The bilateral channels were dilated with a step-by-step dilator and the lower edge of the superior lamina and the interlaminar space can be touched by the dilator. The operator held the arthroscope in his left hand and the instrument in his right hand. Through the two channels, the camera lens and instrument will meet in the space around the interlaminar window in a continuous perfusion water environment.

The structures such as the inferior edge of the superior lamina, the root of the spinous process, the upper edge of the inferior lamina, the inner edge of the facet joint, and interlaminar ligamentum flavum were exposed using a plasma radio-frequency knife. Tools such as the power grinding drill, osteotome, and gun rongeur were used to remove bones of, for example, the lower edge of the upper lamina, the upper edge of the lower lamina, and the medial side of the facet joint. Then the ligamentum flavum was removed. The intervertebral disc that compressed the nerve was explored and removed. After confirming that there was no nerve compression or active bleeding, the instrument was removed and the incision was closed. A representative case is shown in **Figure 1**.

Surgeon's experience: the surgeon, a senior orthopedic (spinal surgery subspecialty) doctor, independently completed more than 500 single-portal spinal endoscopic operations and more than 1,000 lumbar open decompression operations before starting these cases, and completed spinal minimally invasive (including UBE) related training in a number of spinal centers. The first assistant is one of two regular spinal surgeons.

Observation Indicators

(1) General patient demographics and condition: age, sex, and underlying disease; (2) preoperative-related indexes: duration of preoperative symptoms, preoperative visual analog scale score (VAS), Oswestry disability index score (ODI), and target segment dural sac area; (3) indexes related to operation: operation time and amount of bleeding; (4) postoperative-related indicators: postoperative hospital stay, VAS score, ODI score, Macnab grade (the patient is asked to rate his level of wellbeing, generally after surgery; the patient choose one of the four: (1) excellent, (2) good, (3) fair, and (4) poor) (12), and target segment dural sac area, complications, and reoperation.

Statistical Analysis

SPSS20.0 software was used for statistical analysis. The independent samples Student's t-test was used to compare the measurement data between groups, and the paired samples Student's t-test was used to compare the measurement data before and after the operation. The chi-square test was used to compare categorical parameters. Significance was assigned at $P < 0.05$.

The learning curve was analyzed by CUSUM analysis. The formula is as follows: $CUSUM = \sum_{i=1}^{n} (Xi - u)$. Xi indicates the actual operation time for each patient and u indicates the average operation time of this group of patients. The difference between the operation time of each patient in chronological order and the average operation time of the whole group was summed and the learning curve was obtained.

RESULTS

There were 52 men and 45 women. The age was 21.0–86.0 (51.5 ± 15.4) years old. The body mass index was 16.1–31.6 (23.9 ±

Abbreviations: UBE, Unilateral biportal endoscopy; CUSUM, Cumulative summation; VAS, Visual analog scale; ODI, Oswestry disability index.

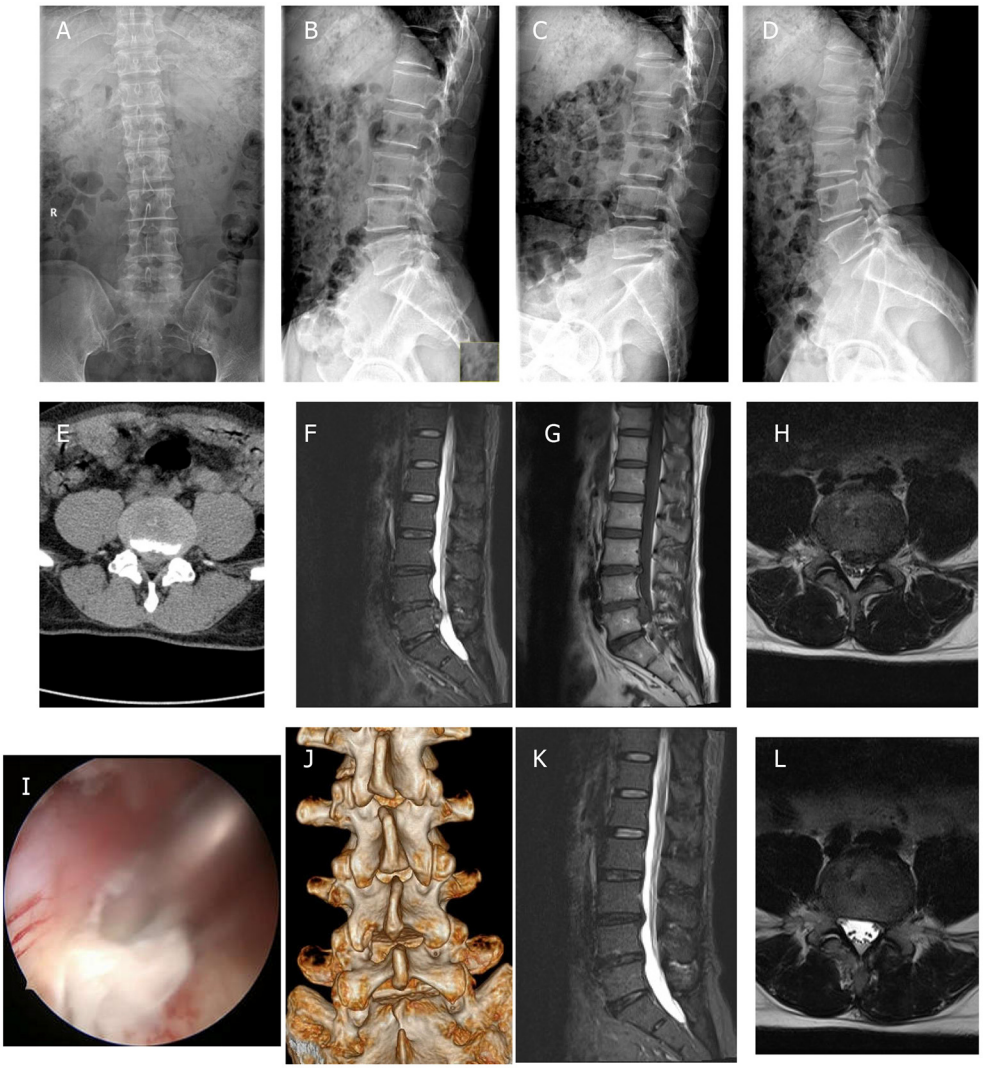


FIGURE 1 | Unilateral biportal endoscopic (UBE) diskectomy was performed on a 47-year-old male patient with L4/5 lumbar disc herniation. **(A,B)** Preoperative anteroposterior and lateral plain radiographs; **(C,D)** preoperative flexion and extension radiographs; **(E)** preoperative CT scans; **(F–H)** preoperative MRI scans; **(I)** diskectomy was performed to ensure adequate decompression of the nerve tissue; **(J)** postoperative 3D-CT scans; and **(K,L)** postoperative MRI scans.

4.8) kg/m^2. The duration of preoperative symptoms was 1–240 (24.4 ± 39.5) months. Among the 97 patients, 19 cases were complicated with hypertension, diabetes, old cerebral infarction, rheumatoid, etc. The detailed demographic data are presented in **Table 1**.

All 97 patients underwent the UBE operation successfully. The follow-up time was 18–36 (22.6 ± 3.6) months. The operation time was 30–241 (97.9 ± 34.7) min. The estimated intraoperative blood loss was 10–50 (20.4 ± 5.0) ml. The postoperative hospital stay was 1–14 (4.4 ± 2.1) days. The VAS score of lower limb pain decreased from 5.75 ± 0.81 before the operation to 0.39 ± 0.28 at the last follow-up ($P < 0.05$). The ODI score decreased from 66.48 ± 4.43 before the operation to 14.57 ± 3.99 at the last follow-up ($P < 0.05$). The postoperative MacNab grade was grade 1 in 84 cases (86.6%), grade 2 in 7 cases (7.2%), grade 3 in 6 cases (6.2%), and grade 4 in 0 cases. The area of the dural sac at the narrowest part of the target segment increased from 89.34 ± 32.85 mm^2 to 140.86 ± 39.87 mm^2 ($P < 0.05$).

During the follow-up, 4 complications occurred. Complications of dural injury were found in 2 cases, of which 1 case was managed by wound expansion and suture in the later stage of incision eminence and exudation. A total of 2 cases of residual nerve compression of intervertebral disc herniation were cured by percutaneous transforaminal endoscopic discectomy surgery. The preoperative and postoperative characteristics of the whole group of cases are listed in **Table 2**.

The operation time showed a downward trend as a whole. The scatter chart of the operation time is shown in **Figure 2**. The CUSUM analysis curve of the learning curve is shown in **Figure 3**. CUSUM method showed that the curve reached the

TABLE 1 | Demographic factors of patients included in this study.

Characteristic	Value
Patients (*n*)	97
Age (years)	
Mean ± SD	51.5 ± 15.4
Range	21–86
Sex (*n*)	
Male	52
Female	45
Body mass index (kg/m^2)	
Mean ± SD	23.9 ± 4.8
Range	16.1–31.6
Operative level (*n*)	
L3/4	9
L4/5	40
L5/S1	48
Patents with basic disease (*n*)	19
Duration of symptoms (months)	
Mean ± SD	24.4 ± 39.5
Range	1–240

TABLE 2 | Preoperative and postoperative characteristics of the whole cohort.

Characteristic	Preoperative	Last follow-up	*P*-value*
Leg VAS	5.75 ± 0.81	0.39 ± 0.28	< 0.001
ODI	66.48 ± 4.43	14.57 ±3.99	< 0.001
Sac cross-sectional area	89.34 ± 32.85	140.86 ± 39.87	< 0.001
Macnab criteria			
1 (Excellent)		84 (86.6%)	
2 (Good)		7 (7.2%)	
3 (Fair)		6 (6.2%)	
4 (Poor)		0 (0%)	

Data presented as mean ± SD for numerical parameters and as n (%) for categorical parameters.
**Statistical analyses were performed between the preoperative and postoperative characteristics by paired samples student t-test.*

maximum in the no. 24 case, and then decreased gradually. So the cut-off point of the learning curve was selected as 24 cases. According to the cut-off point, the curve could be divided into two stages: the first stage was the learning stage in which the CUSUM value was increasing (the first 24 cases), and the latter stage was the proficiency stage in which the CUSUM value gradually decreased (after 24 cases).

Comparison of general data between the two stages: there was no significant difference between the two stages in terms of sex, age, body mass index, preoperative complications, duration of preoperative symptoms, preoperative lower limb VAS score, preoperative ODI score, preoperative dural sac area, and operative level ($P > 0.05$). The general characteristics stratified by learning period are listed in **Table 3**.

Comparison of the clinical effects of the two stages: the operation time, postoperative hospital stay, and the proportion of Macnabcriteria1 grade in the second stage were improved from the first stage ($P < 0.05$). There was no significant difference in the incidence of postoperative complications, VAS, ODI, and postoperative dural sac area between the two stages ($P > 0.05$). The clinical effect characteristics according to the learning period are listed in **Table 4**.

DISCUSSION

The ideal management strategy for lumbar disc herniation remains controversial (13). Surgical treatment is a common method of treatment, which can be more effective than conservative treatment in patients with severe lumbar spinal nerve compression (14). With the main purpose of surgery to relieve nerve compression, there are many ways of performing the operation, namely, open surgery, microscopic surgery, and percutaneous transforaminal endoscopic surgery (15). Decompression combined with internal fixation is not superior to simple decompression in many cases (16). In recent years, there have been increasing reports of UBE surgery for lumbar disc herniation and lumbar spinal stenosis (5–8). In addition, the UBE technique can be used for nerve decompression of burst fracture (17), excision of the perispinal cyst (18, 19), clearance of epidural abscess (20), treatment of epidural lipomatosis (21), treatment of foraminal stenosis (8, 22), lumbar interbody fusion (6), and revision surgery (23).

The unilateral biportal endoscopic (UBE) technique uses an independent working channel, which can achieve complete decompression under a wide visual field of the arthroscopy (9). During the making of the channel, there is no need to strip away too much soft tissue. The lens and instrument are operated directly through soft tissue channels to the target. We found in our practice that even for obese patients, no significant difficulty was increased in the surgery. The channel provides less restriction for instrument movement, and the continuous perfusion of saline during the operation is a major advantage for infection prevention. Compared with microscope technology, UBE technology has a higher success rate, shorter operation time and hospital stay (24). In our study, 86.6% of patients got MacNab grade 1. Most surgeons choose a 30-degree arthroscopic lens, which can be used to observe the lateral structure of the lens because of its wide field of view (25). UBE technique can allow visualization of the contralateral spinal canal and intervertebral foramen (5). Compared with percutaneous transforaminal endoscopic surgery, the UBE technique has less radiation exposure (26). The injury of the multifidus muscle after UBE is minimal (27). Other advantages of the UBE technique are less destruction of the facet joint, lower incidence of complications, a lesser degree of postoperative back pain, and higher satisfaction (24, 28–30). UBE technique can essentially be used as an alternative to the microscope technique (31, 32). Compared with microscopic surgery, endoscopic surgery such as UBE has been found to contribute to less pain in the early stage after the operation (33). In addition, the implementation of UBE technology does not require the purchase of special lenses and instruments as seen in the percutaneous transforaminal

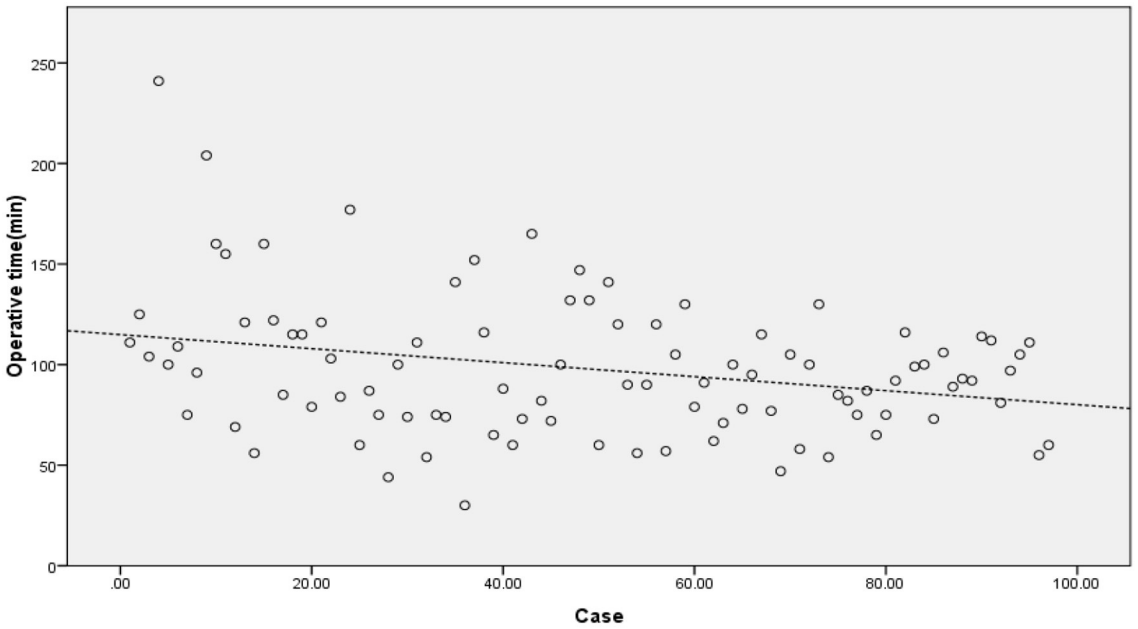


FIGURE 2 | The scatter chart of the operation time showed a downward trend. The dashed line was automatically linear fitted by SPSS software.

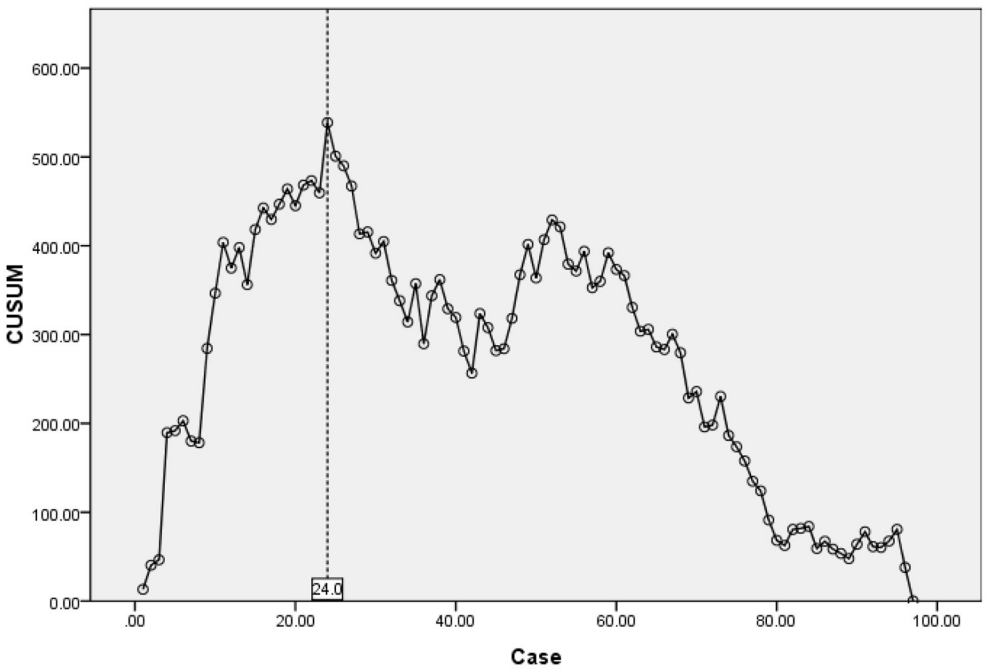


FIGURE 3 | CUSUM for learning curve reached the maximum in no. 24 case, revealed competency after 24 cases.

endoscopic technique. UBE can use general arthroscopic lenses and open spinal surgical instruments, which is more conducive to wide acceptance in most hospitals.

The unilateral biportal endoscopic (UBE) technique requires both hands to operate the lens and surgical instruments and requires sufficient coordination of both hands and stable instrument operation with a single hand. In the early stage, it is difficult for spinal surgeons who have no experience in using arthroscopic equipment to coordinate the depth and direction of the lens, move the instruments quickly and smoothly

TABLE 3 | General characteristics stratified by learning period.

Characteristic	Early cases (1–24)	Late cases (25–97)	*P*-value*
Patients (*n*)	24	73	
Age (years)	50.5 ± 15.9	51.9 ± 15.3	0.703
Sex (male to female)	10:14	42:31	0.239
Body mass index (kg/m^2)	23.3 ± 5.2	24.1 ± 4.7	0.386
Patents with basic disease (*n*)	4 (16.7%)	15 (20.5%)	0.465
Preoperative duration of symptoms (months)	19.1 ± 31.5	26.2 ± 41.8	0.447
Preoperative leg VAS	5.55 ± 0.81	5.81 ± 0.80	0.161
Preoperative ODI	65.71 ± 4.90	66.74 ± 4.27	0.325
Preoperative sac cross-sectional area	91.80 ± 25.90	88.53 ± 34.83	0.674
Operative level (L3/4:L4/5:L5/S1)	2:11:11	7:29:37	0.102

Data presented as mean ± SD for numerical parameters, and as n (%) for categorical parameters.
**Statistical analyses were performed between early and late groups.*

TABLE 4 | Clinical effect characteristics stratified by learning period.

Characteristic	Early cases (1–24)	Late cases (25–97)	*P*-value*
Patients	24	73	
Operative time (min)	120.3 ± 43.8	90.5 ± 27.8	0.004
Postoperative hospital stay (days)	4.7 ± 2.4	3.9 ± 1.8	0.037
Complications (*n*)	2 (8.33%)	2 (2.74%)	0.255
Last follow-up leg VAS	0.35 ± 0.31	0.37 ± 0.27	0.783
Last follow-up ODI	11.21 ± 3.82	15.67 ± 3.40	0.104
Last follow-up sac cross-sectional area	147.84 ± 44.45	138.57 ± 38.30	0.326
Macnab criteria I(Excellent)	18 (75.0%)	66 (90.4%)	0.044

Data presented as mean ± SD for numerical parameters and as n (%) for categorical parameters.
**Statistical analyses were performed between early and late groups.*

in and out of the instrument channel and quickly acquire the field of vision. If the operation is performed incorrectly, complications such as dural injury often occur in UBE surgery (10). A total of 2 cases of dural injury were found in our patients, too. These have higher requirements for the surgeon's UBE technology, the cooperation of the surgical team, and the perioperative management, which have become a big obstacle to the further popularization and development of this technology. Navigating the learning curve quickly and safely is a core issue in the clinical application of UBE. At present, there are many studies on the learning curve of transforaminal endoscopy, but few studies exist on the learning curve of UBE technology.

As a new technology for the minimally invasive spine, UBE contributes a certain learning curve, which is mainly reflected in operation time and complications. CUSUM method is a quantitative analysis method for analyzing the learning curve of surgical techniques (11). Many other studies on the learning curve of surgical techniques are mostly based on the method of grouping all cases in order, which is subjective. And the cut-off point of the learning curve is often an integer multiple of the number of grouped cases, so the results are inaccurate. In our study, the CUSUM method is selected for the analysis. To obtain the operation time of each patient, the relationship between the operation time of each patient and the average value of the group is calculated, and the approximate parabola curve is obtained. At the highest point of the parabola curve, the learning curve is divided into two stages. According to the formula, the operation time of most cases before the highest point of the parabola is longer than the average operation time, and the operation time of most cases after the highest point is < the average operation time. There is no need for artificial subjective grouping in the study of the CUSUM method, which is more objective and accurate than the grouping method (34–36). According to the highest point of the CUSUM curve (**Figure 3**), there were 1–24 cases in the early stage of this study and 25–97 cases in the later stage. This graph reveals that the initial curve is very steep, but it does not take too many cases to reach the highest point. With the increase in the number of cases (after 24 cases), the CUSUM curve of operation time showed a downward trend to be stable in the later stage. Evidence of the gradual decrease of operation time can also be seen in the scatter chart of operation time (**Figure 2**). This shows that the difficulties encountered at the beginning of UBE technology, such as long operation time, are short-lived. After a period of learning and acclimation, the surgeons become more familiar with the surgical equipment and surgical procedures. Meanwhile, with the gradual optimization of the operating room procedures and the cooperation of other personnel, the learning curve gradually becomes more stable.

Through the comparison of the data of the two stages, there is no statistical difference in the general condition and preoperative index of the patients. But the operation time, postoperative hospital stay, and the proportion of Macnabcriteria1 grade in the second stage are all improved from those in the first stage, and the difference is statistically significant. This may be due to multiple reasons: the technique of the surgeon improves; the cooperation of fixed assistants gains understanding; anesthesia, nursing, and other surgical team cooperation are gradually optimized, and perioperative management is optimized. Although the operation time shortened with the learning stage, there was no significant difference in the incidence of postoperative complications, last follow-up VAS, ODI, and the area of the dural sac after operation between the two stages. This indicated that in our earliest cases, although it takes a longer time to operate, it still ensures a clinical effect and safety that is essentially the same as that in the mature stage. Looking at the CUSUM curve, it shows that in about 42–52 cases, the curve increased slightly again. This occurrence may be related to the increasing challenge of more difficult and complex cases after the surgical technique becomes

proficient. Usually, as the technique is mastered, surgeons will unconsciously extend the application of the technique to more difficult cases that they may be reluctant to choose at an early stage (11). As we can see in our cases, the proportion of patients with the basic disease and the duration of preoperative symptoms in the second stage cases were higher than those in the first stage, although there was no significant statistical difference (**Table 3**).

What is the difference between the learning curve of the UBE technique and other invasive techniques such as percutaneous transforaminal endoscopic surgery? With regard to the learning curve of percutaneous transforaminal endoscopic surgery, the cut-off point reported in the early literature was about 40–70 cases (37, 38), while the cut-off point reported later in the new literature was about 20 cases (39, 40). However, like the early explorers of UBE technology in China, it only takes about 24 cases to master this technique skillfully, and its learning curve is shorter than that of transforaminal endoscopic surgery reported in the early literature. The shortening of the learning curve means that the operation time, hospital stay, operation costs, and complications can be reduced in a short time, which is more beneficial to patients and more likely to be recognized by surgeons. UBE technology provides the advantages of minimally invasive percutaneous transforaminal endoscopic surgery and flexible operation of open surgery, so it is currently being widely promoted in China.

What factors can optimize the learning curve? According to our experience, surgeons need rich experience in spinal surgery before carrying out this technique, and it is better to have experience in single-portal spinal endoscopy such as percutaneous transforaminal endoscopic surgery and double-portal endoscopic surgery such as arthroscopy surgery. At the same time, the surgeon must be trained in UBE technology. Our department has held UBE training using the plastic model and the fresh specimens of piglet spine many times, which is helpful for the surgeons to successfully overcome the steep learning curve of UBE technology. In the early stage, one should try to select the cases with typical, unilateral symptoms, clear surgical indications, less degeneration, less operative area complexity, and then gradually carry out the more difficult cases after gaining skill. Some special instruments needed in UBE, such as arthroscopy, plasma-mediated ablation probes, radio-frequency probes, and grinding drill, must be well prepared. Our general experience is for a right-handed surgeon to place arthroscope, water perfusion equipment, and other observation equipment on the left hand, while radio-frequency probe, grinding drill, and other energy power equipment on the right hand to avoid entanglement of the devices. Maintaining a clear field of vision requires the anesthesia team to provide an adequate degree of anesthesia, maintain normal blood pressure, and good muscle relaxation. This requires communication and coordination with the anesthesia team. During the operation, it is necessary to maintain the appropriate water pressure of the operating cavity. And one must pay attention to the appropriate perfusion pressure and the placement of the casing, and keep the effluent unobstructed at all times (41).

CONCLUSIONS

As a new minimally invasive endoscopic technique for the spine, UBE surgery requires coordination of both hands and one-handed operation of instruments. The learning curve is steep, but a few cases (about 24 cases) are required to overcome the learning curve. If the learning curve can be navigated smoothly, this technology can provide the advantages of less surgical trauma, flexible and efficient operation under the endoscope, and rapid recovery after the operation. In this study, CUSUM analysis was used to analyze the learning curve of a single segmental UBE in the operation of lumbar disc herniation performed by the same surgeon in the early stage. The results show that after experiencing the learning curve of 24 cases, the surgeon can reach a more skilled and stable level of operation, and can significantly reduce the operation time and improve satisfaction. In summary, the steep learning curve in the early stage can be mitigated by strengthening and training before performing this operation and selecting less complex cases in the early stage.

This study does have limitations. This study analyzes cases performed by a single surgeon that already has rich experience in open and endoscopic spinal surgery before this procedure, providing a shorter learning curve, while for young surgeons with less experience, the learning curve of UBE may be longer. However, as a very early explorer of UBE in China, the surgeon can learn from less UBE experience, and the initial development is slow progress. Later operators may have more experience to learn from and may need fewer cases to overcome the learning curve. Another limitation is that only single segment lumbar disc herniation cases are selected, multisegment and other diseases were excluded. Although the use of UBE technology for other diseases may have an impact on the cut-off point of the learning curve, the vast majority of early UBE techniques are used to treat single-segment lumbar disc herniation. Therefore, this aspect should contribute little impact on the UBE learning curve.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Scientific Ethics Committee of the Second Affiliated Hospital of Anhui Medical University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

LC: conceptualization, validation, data curation, and writing—original draft. BZ: investigation. H-zZ: software. Y-gW: methodology. Y-sS: formal analysis. Q-fW: investigation. J-jL: visualization. D-sT: methodology and formal analysis. J-hJ: conceptualization and supervision. All authors contributed to the article and approved the submitted version.

REFERENCES

1. Konstantinou K, Dunn KM. Sciatica: review of epidemiological studies and prevalence estimates. *Spine*. (2008) 33:2464–72. doi: 10.1097/BRS.0b013e318183a4a2
2. Ma Z, Yu P, Jiang H, Li X, Qian X, Yu Z, et al. Conservative treatment for giant lumbar disc herniation: clinical study in 409 cases. *Pain Physician*. (2021) 24:E639–48. doi: 10.36076/ppj.2021.24.E639
3. Benzakour T, Igoumenou V, Mavrogenis AF, Benzakour A. Current concepts for lumbar disc herniation. *Int Orthop*. (2018) 43: 841–51. doi: 10.1007/s00264-018-4247-6
4. Choi HS, Kwak KW, Kim SW. Ahn SH. Surgical versus conservative treatment for lumbar disc herniation with motor weakness. *J Korean Neurosurg Soc*. (2013) 54:183–8. doi: 10.3340/jkns.2013.54.3.183
5. Hwa EJ, Hwa HD, Son SK, Park CK. Percutaneous biportal endoscopic decompression for lumbar spinal stenosis: a technical note and preliminary clinical results. *J Neurosurg Spine*. (2016) 24:602–7. doi: 10.3171/2015.7.SPINE15304
6. Heo DH, Son SK, Eum JH, Park CK. Fully endoscopic lumbar interbody fusion using a percutaneous unilateral biportal endoscopic technique: technical note and preliminary clinical results. *Neurosurg Focus*. (2017) 43:E8. doi: 10.3171/2017.5.FOCUS17146
7. Heo DH, Quillo-Olvera J, Park CK. Can percutaneous biportal endoscopic surgery achieve enough canal decompression for degenerative lumbar stenosis? prospective case-control study. *World Neurosurg*. (2018) 120:e684–9. doi: 10.1016/j.wneu.2018.08.144
8. Ahn JS, Lee HJ, Choi DJ, Lee KY, Hwang SJ. Extraforaminal approach of biportal endoscopic spinal surgery: a new endoscopic technique for transforaminal decompression and discectomy. *J Neurosurg Spine*. (2018) 28:492–8. doi: 10.3171/2017.8.SPINE17771
9. Pao JL. A review of unilateral biportal endoscopic decompression for degenerative lumbar canal stenosis, *Int J Spine Surg*. (2021) 15:S65–71. doi: 10.14444/8165
10. Lee HG, Kang MS, Kim SY, Cho K, Na Y, Cho J. Dural injury in unilateral biportal endoscopic spinal surgery. *Global Spine J*. (2021) 11:845–51. doi: 10.1177/2192568220941446
11. Cook JA, Ramsay CR, Fayers P. Statistical evaluation of learning curve effects in surgical trials. *Clin Trials*. (2004) 1:421–7. doi: 10.1191/1740774504cn042oa
12. Macnab I. Negative disc exploration. an analysis of the causes of nerve-root involvement in 68 patients. *J Bone Joint Surg Am*. (1971) 53:891–903. doi: 10.2106/00004623-197153050-00004
13. Zaina F, Tomkins-Lane C, Carragee E, Negrini S. Surgical versus nonsurgical treatment for lumbar spinal stenosis. *Spine Phila Pa*. (2016) 41:E857–68. doi: 10.1097/BRS.0000000000001635
14. Weinstein JN, Tosteson TD, Lurie JD, Anna NA, Tosteson SD, Emily Blood MS, et al. Surgical versus non-surgical therapy for lumbar spinal stenosis. *N Engl J Med*. (2008) 358:794–810. doi: 10.1056/NEJMoa0707136
15. Wei FL, Li T, Gao QY, Yang Y, Gao HR, Qian JX. et al. Eight surgical interventions for lumbar disc herniation: a network meta-analysis on complications. *Front Surg*. (2021) 8:679142. doi: 10.3389/fsurg.2021.679142
16. Försth P, Ólafsson G, Carlsson T, Frost A, Borgström F, Fritzell P, et al. A randomized, controlled trial of fusion surgery for lumbar spinal stenosis. *N Engl J Med*. (2016) 374:1413–23. doi: 10.1056/NEJMoa1513721
17. Quillo-Olvera J, Quillo-Olvera D, Quillo-Reséndiz J, Barrera-Arreola M. Unilateral biportal endoscopic-guided transcorporeal vertebroplasty with neural decompression for treating a traumatic lumbar fracture of L5. *World Neurosurg*. (2020) 144:74–81. doi: 10.1016/j.wneu.2020.08.130
18. Sharma SB, Lin GX, Jabri H, Siddappa ND, Kim JS. Biportal endoscopic excision of facetal cyst in the far lateral region of L5S1:2-dimensional operative video. *Oper Neurosurg. (Hagerstown)*. (2020) 18:E233. doi: 10.1093/ons/opz255
19. An JW, Lee CW. Surgical treatment of extra-foraminal gas containing pseudocyst compressing L5 nerve root by using unilateral biportal endosopy: a case report. *World Neurosurg*. (2019) 124:145–50. doi: 10.1016/j.wneu.2018.12.186
20. Kang T, Park SY, Lee SH, Park JH, Suh SW. Spinal epidural abscess successfully treated with biportal endoscopic spinal surgery. *Medicine. (Baltimore)*. (2019) 98:e18231. doi: 10.1097/MD.0000000000018231
21. Kang SS, Lee SC, Kim SK. A novel percutaneous biportal endoscopic technique for symptomatic spinal epidural lipomatosis: technical note and case presentations. *World Neurosurg*. (2019) 129:49–54. doi: 10.1016/j.wneu.2019.05.214
22. Park JH, Jung JT, Lee SJ. How i do it: L5/S1 foraminal stenosis and far-lateral lumbar disc herniation with unilateral bi-portal endoscopy. *Acta Neurochir. (Wien)*. (2018) 160:1899–903. doi: 10.1007/s00701-018-3630-9
23. Kim KR, Park JY. The technical feasibility of unilateral biportal endoscopic decompression for the unpredicted complication following minimally invasive transforaminal lumbar interbody fusion: case report. *Neurospine*. (2020) 17(Suppl. 1):S154–9. doi: 10.14245/ns.2040174.087
24. Min WK, Kim JE, Choi DJ, Park EJ, Heo J. Clinical and radiological outcomes between biportal endoscopic decompression and microscopic decompression in lumbar spinal stenosis. *J Orthop Sci*. (2020) 25:371–8. doi: 10.1016/j.jos.2019.05.022
25. Kim JE, Choi DJ. Unilateral biportal endoscopic decompression by 30° endoscopy in lumbar spinal stenosis: technical note and preliminary report. *J Orthop*. (2018) 15:366–71. doi: 10.1016/j.jor.2018.01.039
26. Merter A, Karaeminogullari O, Shibayama M. Comparison of radiation exposure among 3 different endoscopic diskectomy techniques for lumbar disk herniation. *World Neurosurg*. (2020) 139:e572–9. doi: 10.1016/j.wneu.2020.04.079
27. Ahn JS, Lee HJ, Park EJ, Kim SB, Choi D, Kwon Y, et al. Multifidus muscle changes after biportal endoscopic spinal surgery: magnetic resonance imaging evaluation. *World Neurosurg*. (2019) 130:e525–34. doi: 10.1016/j.wneu.2019.06.148
28. 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: E323–28. doi: 10.1097/BSD.0000000000001122
29. Ito Z, Shibayama M, Nakamura S, Yamada M, Kawai M, Takeuchi M, et al. Clinical comparison of unilateral biportal endoscopic laminectomy versus microendoscopic laminectomy for single-level laminectomy: a single-center, retrospective analysis. *World Neurosurg*. (2021) 148:e581–8. doi: 10.1016/j.wneu.2021.01.031
30. Kang T, Park SY, Kang CH, Lee SH, Park JH, Suh SW. Is biportal technique/endoscopic spinal surgery satisfactory for lumbar spinal stenosis patients? a prospective randomized comparative study. *Medicine. (Baltimore)*. (2019) 98:e15451. doi: 10.1097/MD.0000000000015451
31. Park SM, Park J, Jang HS, et al. Biportal endoscopic versus microscopic lumbar decompressive laminectomy in patients with spinal stenosis: a randomized controlled trial. *Spine J*. (2020)20:156–65. doi: 10.1016/j.spinee.2019.09.015
32. Pranata R, Lim MA, Vania R, July J. Biportal endoscopic spinal surgery versus microscopic decompression for lumbar spinal stenosis: a systematic review and meta-analysis. *World Neurosurg*. (2020) 138:e450–8. doi: 10.1016/j.wneu.2020.02.151
33. Heo DH, Lee DC, Park CK. Comparative analysis of three types of minimally invasive decompressive surgery for lumbar central stenosis: biportal endoscopy, uniportal endoscopy, and microsurgery. *Neurosurg Focus*. (2019) 46:E9. doi: 10.3171/2019.2.FOCUS197
34. Buchmann P, Steurer J. [The learning curve in surgery: possibilities and limits of this method]. *Swiss Surg*. (2002) 8:106–9. doi: 10.1024/1023-9332.8.3.106
35. Chan G, Pautler SE. Use of cumulative summation. (CUSUM) as a tool for early feedback monitoring in robot-assisted radical prostatectomy outcomes performance. *Can Urol Assoc J*. (2019)13:53–8. doi: 10.5489/cuaj.5350
36. Chang WR, McLean IP. CUSUM: a tool for early feedback about performance. *BMC Med Res Methodol*. (2006) 6:8. doi: 10.1186/1471-2288-6-8
37. Morgenstern R, Morgenstern C, Yeung AT. The learning curve in foraminal endoscopic discectomy: experience needed to achieve a 90% success rate. *SAS J*. (2007)1:100–7. doi: 10.1016/S1935-9810(07)70054-3
38. Tenenbaum S, Arzi H, Herman A, Friedlander A, Levinkopf M, Arnold PM. Percutaneous posterolateral transforaminal endoscopic discectomy: clinical outcome, complications, and learning curve evaluation. *Surg Technol Int*. (2011) 21:278–83.
39. 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. (Baltimore)*. (2021) 100:e24346. doi: 10.1097/MD.0000000000024346

40. 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) 44:309–17. doi: 10.1007/s00264-019-04448-1
41. Hong YH, Kim SK, Hwang J, Eum J-H, Heo D-H, Suh D-W, 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

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: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers | Frontiers in Surgery

ORIGINAL RESEARCH
published: 18 May 2022
doi: 10.3389/fsurg.2022.888148

Risk Factors of Bone Nonfusion After Spinal Tuberculosis Debridement Bone Graft Fusion and Internal Fixation

*Zihan Wei[1], Ying Zhang[1], Sizhen Yang[1], Jiawen Ye[1], Xu Hu[1], Tian Li[2] and Tongwei Chu[1]**

[1]Department of Orthopedics, Xinqiao Hospital of Chongqing/Second Affiliated Hospital of Army Medical University, Chongqing, China, [2]School of Basic Medicine, Fourth Military Medical University, Xi'an, China

Objective: To retrospectively analyze bone graft nonfusion risk factors in spinal tuberculosis patients after lesion debridement, bone graft fusion and internal fixation.

Methods: The clinical data of 131 patients who underwent spinal tuberculosis debridement, bone graft fusion and internal fixation in our hospital from March 2015 to March 2018 were retrospectively analyzed. The patients were divided into two groups according to bone fusion after the operation; there were 37 patients in the nonfusion group and 94 in the fusion group. The basic information and follow-up data of the patients were collected to evaluate the risk factors for bone graft nonfusion 1 year after surgery.

Results: The severity of osteoporosis in the nonfusion group was significantly greater than that in the fusion group ($p < 0.05$). There were statistically significant differences between the two groups in terms of continuous multisegment status, disease duration, intraoperative surgical methods and whether patients received standardized drug treatment for 12 months after surgery ($p < 0.05$). Multivariate logistic regression analysis showed that long disease duration, posterior approach, and degree of osteoporosis were risk factors for postoperative bone graft nonfusion (OR > 1, $p < 0.05$), while standard drug treatment for 1 year after surgery was a protective factor (OR < 1, $p < 0.05$).

Conclusion: Spinal tuberculosis patients who had a long disease course, who underwent simple posterior debridement, or who had severe osteoporosis had a higher risk of bone graft nonfusion after surgery. Tuberculosis treatment is beneficial for the osseous fusion of the postoperative bone graft area.

Keywords: spinal tuberculosis, postoperative bone nonfusion, risk factor, retrospective study, orthopeadics

OPEN ACCESS

Edited by:
Hengxing Zhou,
Tianjin Medical University General Hospital, China

Reviewed by:
Cao Yang,
Wuhan Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, China
Xing Du,
First Affiliated Hospital of Chongqing Medical University, China

****Correspondence:***
Tongwei Chu
chutongwei@tmmu.edu.cn

Specialty section:
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

Received: *02 March 2022*
Accepted: *18 April 2022*
Published: *18 May 2022*

Citation:
Wei Z, Zhang Y, Yang S, Ye J, Hu X, Li T and Chu T (2022) Risk Factors of Bone Nonfusion After Spinal Tuberculosis Debridement Bone Graft Fusion and Internal Fixation. Front. Surg. 9:888148. doi: 10.3389/fsurg.2022.888148

BACKGROUND

Tuberculosis is one of the most widespread infectious diseases in the world that occurs worldwide (1). According to researchers' estimates, approximately one-quarter of the world's population has been infected with pulmonary tuberculosis, and some tuberculosis infections can be found concomitantly outside the lungs. The most common type of extrapulmonary tuberculosis is bone tuberculosis with

the spine being the most common site of bone tuberculosis, accounting for approximately half of all bone tuberculosis cases (2). At present, there are various options for the treatment of spinal tuberculosis, such as the use of standardized anti-tuberculosis drug therapy (3), but there are still some patients whose disease progresses after drug treatment, resulting in neurological damage and even paraplegia. Surgery is required when necessary (4). In the early stage, simple debridement or abscess drainage was often used to treat these patients (5), but these treatments could not improve the deformity or instability caused by the destruction of the spinal structure (6), so these methods have been gradually abandoned. Currently, spinal tuberculosis debridement and bone grafting, fusion and internal fixation are the most commonly used surgical methods for the treatment of spinal tuberculosis, and their efficacy in correcting kyphosis and relieving spinal cord and nerve compression has been widely recognized. One of the key aspects of these procedures is whether the implanted bone can be fused with the patient's autologous bone, which will directly affect postoperative symptom relief and quality of life of the patient. Therefore, the risk factors for the complication of postoperative bone graft nonfusion deserve our close attention. In this study, the relevant data of patients who underwent spinal tuberculosis lesion removal, bone graft fusion and internal fixation in our hospital from March 2015 to March 2018 retrospectively analyzed, and the risk factors for bone graft nonfusion after spinal tuberculosis surgery were assessed. The findings and the suggestions for improvement of the treatment plan provide a relevant reference, and the report is as follows.

MATERIALS AND METHODS

General Data

The study design can be found in **Figure 1**. The general data, surgical information and follow-up data of patients who underwent spinal tuberculosis debridement, bone grafting, fusion and internal fixation in our hospital from March 2015 to March 2018 were retrospectively analyzed. A total of 131 patients were included, including 58 females and 73 males. They were divided into a fusion group (94 cases) and a nonfusion group (37 cases) according to whether the bone

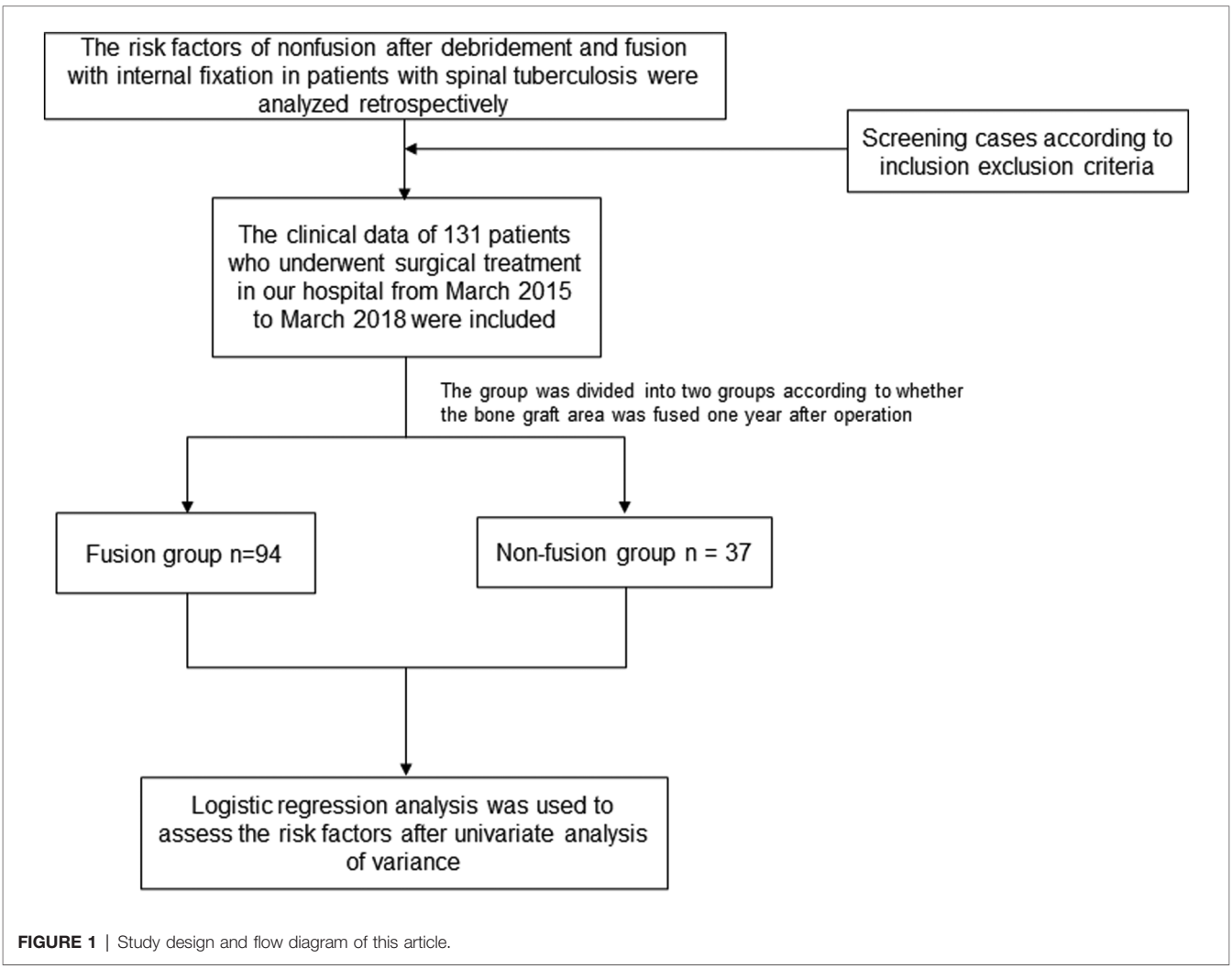


FIGURE 1 | Study design and flow diagram of this article.

fused one year after the graft (7). Whether bone fusion occurs according to the theory of Bridwell et al. They divided the graft fusion into four levels. Grade I: Fused with remodeling and trabeculae. Grade II: Graft intact, not fully remodeled and incorporated though; no lucencies. Grade III: Graft intact, but a definite lucency at the top or bottom of the graft. Grade IV: Definitely not fused with resorption of bone graft and with collapse (8). This study defines Grade I and Grade II as bone graft fusion. The general data of the two groups of patients, including sex, height, weight and body mass index (BMI), were not significantly different ($p > 0.05$) and were comparable. Regarding the severity of osteoporosis in the two groups (no osteoporosis/osteoporosis/severe osteoporosis), osteoporosis grading was based on the T value in the bone density test. $T \geq -1$ indicated no osteoporosis, $-2.5 \leq T < -1$ indicated osteoporosis, and $T < -2.5$ indicated severe osteoporosis; the difference was statistically significant ($p < 0.05$). To rule out the effects of bone graft materials and ensure a higher fusion rate, all patients in this study were treated with autogenous bone graft. Declaration of Helsinki was followed throughout the study, and all patients were fully informed and signed informed consent before surgery.

Inclusion and Exclusion Criteria

The inclusion criteria were as follows: ① patients with typical imaging features or clinical symptoms of spinal tuberculosis and postoperative pathological results clearly showing spinal tuberculosis; ② patient age <75 years old and ≥18 years old; ③ noninterrupted diseased segment; and ④ regular anti-tuberculosis treatment before operation, operative indications and normal operating conditions.

The exclusion criteria were as follows: ① concomitant spinal tuberculosis of the cervical and sacral spine; ② concomitant active tuberculosis in other parts; ③ concomitant insufficiency of important organs such as the heart, brain and kidney or serious diseases, which make the patient unable to tolerate drugs or surgery; and ④ Redo or revision spinal tuberculosis surgery.

Clinical Data

Preoperative, intraoperative and postoperative follow-up data of patients were collected. The preoperative data were as follows: ① Local kyphosis angle: According to the patient's preoperative X-ray film, the local kyphosis angle caused by spinal tuberculosis was measured and recorded. The included angle was that of the tangent to the upper edge of the vertebral body: a negative value represents lordosis, and a positive value represents kyphosis; ② Japanese Orthopaedic Association (JOA) score, including subjective symptoms (9 points), clinical signs (6 points), and daily activity limitation (14 points), which was used to evaluate human functional impairment; ③Visual analog scale (VAS) pain score (0 points represent no pain, 10 points represent the most severe pain that is unbearable), which was used for pain assessment; ④ Erythrocyte sedimentation rate (ESR) of preoperative venous blood test; ⑤ C-reaction protein (CRP) in venous blood test of patients before surgery; ⑥ Adjacent multisegment thoracic tuberculosis status (that is, whether the number of consecutive involved segments is greater than or equal to 3 segments); and ⑦ course of disease. The intraoperative data were as follows: ① surgical method (anterior debridement or posterior debridement); ② operation time; and ③ intraoperative blood loss. The postoperative follow-up data were as follows: completion of 1 year of standardized anti-tuberculosis drug treatment (drug treatment plan is isoniazid + rifampicin + ethambutol + pyrazinamide). Additionally, adverse reactions such as liver function damage and gastrointestinal reactions were monitored, and drug use was adjusted according to the patient's condition, if the patient has a reasonable excuse to make a rational medication adjustment, we also believe that the patient is receiving standard medication.

Statistical Processing

SPSS 25.0 was used for statistical analysis. The measurement data with a normal distribution are expressed as the mean ± standard deviation, and T test or analysis of variance were used for analyses. Measurement data conforming to a skewed distribution are expressed as the median (interquartile distance), and the rank sum test was used for analyses. The count data are expressed as frequencies and were analyzed by the χ^2 test. The analysis of risk factors was based on the significant difference in single factor analysis, logistic regression analysis was used to analyze the risk factors, and $p < 0.05$ indicated a significant difference.

RESULTS

Comparison of Two Sets of General Data

There were no significant differences in sex, height, weight or BMI between the two groups ($p > 0.05$). The severity of osteoporosis in the nonfusion group (no osteoporosis/osteoporosis/severe osteoporosis) was significantly higher than that in the fusion group ($p < 0.05$) **Table 1**.

Comparison of Preoperative Data Between the Two Groups

There was a statistically significant difference in continuous multisegment spinal tuberculosis and disease duration between the two groups ($p < 0.05$). The nonfusion group had more

TABLE 1 | Comparison of two sets of general data.

	Fusion	Nonfusion	Statistics	*p* value
Sex (female/male)	42/52	16/21	0.022	0.881
Height (cm)	162.77 ± 7.29	165.11 ± 5.93	−1.721	0.088
Weight (kg)	57 (47–65)	63 (49–68)	−1.702	0.089
BMI (kg/m^2)	21.29 (19.14–23.34)	22.06 (19.65–23.88)	−1.14	0.254
Osteoporosis severity	76/9/9	21/6/10	8.680	0.013

patients with continuous multisegment spinal tuberculosis, and the disease duration was longer. There was no significant difference in preoperative local kyphosis, JOA, VAS, ESR or CRP between the two groups ($p > 0.05$) (**Table 2**).

Comparison of Intraoperative and Follow-Up Data Between the Two Groups

There were significant differences in the surgical methods (anterior debridement/posterior debridement) and treatment with standardized anti-tuberculosis drug therapy for 1 year between the two groups ($p < 0.05$). There was no significant difference in operation time or intraoperative blood loss ($p > 0.05$) (**Table 3**).

Logistic Multivariate Regression Analysis of Related Risk Factors

According to the results of univariate analysis and clinical experience, we selected the indicators of multivariate regression analysis and found that a long course of disease, the use of posterior debridement, and the severity of osteoporosis were risk factors for postoperative bone nonfusion (OR > 1, $p < 0.05$), and 1-year standardized anti-tuberculosis drug treatment was a protective factor (OR < 1, $p < 0.05$) (**Table 4**).

Typical Images of Patients

A 32-year-old male patient was diagnosed with thoracic vertebral tuberculosis and underwent posterior spinal tuberculosis debridement, bone grafting, fusion and internal fixation in our hospital (**Figure 2**). The patient had no osteoporosis and did not take medication regularly one year after surgery. A preoperative CT scan of the thoracic spine showed bone destruction in the thoracic spine. (**C/D**) Postoperative CT scan of the thoracic spine showed that the bone graft exhibited good contact with the upper and lower vertebral bodies. (**E/F**) Plain CT scan of the thoracic spine at the 1-year follow-up. It can be seen that there is a clear boundary between the bone graft and the autologous bone, and the bone graft is not fused.

TABLE 2 | Comparison of preoperative data between the two groups.

	Fusion	Nonfusion	Statistics	*p* value
Local kyphosis	20.15 (9.1–26.3)	11.8 (–4.6–18.3)	–1.825	0.068
JOA	18 (12–20)	19 (12–25)	–1.576	0.115
VAS	4 (4–4)	4 (4–5)	–0.923	0.356
ESR (mm/h)	55.97 ± 17.47	50.76 ± 15.811	1.578	0.117
CRP (μg/mL)	66 (47–95)	65 (25–84)	–1.284	0.199
Consecutive multisegment spinal tuberculosis (no/yes)	73/21	22/15	4.413	0.036
Course of disease (m)	7.5 (4–12)	22 (12–35)	–4.816	<0.001

TABLE 3 | Comparison of intraoperative and follow-up data between the two groups.

	Fusion	Nonfusion	Statistics	*p* value
Surgical method (anterior/posterior)	61/33	13/24	9.566	0.002
Operation time (min)	221.99 ± 82.47	202.73 ± 67.13	1.264	0.208
Intraoperative blood loss (mL)	400 (350–600)	500 (300–600)	–0.449	0.654
1 year of standardized drug therapy (no/yes)	8/68	20/17	32.769	<0.001

DISCUSSION

Tuberculosis patients usually present with respiratory system damage, but some patients may have concomitant or simple extrapulmonary tuberculosis. Spinal tuberculosis, as one of the most common types of extrapulmonary tuberculosis (9), often leads to the destruction of vertebral bodies and intervertebral discs and even paravertebral abscesses. The early symptoms are radicular pain, local weakness, and hypoesthesia in the area innervated by the affected nerve, and severe cases may result in paraplegia (10). The current treatment options for spinal tuberculosis mainly include drug therapy and surgery. Regarding the use of anti-tuberculosis drugs as the basic treatment (11), when the treatment effect is not good or severe nerve damage and spinal deformity occur (12), surgery is the only option. An important way to treat spinal tuberculosis (13) is to maintain spinal stability through decompression and correction of local kyphosis (14), relieve the symptoms of patients, and improve the quality of life of patients. Spinal tuberculosis foci debridement and bone grafting, fusion and internal fixation, as some of the accepted surgical procedures for the treatment of spinal tuberculosis (15), have been widely implemented due to their advantages of short operation time, quick recovery, and low recurrence rate (16). However, there are postoperative complications, such as sinus formation, pleural or peritoneal injury, and nonfusion of bone grafts. Among these complications, nonfusion or delayed union of the bone graft has the most serious impact on the prognosis of the patient and may lead

TABLE 4 | Logistic multivariate regression analysis of related risk factors.

	B	SE	*p* value	OR (95% CI)
Continuous multisegment Spinal tuberculosis	0.511	0.538	0.342	1.667 (0.58–4.787)
Course of disease	0.023	0.011	0.038	1.023 (1.001–1.046)
Posterior debridement	1.037	0.51	0.042	2.822 (1.039–7.665)
Osteoporosis				
Light/none	1.106	0.729	0.129	3.023 (0.724–12.616)
Severe/None	1.847	0.684	0.007	6.339 (1.659–24.226)
One year of standardized drug therapy	–2.781	0.578	0	0.062 (0.02–0.192)

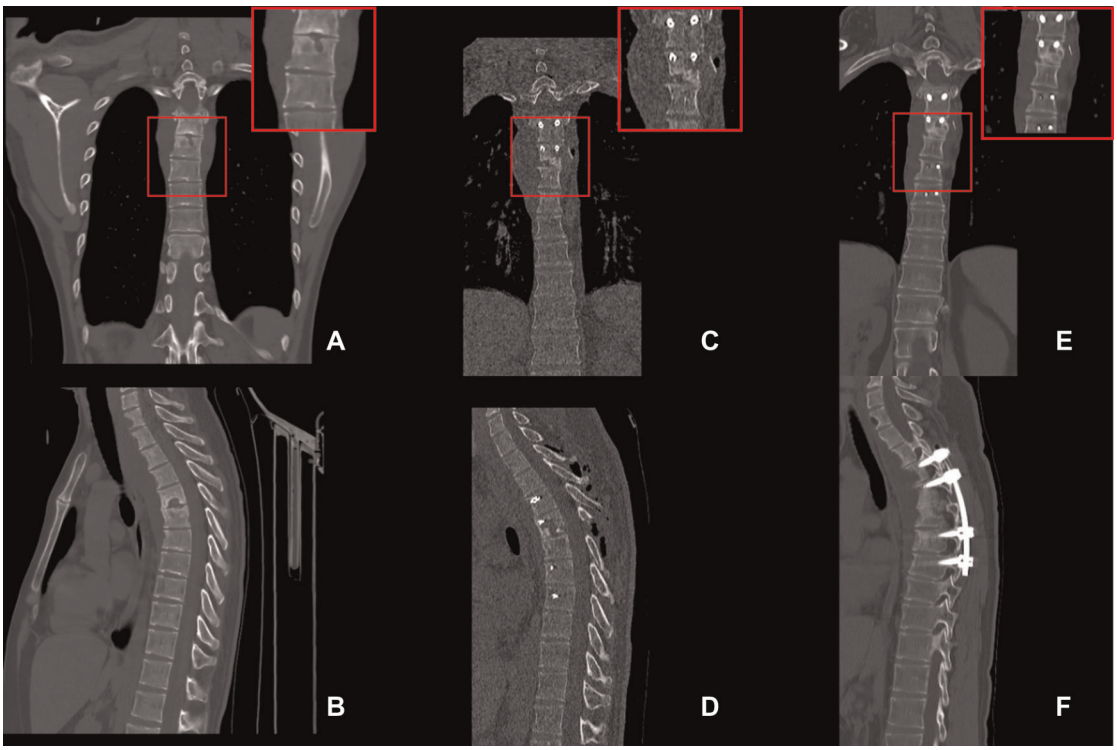


FIGURE 2 | Images for selected typical case. A 32-year-old male patient was diagnosed with thoracic vertebral tuberculosis and underwent posterior spinal tuberculosis debridement, bone grafting, fusion, and internal fixation in our hospital (**Figure 2**). The patient had no osteoporosis and did not take medication regularly one year after surgery. (**A**/**B**) **A** are the preoperative CT scan of the thoracic spine showed bone destruction in the thoracic spine. (**C/D**) Postoperative CT scan of the thoracic spine showed that the bone graft exhibited good contact with the upper and lower vertebral bodies. (**E/F**) Plain CT scan of the thoracic spine at the 1-year follow-up. There is a clear boundary between the bone graft and the autologous bone, and the bone graft is not fused.

to subsidence of the diseased vertebra, displacement of the internal fixation or even fracture, which not only causes movement disorder of the normal motor unit but also may lead to the failure of the patient's operation and reoperation.

In this study, we conducted a detailed assessment of the risk factors for bone nonfusion after spinal tuberculosis debridement, bone graft fusion and internal fixation based on relevant case data. Regarding the general information of the patients, there was no significant difference in sex, height, weight or BMI between the two groups ($p > 0.05$), and the two groups were comparable. The severity of osteoporosis (no osteoporosis/osteoporosis/severe osteoporosis) in the nonfusion group was significantly greater than that in the fusion group, and the difference was statistically significant ($p < 0.05$), which may be due to decreased density, defects in trabecular bone microarchitecture, and inherent defects in the material properties of bone tissue (17) resulting in poor bone healing. Additionally, osteoporosis may lead to the collapse of the intervertebral space, resulting in the loosening of the firm bone graft, which is more likely to cause nonfusion of the bone graft after surgery. This study found that among the two indicators of continuous multisegment spinal tuberculosis and disease duration, patients with continuous multisegment spinal tuberculosis and a longer disease course had a higher probability of postoperative bone nonfusion, and the difference was statistically significant ($p < 0.05$). Because spinal tuberculosis has the characteristics of affecting adjacent segments and spreading down ligaments, continuous multisegment spinal tuberculosis is often associated with more severe spinal cord injury and kyphosis than single-segment spinal tuberculosis (18), which also leads to the need to remove more bone to correct the deformity during surgery, possibly affecting the fusion rate of the bone graft to a certain extent. The length of the disease course can also reflect the severity of the spinal damage to a certain extent. Patients with a longer disease course tend to have a wider range of abscesses and more serious bone destruction, which will also affect surgical debridement and the bone grafting fusion effect. There was no significant difference in preoperative local kyphosis, JOA, VAS, ESR or CRP between the two groups ($p > 0.05$). Multivariate regression analysis also confirmed that the severity of osteoporosis and the length of the disease course were independent risk factors for postoperative bone graft nonfusion.

At present, there are two main approaches for the debridement of spinal tuberculosis lesions: anterior debridement and posterior debridement (19). Since spinal tuberculosis lesions are usually located in the anterior column, the advantage of anterior debridement is that the lesions can

be directly exposed. For spinal tuberculosis lesions, more thorough debridement and spinal cord decompression can be performed, and bone grafting can be performed in a better surgical field when performing bone grafting. However, anterior exposure of the upper thoracic region is difficult due to the anatomic characteristics of the anterior approach, so it is sometimes not suitable for patients with multisegmental thoracic vertebral involvement (20). The results of this study revealed that there were significant differences between the two groups in terms of the surgical method (anterior debridement or posterior debridement) and whether the patient received standardized drug therapy for 1 year after surgery ($p < 0.05$). There was no significant difference in operation time or blood loss between the two groups (>0.05). Posterior debridement will reduce the rate of postoperative bone graft fusion, but according to the surgical risk and trauma of patients, the choice of surgical method should still vary from person to person, and the anterior approach should not be insisted on to ensure bone graft fusion because it could lead to an increased risk of other complications. As the basis of all treatments, drug therapy for spinal tuberculosis should be used in a standardized manner before and after surgery. According to some data, drug therapy can improve fusion after spinal tuberculosis surgery (3); therefore, postoperative standardized drug therapy should not be ignored. Multivariate regression analysis also confirmed that posterior debridement was an independent risk factor for bone graft fusion, and the completion of one-year postoperative standardized drug therapy was a protective factor for bone graft fusion. This study has the limitation that the number of cases was somewhat small, and we will continue to improve and expand upon this study in follow-up work.

In summary, although most patients with spinal tuberculosis can achieve good symptom relief and stable bone graft fusion after surgery, patients with more severe osteoporosis, a longer disease course, or posterior debridement surgery may have a significantly higher risk of postoperative bone graft nonfusion or delayed fusion than other patients. Completion of standardized anti-tuberculosis drug therapy after operation can reduce the risk of nonfusion of bone grafts to a certain extent. The results of this study can provide a more systematic and comprehensive treatment plan and reference for spine surgeons in the surgical treatment of spinal tuberculosis.

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 Medical Ethics Committee of the Second Affiliated Hospital Army Military Medical University. 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

Writing: ZW, YZ; Study performance: ZW, SY, JY, XH; Study design: TL, TC; Article revision: TC. All authors contributed to the article and approved the submitted version.

FUNDING

This research was funded by the General project of Chongqing Natural Science Foundation of China (No. cstc2020jcyj-msxmX0688), National Key Research and Development Plan Project (2016YFC1101504), and the Clinical Research Project of the Second Affiliated Hospital of the Army Military Medical University (2018XLC2016).

ACKNOWLEDGMENTS

We thanked AJE for language editing service.

REFERENCES

1. Tuli SM. Historical aspects of Pott's disease (spinal tuberculosis) management. *Eur Spine J*. (2013) 22(Suppl 4):529–38. doi: 10.1007/s00586-012-2388-7
2. Gautam MP, Karki P, Rijal S, Singh R. Pott's spine and paraplegia. *J Nepal Med Assoc*. (2005) 44(159):106–15. PMID: 16570378
3. Jutte PC, Van Loenhout-Rooyackers JH. Routine surgery in addition to chemotherapy for treating spinal tuberculosis. *Cochrane Database Syst Rev*. (2006) 25(1):Cd004532. doi: 10.1002/14651858.CD004532.pub2
4. Pola E, Rossi B, Nasto LA, Colangelo D, Logroscino CA. Surgical treatment of tuberculous spondylodiscitis. *Eur Rev Med Pharmacol Sci*. (2012) 16(Suppl 2): 79–85. PMID: 22655486
5. Khanna K, Sabharwal S. Spinal tuberculosis: a comprehensive review for the modern spine surgeon. *Spine J*. (2019) 19(11):1858–1870. doi: 10.1016/j.spinee.2019.05.002
6. Jin W, Wang Q, Wang Z, Geng G. Complete debridement for treatment of thoracolumbar spinal tuberculosis: a clinical curative effect observation. *Spine J*. (2014) 14(6):964–70. doi: 10.1016/j.spinee.2013.07.466
7. Zeng Y, Fan Y, Luo F, Hou TY, Dai F, Xu JZ, et al. Tricortical iliac crest allograft with anterolateral single rod screw instrumentation in the treatment of thoracic and lumbar spinal tuberculosis. *Sci Rep*. (2020) 10(1): 13037. doi: 10.1038/s41598-020-70007-z
8. Bridwell KH, Lenke LG, McEnery KW, Baldus C, Blanke K. Anterior fresh frozen structural allografts in the thoracic and lumbar spine. Do they work if combined with posterior fusion and instrumentation in adult patients with kyphosis or anterior column defects? *Spine (Phila Pa 1976)*. (1995) 20(12): 1410–8. PMID: 7676341
9. Ketata W, Rekik WK, Ayadi H, Kammoun S. Extrapulmonary tuberculosis. *Rev Pneumol Clin*. (2015) 71(2–3):83–92. doi: 10.1016/j.pneumo.2014.04.001

10. Jain AK, Kumar J. Tuberculosis of spine: neurological deficit. *Eur Spine J*. (2013) 22(Suppl 4):624–33. doi: 10.1007/s00586-012-2335-7
11. Kumar K. Spinal tuberculosis, natural history of disease, classifications and principles of management with historical perspective. *Eur J Orthop Surg Traumatol*. (2016) 26(6):551–8. doi: 10.1007/s00590-016-1811-x
12. Yin XH, Yan L, Yang M, Zhang K, He BR, Liu ZK, et al. Posterolateral decompression, bone graft fusion, posterior instrumentation, and local continuous chemotherapy in the surgical treatment of thoracic spinal tuberculosis. *Medicine (Baltimore)*. (2018) 97(51):e13822. doi: 10.1097/md.0000000000013822
13. Liu J, Wan L, Long X, Huang S, Dai M, Liu Z. Efficacy and Safety of Posterior Versus Combined Posterior and Anterior Approach for the Treatment of Spinal Tuberculosis: A Meta-Analysis. *World Neurosurg*. (2015) 83(6):1157–65. doi: 10.1016/j.wneu.2015.01.041
14. Yao Y, Zhang H, Liu H, Zhang Z, Tang Y, Zhou Y. Prognostic Factors for Recovery After Anterior Debridement/Bone Grafting and Posterior Instrumentation for Lumbar Spinal Tuberculosis. *World Neurosurg*. (2017) 104:660–667. doi: 10.1016/j.wneu.2017.05.076
15. Reisener MJ, Pumberger M, Shue J, Girardi FP, Hughes AP. Trends in lumbar spinal fusion-a literature review. *J Spine Surg*. (2020) 6(4):752–761. doi: 10.21037/jss-20-492
16. Sahoo MM, Mahapatra SK, Sethi GC, Dash SK. Posterior-only approach surgery for fixation and decompression of thoracolumbar spinal tuberculosis: a retrospective study. *J Spinal Disord Tech*. (2012) 25(7):E217–23. doi: 10.1097/BSD.0b013e31826a088e
17. Armas LA, Recker RR. Pathophysiology of osteoporosis: new mechanistic insights. *Endocrinol Metab Clin North Am*. (2012) 41(3):475–86. doi: 10.1016/j.ecl.2012.04.006
18. Yin X, Yan L, Yang M, Liu SC, He BR, Liu ZK, et al. Bilateral costotransverse and local continuous chemotherapy approach for debridement, fixation, and fusion of contiguous multisegmental thoracic spinal tuberculosis: A retrospective study. *Medicine (Baltimore)*. (2018) 97(41):e12752. doi: 10.1097/md.0000000000012752
19. Li L, Xu J, Ma Y, Tang DD, Chen YL, Luo F, et al. Surgical strategy and management outcomes for adjacent multisegmental spinal tuberculosis: a retrospective study of forty-eight patients. *Spine (Phila Pa 1976)*. (2014) 39(1):E40–8. doi: 10.1097/brs.0000000000000053
20. Stulík J, Vyskocil T, Bodlák P, Sebesta P, Kryl J, Vojácek J, et al. Injury to major blood vessels in anterior thoracic and lumbar spinal surgery. *Acta Chir Orthop Traumatol Cech*. (2006) 73(2):92–8. PMID: 16735005

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: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers | Frontiers in Surgery

ORIGINAL RESEARCH
published: 09 June 2022
doi: 10.3389/fsurg.2022.885949

Evaluation of the Radiographic Risk Factors of Postoperative Shoulder Imbalance in Adult Scoliosis

Wencan Ke‡, Bingjin Wang‡, Wenbin Hua, Kun Wang, Shuai Li and Cao Yang†*

Department of Orthopaedics, Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China

Objective: This study aimed to evaluate the radiographic risk factors of postoperative shoulder imbalance (PSI) after adult scoliosis (AS) correction surgery.

Methods: Seventy-nine patients with AS undergoing correction surgery at a single institution were reviewed. The mean follow-up was 28 months. Patients were divided into two groups based on their radiographic shoulder height (RSH): (1) the balanced group (RSH <10 mm) and (2) the unbalanced group (RSH ≥10 mm). The preoperative and postoperative Cobb angles of the proximal thoracic (PT), main thoracic (MT), thoracolumbar/lumbar (TL/L) and upper instrumented vertebra (UIV) were measured.

Results: No significant difference was found between the balanced and unbalanced groups when the UIV was T1–2, T3–4, or below T4. Univariate analysis indicated that the unbalanced group had significantly higher postoperative RSH, lower percentage PT correction, and greater percentage MT correction. The classification and regression tree analysis revealed that when the correction percentage of PT curve was more than 55.3%, 84.4% of patients acquired shoulder balance. However, when the correction percentage of PT curve was less than 55.3%, and the correction percentage of MT curve was more than 56%, 65.7% of the patients developed PSI.

Conclusions: In AS correction surgery, a lower percentage correction of the PT curve and greater percentage correction of the MT curve were independent radiographic risk factors of PSI, regardless of the UIV level. Sufficient PT correction is required to achieve postoperative shoulder balance in AS correction surgery when the MT curve is overcorrected.

Keywords: adult scoliosis, correction surgery, postoperative shoulder imbalance, upper instrumented vertebra (UIV), radiographic shoulder height

OPEN ACCESS

Edited by:
Lingxiao Chen,
The University of Sydney, Australia

Reviewed by:
Weishi Li,
Peking University Third Hospital, China
Bin Xu,
College of Medicine, Seoul National University, South Korea

***Correspondence:**
Cao Yang
caoyangunion@hust.edu.cn

†***ORCID:***
Cao Yang,
orcid.org/0000-0002-0058-614X

‡*These authors have contributed equally to this work*

Specialty section:
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

Received: *28 February 2022*
Accepted: *23 May 2022*
Published: *09 June 2022*

Citation:
Ke W, Wang B, Hua W, Wang K, Li S and Yang C (2022) Evaluation of the Radiographic Risk Factors of Postoperative Shoulder Imbalance in Adult Scoliosis. Front. Surg. 9:885949. doi: 10.3389/fsurg.2022.885949

INTRODUCTION

Adult scoliosis (AS) is defined as a three-dimensional deformity of the spine in a skeletally mature patient. According to previous epidemiological studies, the incidence of AS has been 17.0%–29.4% in the past decade (1, 2). As the ageing of populations in modern society accelerates, AS is becoming increasingly burdening (3). Currently, correction surgery is the only effective treatment for AS patients with a large magnitude curve (4, 5). Postoperative shoulder imbalance

(PSI) is a common complications of AS correction surgery, which considerably impacts the postoperative satisfaction of patients (6). However, achieving postoperative shoulder balance remains challenging, with the total incidence of PSI ranging from 25% to 57% (6, 7). Identifying the independent risk factors of PSI can enhance our understanding of this phenomenon and aid in reducing its incidence.

Previous studies regarding the risk factors of PSI mainly focused on adolescent idiopathic scoliosis (AIS). The selection of upper-instrumented vertebra (UIV) is considered one of the main factors responsible for postoperative shoulder balance (8). Previous investigation found that a proximal UIV can avoid the occurrence of PSI (9). However, recent studies have indicated that PSI is not affected by the UIV level (10, 11). Andy et al. reported that a higher preoperative Cobb angle and increased surgical correction lead to an increased risk of PSI (10). In a retrospective review of 145 patients with AIS, John et al. indicated that overcorrection of the main thoracic (MT) curve (>54%) with less correction (<52%) of the proximal thoracic (PT) curve lead to a higher incidence of PSI, regardless of the UIV(11). However, the study of risk factors of PSI in AS correction surgery has not been reported.

AS is a progressive spine deformity, which has a more severe and rigid curve. Correction surgeries for AS always require longer fusion segments, which means that achieving postoperative shoulder balance is more difficult (12–14). The purpose of this study was to evaluate the radiographic risk factors of PSI after AS correction surgery.

MATERIALS AND METHODS

Patient Data

This was a retrospective study conducted at a single institution, and was approved by the institutional review board of our hospital (No. S0469). The study included 79 patients with AS who underwent surgical treatment at our hospital between May 2014 and May 2020. The inclusion criteria were as follows: (1) adult patients with scoliosis who underwent posterior spinal fusion and instrumentation; (2) follow-up period≥12 months; (3) adequate preoperative and postoperative radiographs of the entire spine and appearance photos. The exclusion criteria were as follows: (1) patients with postoperative severe neurological complications; (2) patients who underwent revision surgery.

Radiographic Parameters

All patients had a minimum follow-up period of 12 months, as the literature showed that the shoulder level is stable at one year postoperatively (15, 16). Patients were divided into two groups based on their postoperative radiographic shoulder height (RSH): (1) the balanced group (RSH <10 mm) and (2) the unbalanced group (RSH ≥10 mm). RSH is defined as the height difference between the right and left soft tissue shadows directly superior to the acromioclavicular joint on standing anteroposterior radiographs. PSI was defined as RSH ≥10 mm in this study, similar to previous studies (17, 18). The measurement of preoperative and postoperative RSH was completed by three researchers independently and blinded to each other. An average of the results by the three researchers was calculated and used. Intraclass correlation coefficients (ICC) were calculated to analyze measurement reliability of RSH (19). The Cobb angle of the proximal thoracic (PT), main thoracic (MT), and thoracolumbar/lumbar (TL/L) were measured pre- and postoperatively. The degree and percentage of correction of each curve were also calculated. In addition, the UIV was determined in all patients. The classification and regression tree analysis was used to identify independent drivers of PSI in multivariate analysis (20).

Statistical Analysis

All statistical analyses were performed using SPSS (Version 22.0, SPSS, Chicago, Illinois, USA). Intraclass correlation coefficients (ICC) were calculated to analyze measurement reliability of RSH. The "model", "type", and "definition" selections of ICC were "Two-way mixed effects", "Mean of k raters", and "Consistency", respectively. An ICC of more than 0.75 was considered as great reliability. Univariate analysis using the Student's independent t-test and χ^2 test were conducted to compare continuous and categorical variables, respectively. The classification and regression tree analysis was used to identify independent drivers of PSI in multivariate analysis. This method starts with the core node comprising of the total sample, each node is divided into two child nodes repetitively by recursive partitioning, thus creating a tree like structure. The classification trees were elaborated using the Gini splitting rule. The minimum number of patients for the parent node was set at 40, and the minimum for child nodes at 3. The maximum classification tree depth was 5. $P < 0.05$ was considered statistically significant.

RESULTS

In this study, 79 AS patients who underwent posterior instrumentation correction surgery were included (**Table 1**). Among them, 58 were female and 21 were male. The average age was 35.9 ± 12.7 years (ranging from 21 to 62 years). The mean follow-uptime was 28 months (ranging from 12 to 60 months). Overall, 48 patients had shoulder balance and 31 had shoulder imbalance at follow-up.

As shown in **Table 2**, there was no significant difference between the balanced and unbalanced groups regarding

TABLE 1 | Baselinse patient demographics.

Parameters	Balanced	Unbalanced	Total
Age (year)	35.7 ± 12.8	36.2 ± 12.4	35.9 ± 12.7
Gender			
Female	35	23	58
Male	13	8	21
PSI	48 (60.8%)	31 (39.2%)	79
Follow-up (month)	28.6	27.1	28

TABLE 2 | The UIV levels of balanced and unbalanced group.

	Balanced	Unbalanced	*P*-value
UIV			0.512
T1–2	17	12	
T3–4	28	15	
>T4	3	4	

TABLE 3 | Preoperative and postoperative scoliosis parameters.

Parameter	Balanced		Unbalanced		*P*-value
	Mean	SD	Mean	SD	
RSH					
Preop (mm)	6.4	2.2	7.3	2.5	0.124
Postop (mm)	5.9	2.3	21.8	7.1	<0.001*
PT					
Preop Cobb (degrees)	38.9	15.7	41.0	16.2	0.577
Postop Cobb (degrees)	16.6	6.7	19.5	8.2	0.093
Cobb correction (degrees)	22.3	10.8	21.5	8.6	0.721
Cobb correction (percentage)	56.5%	0.07	52.8%	0.07	0.026*
MT					
Preop Cobb (degrees)	79.6	31.2	82.0	31.1	0.736
Postop Cobb (degrees)	35.1	15.3	29.8	15.7	0.146
Cobb correction (degrees)	44.5	20.5	52.2	21.7	0.116
Cobb correction (percentage)	55.6%	0.11	64.0%	0.12	0.002*
TL/L					
Preop Cobb (degrees)	48.2	16.9	43.8	17.6	0.269
Postop Cobb (degrees)	19.7	10.9	18.7	9.4	0.681
Cobb correction (degrees)	28.5	12.9	25.1	13.0	0.258
Cobb correction (percentage)	58.8%	0.16	56.1%	0.14	0.465

RSH, radiographic shoulder height; PT, proximal thoracic; MT, major thoracic curve; TL/L, thoracolumbar/lumbar curve.
**Statistical significance.*

whether the UIV was T1–2, T3–4, or below T4 ($P = 0.512$). The pre- and postoperative scoliosis parameters were shown in **Table 3**. The ICC for preoperative and postoperative RSH was 0.991 (95% CI, 0.987–0.994) and 0.998 (95% CI, 0.997–0.999), respectively. Univariate analysis indicated that the unbalanced group had significantly higher postoperative RSH, lower percentage PT correction, and greater percentage MT correction. The classification and regression tree analysis demonstrated that when the correction percentage of PT curve was more than 55.3%, 84.4% of the patients had balanced shoulder (**Figure 1**). In addition, when the correction percentage of PT curve was less than 55.3% and the correction percentage of MT curve was less than 56%, 75% of the patients achieved postoperative shoulder balance. However, when the correction percentage of PT was less than 55.3%, and the correction percentage of MT curve was more than 56%, 65.7% of the patients developed PSI ($P = 0.038$).

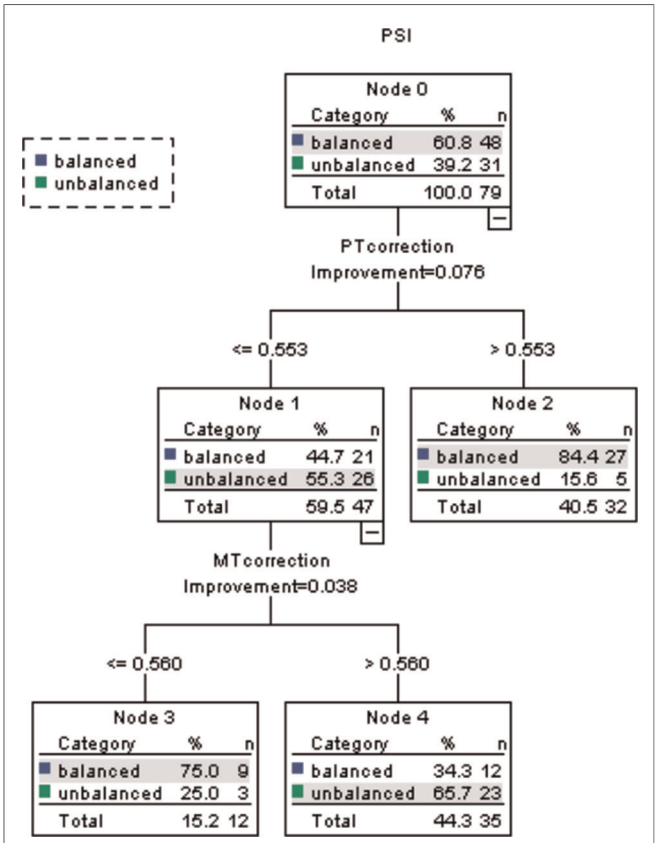


FIGURE 1 | Classification and regression tree analysis for predicting postoperative shoulder imbalance.

DISCUSSION

The aim of this study was to analyze the factors that predict PSI after AS correction surgery. We found that a lower percentage correction of the PT curve and greater percentage correction of the MT curve were independent radiographic risk factors of PSI. Larger correction of the MT (>56%) with a relatively lower correction of the PT (<55.3%) lead to PSI in 65.7% of the patients. In contrast, when the correction percentage of PT curve was more than 55.3%, 84.4% of the patients had balanced shoulder. In addition, the incidence of PSI was independent of the UIV level.

Achieving postoperative shoulder balance is a significant but difficult goal in correction surgery of spine deformity. The choice of UIV level is considered to be one of the main factors potentially responsible for PSI, though this is still controversial. To date, there is no consensus regarding the UIV selection in correction surgery, which is a point of contention among many spine surgeons (8, 21, 22). According to a previous guidelines for AIS, a UIV of T2 was suggested for patients with a preoperative high left shoulder, T3 for those with a balanced shoulder, T4 or below for those with a high right shoulder (9). However, Jaysson et al. found that choosing T4 as UIV was more effective to avoid PSI than

either T2 or T3, regardless of which shoulder was raised preoperatively (23). Recently, several studies reported that PSI is not affected by UIV levels (10, 24). The findings of these articles were consistent with our results that UIV did not affect the incidence of PSI. Our results further suggested that a proximal UIV may not be sufficient to achieve postoperative shoulder balance; rather, adequate percentage correction of the PT is paramount in avoiding the occurrence of PSI.

Another key finding of this study was that a lower percentage correction of the PT curve and greater percentage correction of the MT curve were independent risk factors of PSI in AS correction surgery. Representative cases of a patient with postoperative balanced shoulder (relative larger correction of the PT and lower correction of the MT) and of a patient with postoperative unbalanced shoulder (relative lower correction of PT curve and greater correction of the MT curve) were shown in **Figures 2A–D**, respectively. In a systematic review of risk factors for PSI after correction surgery for scoliosis, Zhang et al. indicated that adequate correction of the PT and moderate correction of the MT was suggested to avoid PSI (6). Other studies also reported that overcorrection of the MT curve leads to a high incidence of PSI (24, 25). In addition, John et al. reported that larger correction of the MT curve (>54%) with simultaneous less correction (<52%) of the PT curve resulted in PSI in 59% of patients in Lenke type 1 and 2 AIS. Similar results were also observed in patients with AS in our study. Therefore, the PT curve should be sufficiently corrected to achieve postoperative shoulder balance in AS correction surgery when the MT curve is overcorrected.

To our knowledge, this is the first study to evaluate the risk factors of PSI after correction surgery of adult spine deformity. Patients with AS tend to have a larger and rigid curve, which are more difficult to correct than that in AIS. John et al. reported that when the correction percentage of PT curve was more than 52%, 80% of the patients achieved shoulder balance in Lenke type 1 and 2 AIS. However, only when the correction percentage of PT curve was more than 56% in AS correction surgery, a higher proportion of shoulder balance can be achieved. This means that a greater correction percentage of PT curve is required to maintain shoulder balance in AS. The reason may be that the PT curve in AS patients is relatively stiff, while the PT curve of AIS patients is less rigid, thus possessing self-correction ability. Indeed, several studies have reported that a flexible PT will continue to correct automatically after the MT curve is corrected (26–28). Although the PT curve is rigid in AS, the correction can be achieved through compression across the convexity and distraction through the concavity of the PT curve. During the past several decades, the posterior column osteotomy techniques have advanced considerably, thereby enabling spine surgeons to significantly correct the MT curve (29, 30). However, if the PT curve is not also adequately corrected, a higher proportion of PSI will occur.

This study has several limitations. First, this was a single-center study with a small sample size, which may result in a

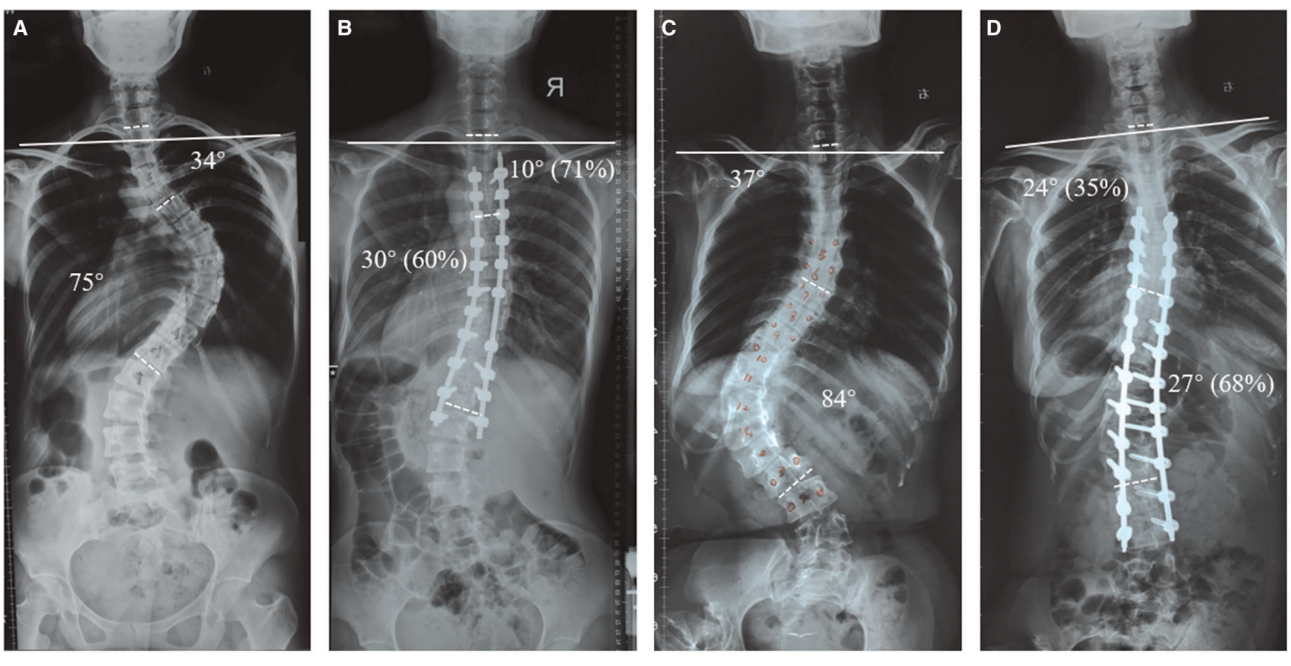


FIGURE 2 | The preoperative (**A**) and postoperative (**B**) images of one patient who underwent relative larger correction of PT curve and lower correction of the MT curve, resulting in postoperative balanced shoulder. The preoperative (**C**) and postoperative (**D**) images of one patient who underwent relative lower correction of PT curve and greater correction of the MT curve, resulting in postoperative imbalanced shoulder.

selection bias. Second, several other factors such as T1 tilt, clavicle angle, and coracoid height difference, were not measured and discussed. Third, only RSH was used to estimate shoulder balance in our study, which may not be fully representative of clinical shoulder balance.

CONCLUSION

In conclusion, we found that a lower percentage correction of the PT curve and greater percentage correction of the MT curve were independent radiographic risk factors of PSI after AS correction surgery, regardless of the UIV level. Greater correction of the MT (>56%) with relative lower correction of the PT (<55.3%) lead to PSI in 65.7% of the patients. On the contrary, when the correction percentage of PT was more than 55.3%, 84.4% of the patients had a balanced shoulder. Therefore, the PT curve should be sufficiently corrected to achieve postoperative shoulder balance in AS correction surgery when the MT curve is overcorrected.

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 studies involving human participants were reviewed and approved by Tongji Medical College, Huazhong University of Science and Technology. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

WK and CY designed the study. WK, BW, WH, KW, and SL collected, assembled, and analyzed the data. WK and BW wrote the manuscript. All authors contributed to the article and approved the submitted version.

FUNDING

This study was supported by the National Natural Science Foundation of China (82130072, 82072505, 81772401, and 81904020).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsurg.2022.885949/full#supplementary-material.

REFERENCES

1. Watanuki A, Yamada H, Tsutsui S, En-yo Y, Yoshida M, Yoshimura N. Radiographic features and risk of curve progression of de-novo degenerative lumbar scoliosis in the elderly: a 15-year follow-up study in a community-based cohort. *J Orthop Sci*. (2012) 17(5):526–31. doi: 10.1007/s00776-012-0253-5
2. Jimbo S, Kobayashi T, Aono K, Atsuta Y, Matsuno T. Epidemiology of degenerative lumbar scoliosis: a community-based cohort study. *Spine*. (2012) 37(20):1763–70. doi: 10.1097/BRS.0b013e3182575eaa
3. Safaee M, Ames C, Smith J. Epidemiology and socioeconomic trends in adult spinal deformity care. *Neurosurgery*. (2020) 87(1):25–32. doi: 10.1093/neuros/nyz454
4. Hassanzadeh H, Jain A, El Dafrawy M, Ain M, Mesfin A, Skolasky R, et al. Three-column osteotomies in the treatment of spinal deformity in adult patients 60 years old and older: outcome and complications. *Spine*. (2013) 38(9):726–31. doi: 10.1097/BRS.0b013e31827c2415
5. Tarawneh AM, Venkatesan M, Pasku D, Singh J, Quraishi NA. Impact of pedicle subtraction osteotomy on health-related quality of life (HRQOL) measures in patients undergoing surgery for adult spinal deformity: a systematic review and meta-analysis. *Eur Spine J*. (2020) 29(12):2953–9. doi: 10.1007/s00586-020-06439-y
6. Zhang S, Zhang L, Feng X, Yang H. Incidence and risk factors for postoperative shoulder imbalance in scoliosis: a systematic review and meta-analysis. *Eur Spine J*. (2018) 27(2):358–69. doi: 10.1007/s00586-017-5289-y
7. Kwan M, Wong K, Lee C, Chan C. Is neck tilt and shoulder imbalance the same phenomenon? A prospective analysis of 89 adolescent idiopathic scoliosis patients (Lenke type 1 and 2). *Eur Spine J*. (2016) 25(2):401–8. doi: 10.1007/s00586-015-4016-9
8. Lee CS, Hwang CJ, Lee DH, Cho JH. Does fusion to T2 compared with T3/T4 lead to improved shoulder balance in adolescent idiopathic scoliosis with a double thoracic curve? *J Pediatr Orthop B*. (2019) 28(1):32–9. doi: 10.1097/BPB.0000000000000520
9. Rose P, Lenke L. Classification of operative adolescent idiopathic scoliosis: treatment guidelines. *Orthop Clin North Am*. (2007) 38(4):521–9, vi. doi: 10.1016/j.ocl.2007.06.001
10. Hiett A, Tung R, Emanuelli E, Sherman A, Anderson JT, Schwend RM. The amount of surgical correction of the main thoracic curve is the best predictor of postoperative clinical shoulder balance in patients with Adolescent Idiopathic Scoliosis. *Spine Deform*. (2020) 8(6):1279–86. doi: 10.1007/s43390-020-00147-9
11. Sielatycki JA, Cerpa M, Beauchamp EC, Shimizu T, Wei C, Pongmanee S, et al. The amount of relative curve correction is more important than upper instrumented vertebra selection for ensuring postoperative shoulder balance in Lenke Type 1 and Type 2 adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)*. (2019) 44(17):E1031–7. doi: 10.1097/BRS.0000000000003088
12. Pizones J, Moreno-Manzanaro L, Sanchez Perez-Grueso FJ, Vila-Casademunt A, Yilgor C, Obeid I, et al. AS-Restoring the ideal Roussouly sagittal profile in adult scoliosis surgery decreases the risk of mechanical complications. *Eur Spine J*. (2020) 29(1):54–62. doi: 10.1007/s00586-019-06176-x
13. Guevara-Villazón F, Boissiere L, Hayashi K, Larrieu D, Ghailane S, Vital J, et al. Multiple-rod constructs in adult spinal deformity surgery for pelvic-fixated long instrumentations: an integral matched cohort analysis. *Eur Spine J*. (2020) 29(4):886–95. doi: 10.1007/s00586-020-06311-z
14. Buell T, Chen C, Nguyen J, Christiansen P, Murthy S, Buchholz A, et al. Surgical correction of severe adult lumbar scoliosis (major curves ≥75°): retrospective analysis with minimum 2-year follow-up. *J Neurosurg Spine*. (2019):1–14. doi: 10.3171/2019.3.Spine1966
15. Yong MR, Izatt MT, Adam CJ, Labrom RD, Askin GN. Secondary curve behavior in Lenke type 1C adolescent idiopathic scoliosis after thoracoscopic selective anterior thoracic fusion. *Spine (Phila Pa 1976)*. (2012) 37(23):1965–74. doi: 10.1097/BRS.0b013e3182583421

16. Terheyden JH, Wetterkamp M, Gosheger G, Bullmann V, Liljenqvist U, Lange T, et al. Predictors of shoulder level after spinal fusion in adolescent idiopathic scoliosis. *Eur Spine J*. (2018) 27(2):370–80. doi: 10.1007/s00586-017-5210-8
17. Han X, Liu Z, Qiu Y, Sha S, Yan H, Jin M, et al. Clavicle chest cage angle difference: is it a radiographic and clinical predictor of postoperative shoulder imbalance in Lenke I adolescent idiopathic scoliosis? *Spine*. (2016) 41(17):1346–54. doi: 10.1097/brs.0000000000001521
18. Liljenqvist U, Halm H, Bullmann V. Spontaneous lumbar curve correction in selective anterior instrumentation and fusion of idiopathic thoracic scoliosis of Lenke type C. *Eur Spine J*. (2013) 22(Suppl 2):S138–48. doi: 10.1007/s00586-012-2299-7
19. Chiu CK, Chan CYW, Tan PH, Goh SH, Ng SJ, Chian XH, et al. Conformity and changes in the radiological neck and shoulder balance parameters throughout 3-year follow-up period: do they remain the same? *Spine (Phila Pa 1976)*. (2020) 45(6):E319–28. doi: 10.1097/BRS.0000000000003275
20. Lee CF, Fong DYT, Cheung KMC, Cheng JCY, Ng BKW, Lam TP, et al. A new risk classification rule for curve progression in adolescent idiopathic scoliosis. *Spine J*. (2012) 12(11):989–95. doi: 10.1016/j.spinee.2012.05.009
21. Erken HY, Burc H, Saka G, Aydogan M. Disagreements in surgical planning still exist between spinal surgeons in adolescent idiopathic scoliosis: a multisurgeon assessment. *Eur Spine J*. (2014) 23(6):1258–62. doi: 10.1007/s00586-014-3278-y
22. Zhao J, Chen Z, Yang M, Li G, Zhao Y, Li M. Does spinal fusion to T2, T3, or T4 affects sagittal alignment of the cervical spine in Lenke 1 AIS patients: a retrospective study. *Medicine (Baltimore)*. (2018) 97(5):e9764. doi: 10.1097/MD.0000000000009764
23. Brooks JT, Bastrom TP, Bartley CE, Lonner BS, Shah SA, Miyanji F, et al. In search of the ever-elusive postoperative shoulder balance: is the T2 UIV the key? *Spine Deform*. (2018) 6(6):707–11. doi: 10.1016/j.jspd.2018.03.010
24. Moorthy V, Goh G, Guo C, Tan S, Chen J, Soh R. Risk factors of postoperative shoulder imbalance in adolescent idiopathic scoliosis: the role of sagittal spinopelvic parameters and upper instrumented vertebrae selection. *Clin Spine Surg*. (2021) 35(1):e137–42. doi: 10.1097/bsd.0000000000001153
25. Chang D-G, Kim J-H, Kim S-S, Lim D-J, Ha K-Y, Suk S-I. How to improve shoulder balance in the surgical correction of double thoracic adolescent idiopathic scoliosis. *Spine*. (2014) 39(23):E1359–67. doi: 10.1097/BRS.0000000000000578
26. Kuklo T, Lenke L, Won D, Graham E, Sweet F, Betz R, et al. Spontaneous proximal thoracic curve correction after isolated fusion of the main thoracic curve in adolescent idiopathic scoliosis. *Spine*. (2001) 26 (18):1966–75. doi: 10.1097/00007632-200109150-00006
27. Tang X, Luo X, Liu C, Fu J, Yao Z, Du J, et al. The spontaneous development of cosmetic shoulder balance and shorter segment fusion in adolescent idiopathic scoliosis with Lenke I curve: a consecutive study followed up for 2 to 5 years. *Spine (Phila Pa 1976)*. (2016) 41(12):1028–35. doi: 10.1097/BRS.0000000000001442
28. Yong MRNO, Izatt MT, Adam CJ, Labrom RD, Askin GN. Secondary curve behavior in Lenke type 1C adolescent idiopathic scoliosis after thoracoscopic selective anterior thoracic fusion. *Spine*. (2012) 37(23):1965–74. doi: 10.1097/BRS.0b013e3182583421
29. Hamzaoglu A, Ozturk C, Aydogan M, Tezer M, Aksu N, Bruno MB. Posterior only pedicle screw instrumentation with intraoperative halo-femoral traction in the surgical treatment of severe scoliosis (>100 degrees). *Spine*. (2008) 33(9):979–83. doi: 10.1097/BRS.0b013e31816c8b17
30. Lenke LG, Sides BA, Koester LA, Hensley M, Blanke KM. Vertebral column resection for the treatment of severe spinal deformity. *Clin Orthop Relat Res*. (2010) 468(3):687–99. doi: 10.1007/s11999-009-1037-x

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.

frontiers | Frontiers in Surgery

CASE REPORT
published: 29 June 2022
doi: 10.3389/fsurg.2022.822015

Surgical Correction of Kyphosis in Patients With Camptocormia Associated With Parkinson's Disease: A Case Report and Review of the Literature

Guo-long Mei[1], Hui-ting Wei[2], Yue-rong Ma[2] and Dun Wan[1]**

[1]Spine Department, Sichuan Province Orthopedic Hospital, Chengdu, China, [2]School of Basic Medicine, Chengdu University of Traditional Chinese Medicine, Chengdu, China

OPEN ACCESS

Edited by:
Wei Zeng,
Longyan University, China

Reviewed by:
Lei Ma,
Third Hospital of Hebei Medical University, China
Hridayesh Pratap Malla,
Kyung Hee University, South Korea

***Correspondence:**
Dun Wan
wd.7033@163.com
Yue-rong Ma
mayr666@163.com

Specialty section:
This article was submitted to Orthopedic Surgery, a section of the journal Frontiers in Surgery

Received: 25 November 2021
Accepted: 07 June 2022
Published: 29 June 2022

Citation:
Mei G-l, Wei H-t, Ma Y-r and Wan D (2022) Surgical Correction of Kyphosis in Patients With Camptocormia Associated With Parkinson's Disease: A Case Report and Review of the Literature. Front. Surg. 9:822015. doi: 10.3389/fsurg.2022.822015

Background: Camptocormia is a postural deformity that is characterized by a markedly flexed lumbar spine, with symptoms that worsen with walking and standing. Here, we report a case of camptocormia associated with Parkinson's disease.

Case description: A 70-year-old man with a 7-year history of Parkinson's disease presented with a fall injury that caused lower back pain for 3 months and was aggravated for 2 months. He had been diagnosed with a compression fracture after the fall and had undergone percutaneous kyphoplasty at a local hospital. MRI showed non-union of the L1 vertebra and compression fracture of L2. The patient underwent posterior osteotomy, canal decompression, and internal fixation of the T10-L3 intervertebral plate with bone graft fusion. Postoperative examination showed that the lumbar lordosis was corrected and sensation was restored in both lower extremities. However, after 1 month, the fixation was loosened and a correction surgery was performed at our hospital. At the most recent follow-up at 1.5 years, the patient was found to be in good general health and did not complain of lower back discomfort. He was also actively exercising according to the rehabilitation regimen and had resumed social life.

Conclusion: This is a rare case of camptocormia in a Parkinson's patient that highlights the need for careful evaluation of whether internal spinal fixation surgery is beneficial in such patients.

Keywords: camptocormia, Parkinson, revision surgery, surgical correction of kyphosis, treatment decision

INTRODUCTION

Camptocormia is a kyphotic deformity that is characterized by a markedly flexed thoracic cage and lumbar spine, with symptoms that worsen with walking and standing and decrease with lying down. The term "camptocormia" was coined by two French neurologists by combining the Greek words *kamptos*, which means "curved," and *kormos*, which means "trunk." The term was

used by Brodie as early as 1837 to describe the exaggerated bending of the spine. The etiology of camptocormia is complex, and Parkinson's disease is one of the most important causes. A single-center study showed that the incidence of camptocormia in patients with Parkinson's disease is 6.9% (1), and another study showed that 11 of 16 patients with Parkinson's had camptocormia (2). Further, a study of 1453 Parkinson's patients by Japanese scholars showed that 9.5% of the patients developed camptocormia 8.1 years after onset (3). Additionally, it was more common among female patients than among male patients, and patients with late-onset Parkinson's were more common than those with early-onset Parkinson's (3). It has been found that the signs of camptocormia occur sequentially after the onset of Parkinson's symptoms, and that the incidence of camptocormia is positively correlated with the severity of Parkinson's symptoms (1). Thus, although camptocormia is an uncommon condition, Parkinson's disease and camptocormia seem to be closely related.

The available treatments for camptocormia include oral and intramuscular drugs and surgical treatments such as deep brain stimulation and orthopedic spinal surgery. However, in a retrospective study of 12 patients with Parkinson's who developed camptocormia, no significant symptom relief was found with oral levodopa treatment. Moreover, in another group of nine people who were treated with botulinum toxin type A via rectus abdominis injection, only four experienced symptom relief. Further, no symptom relief was reported with bilateral deep subthalamic nucleus stimulation in one case (2). In a study of 34 patients, discontinuation of pramipexole for Parkinson's was found to alleviate camptocormia symptoms in some patients. Investigators believe that it is probably because Parkinson's is an axial dystonia rather than a myelopathy. However, whether camptocormia associated with Parkinson's can benefit from discontinuing pramipexole is something that needs to be further evaluated (3). With regard to the surgical modalities, a meta-analysis has suggested that, although the use of deep stimulation improved the sagittal imbalance of the spine by 50% in 36.4% of patients, its treatment effect was inconsistent (4). Further, orthopedic spine surgery can completely correct the spinal imbalance, but it is associated with several complications (4). In general, the current studies imply that the efficacy of the treatment modalities for camptocormia is unclear because the etiologies are diverse.

In this article, we report the treatment of a patient with camptocormia caused by Parkinson's disease. Based on the findings, we emphasize on the need for careful assessment of whether this group of patients can benefit from surgery through a review of the medical history and analysis of the current data.

CASE PRESENTATION

The patient was a 70-year-old man with a medical history of Parkinson's disease for 7 years and good disease control through regular treatment with the oral medications levodopa and pramipexole. The patient had undergone rectal polypectomy 1 year ago, but he did not have a remarkable medical history otherwise. He did not have a history of alcohol consumption or smoking. His chief complaint was a 3-month history of pain in the lower back after falling down that had been exacerbated for 2 months.

Three months back, the patient fell off the bed and experienced mild back pain. He was admitted to the local hospital, where he was diagnosed with vertebral compression fractures of L1 and L2 and osteoporosis (**Figures 1A,B**). He then underwent percutaneous kyphoplasty, after which the pain was mildly relieved (**Figures 1C,D**). Two months after the kyphoplasty procedure, his back pain gradually worsened

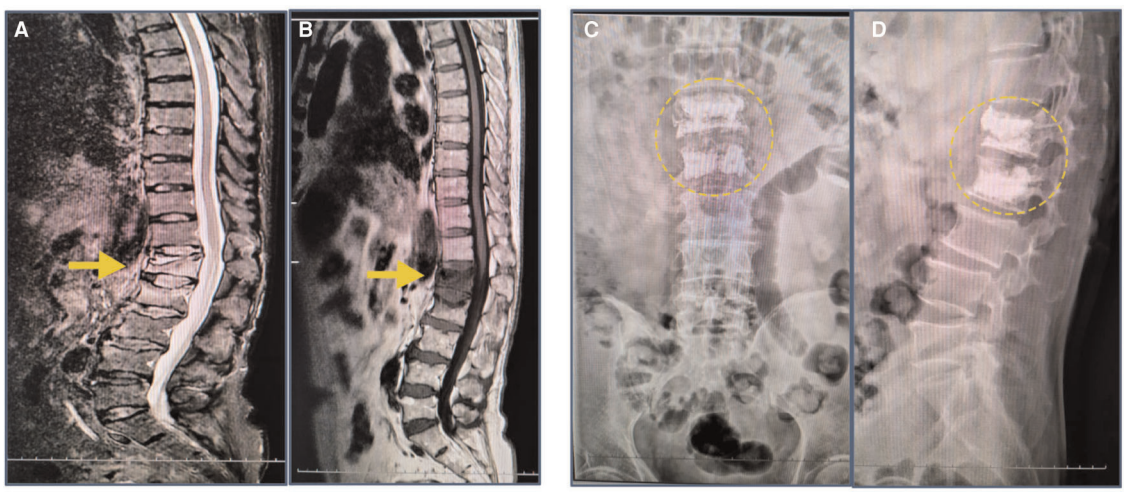


FIGURE 1 | MRI findings after the initial fall; radiographs after the PKP surgery. (**A**,**B**) T1-weighted images revealed compression fractures of the L1 and L2 vertebrae (yellow arrow). (**C**,**D**) The radiograph image reveals L1 and L2 vertebrae that were treated with percutaneous kyphoplasty (yellow circle).

and he also started experiencing radiating pain in the left inguinal and left lateral thigh. He was unable to sit, stand, and walk as a result of the increasing pain, and also experienced weakness while defecating. Physical examination revealed deformity of the thoracolumbar segment in the form of a posterior convexity, as well as localized pressure and percussion pain in the thoracolumbar segment, slight tension in the paravertebral muscles, and dullness of sensation in the left inguinal and lateral thigh. No pathologic signs were observed, but lumbar spine motion was limited. A full-length spine radiograph showed post-vertebroplasty of L1 and L2, compression fracture of T12, kyphosis with sagittal imbalance (Cobb's angle: 45°, PI: 37°, PT: 26°, SS: 11°), and severe osteoporosis (**Figures 2A,B**). MRI of the lumbar spine showed T12-L2 bone edema (**Figures 2C,F**). Laboratory examination showed that the erythrocyte sedimentation rate (ESR) increased to 54.00 mm/h and hemoglobin (HGB) decreased to 113 g/L.

Initial Surgery at Our Hospital

Based on the observations, imaging findings, and the patient's needs, posterior osteotomy, canal decompression, and internal fixation of the T10-L3 intervertebral plate with bone graft fusion was selected as the treatment option. After the surgery, the patient got out of bed with the protection of a brace, and the pain in the lower back was reduced. Additionally, sensation in the lower limbs was normal, and bowel movement was normal too. The surgical incision healed well and met the criteria for first-stage healing. Postoperative lumbar spine radiography and CT showed that the kyphosis was corrected and the nail rod was not loosened (**Figures 3A–F**). The patient was satisfied with the outcome of the surgery and was discharged from the hospital. He was asked to continue with oral Parkinson's therapy with additional bisphosphonates, calcium, and vitamin D3 for anti-osteoporosis treatment. The patient was instructed to wear a brace during all daily activities.

Unfortunately, a follow-up radiograph (**Figures 4A,B**) taken 1 month after surgery showed a loosening of the L3 pedicle screw. The patient was advised to continue anti-osteoporosis treatment and Parkinson's treatment and wear a brace and was counseled in preparation for possible secondary surgery.

Revision Surgery at Our Hospital

Three months after surgery, the patient complained of lower back pain that worsened when walking upright and turning over. Physical examination revealed that in-surgical incision was well healed, there was localized pressure and percussion

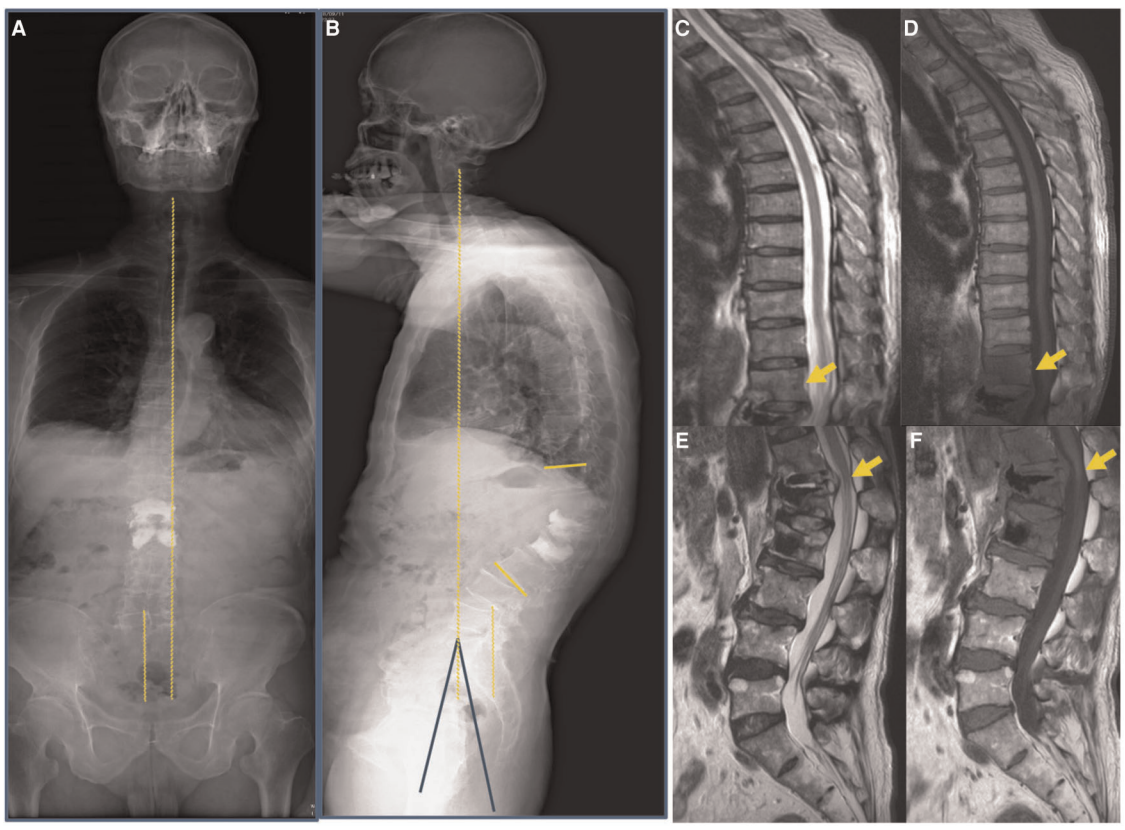


FIGURE 2 | Images were taken at the initial visit to our hospital. (**A**,**B**) A full-length radiograph of the patient's spine indicated sagittal imbalance of the spine (Cobb's angle: 45°, PI: 37°, PT: 26°, SS: 11°). (**C**–**F**) MRI indicated post-vertebroplasty of L1 and L2 and T12-L2 vertebral body with bone edema (yellow arrow).

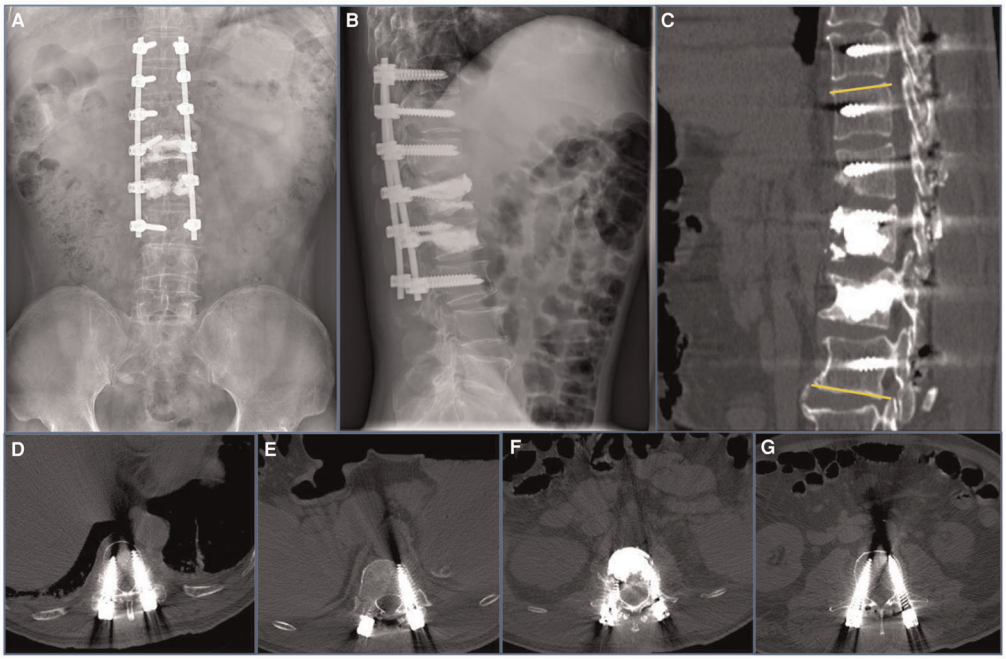


FIGURE 3 | Imaging features after initial surgery at our hospital. (**A**,**B**) Postoperative 1-week radiograph indicated alleviation of the kyphosis. (**C**–**G**) Postoperative 1-week CT scan indicated good internal screw fixation (Cobb's angle: 10°).

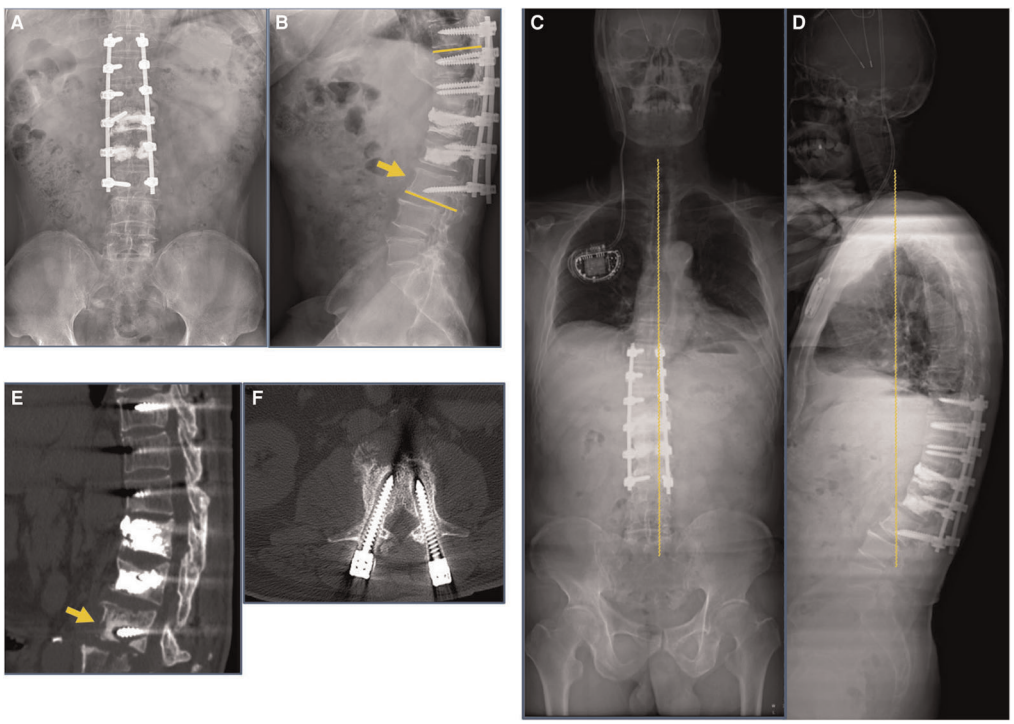


FIGURE 4 | Postoperative 1-month and 3-month imaging findings at our hospital. (**A**,**B**) Postoperative 1-month radiograph indicated loosening of the internal fixation screw of the L3 vertebral body (yellow arrow). (**C**,**D**) Postoperative 3-month follow-up full-length radiograph of the patient's spine indicated Cobb's angle increased to 26°, failure of internal fixation. (**E**,**F**) Postoperative 3-month follow-up CT scan indicated that the L3 vertebral body was loosely fixed internally and the screws had resorbed the surrounding bone (yellow arrow).

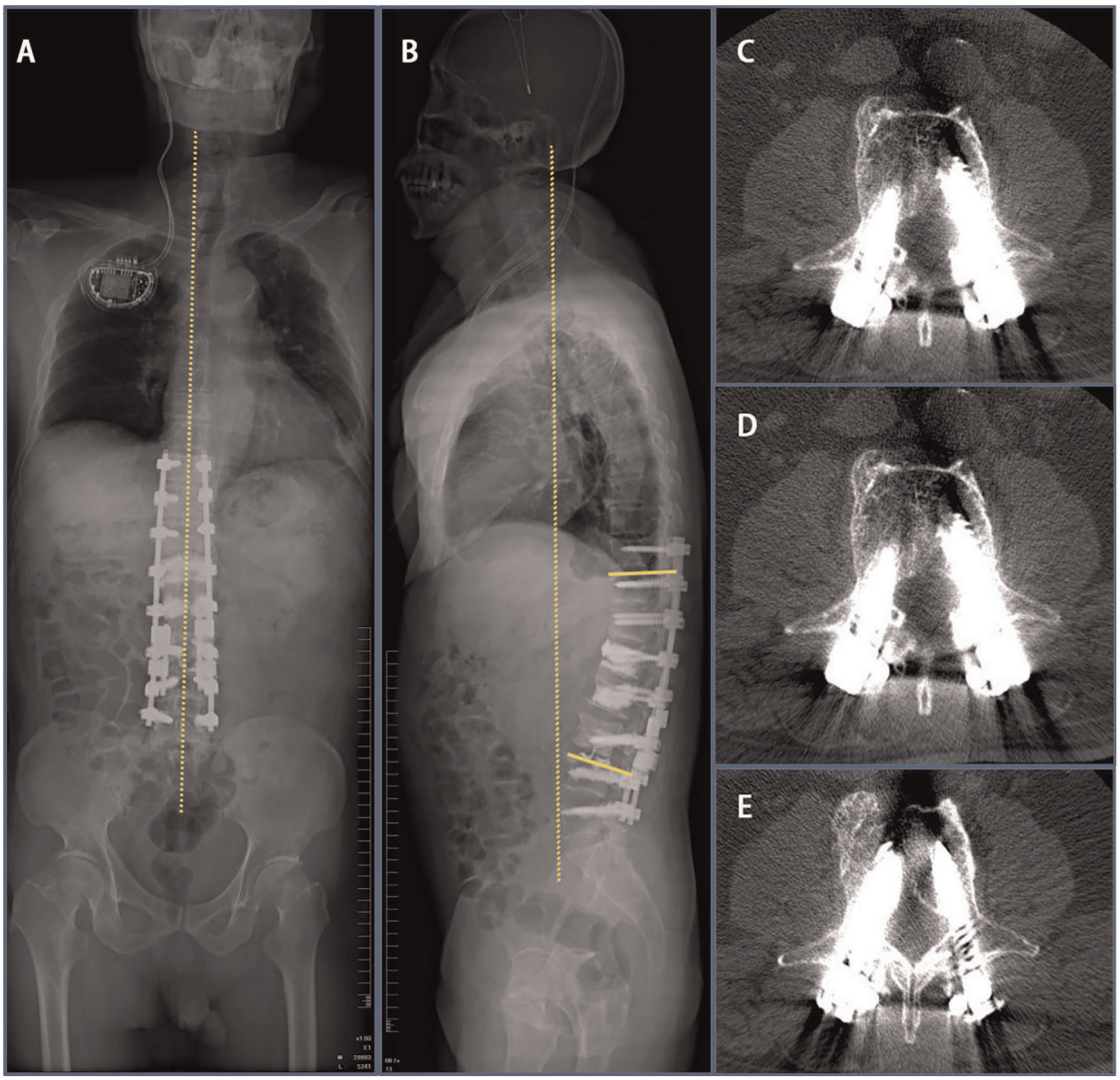


FIGURE 5 | Imaging findings 3 days after revision surgery at our hospital. (**A**,**B**) 3 days after revision surgery full-length radiograph of the patient's spine indicated that Cobb's angle decreased to 20°. (**C**–**E**) CT scan indicated good internal screw fixation.

pain in the distal fixed vertebrae segment, and the muscle strength of the lower limbs was normal. No pathologic signs were observed. CT scan and radiograph of the spine showed that the L3 vertebral body was loosely fixed internally and the screws had resorbed the surrounding bone (**Figures 4C–F**).

Two months after initial surgery, the patient underwent deep-brain electrode placement at West China Hospital. Based on the symptoms, imaging findings, and the patient's needs, the revision surgery was chosen to be performed. As the original internal fixation had failed and the patient had severe osteoporosis, the original L3 screw used for internal fixation was removed. Additionally, the L3–5 vertebral body was lengthened and fixed, the L3–5 vertebral nail tract was reinforced with bone cement, and a Domino joint head device was installed. After revision surgery, physical examination showed that the local pressure pain and percussion pain had been alleviated. Imaging 3 days after revision surgery showed that kyphosis was corrected (Cobb's angle: 22°, PI: 44°, PT: 23°, SS: 21°) and the nail rod was not loosened (**Figures 5A–E**). At the time of discharge, the patient was instructed to continue wearing the brace and continue with active anti-osteoporosis treatment, with regular review of his condition.

One month after revision surgery, imaging showed that the kyphosis was corrected and the internal fixation was stable (**Figures 6A,B**). Two months after revision surgery, the brace was successfully removed. At 3-month and 6-month follow-ups, the patient was in good condition and the internal fixation was stable (**Figures 6C–F**). At the last follow-up conducted 1.5 years after the revision surgery (**Figures 6G–H**), the patient was in good condition and did not complain of lower back discomfort. He had been actively exercising according to the rehabilitation regime and had resumed social life.

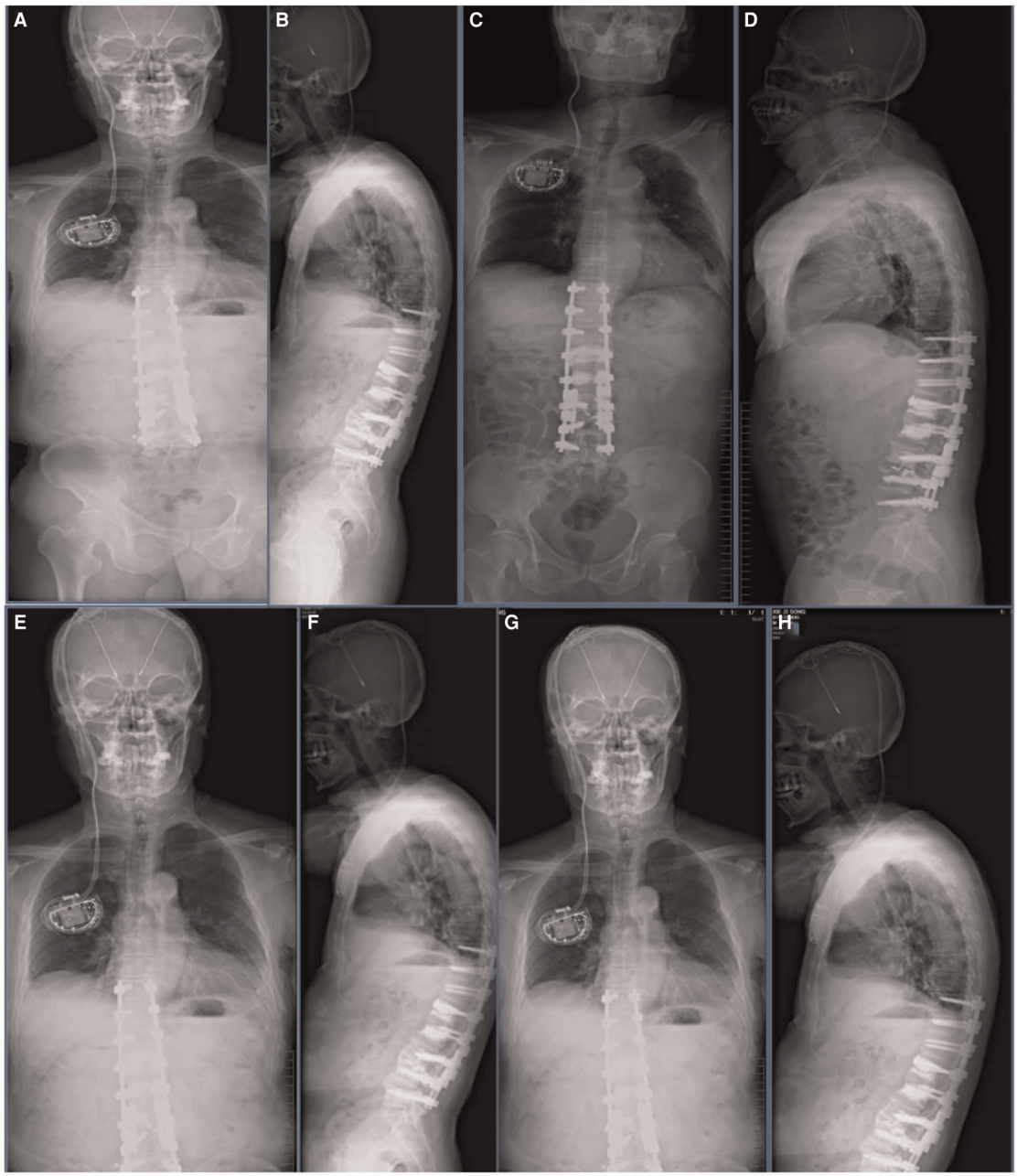


FIGURE 6 | Imaging findings after revision surgery at our hospital. (**A**,**B**) One-month follow-up postoperative radiograph indicated good spinal stability without loosening of the screws. (**C**,**D**) Three-month follow-up postoperative radiograph indicated good spinal stability without loosening of the screws. (**E**,**F**) The patient's radiograph was reviewed 6 months after surgery and showed the good orthopedic status of the spine without loosening of the internal fixation screws. (**G**,**H**) Follow-up radiographs taken 1.5 years after surgery showed no loosening of the internal fixation and good spinal orthopedic status.

DISCUSSION

Here, we report a case of camptocormia in a 70-year-old man with Parkinson's disease who underwent spine surgery with posterior osteotomy, canal decompression, and internal fixation of the problematic intervertebral plate with bone graft fusion. Two other cases were reported in the literature, in which patients with Parkinson's who developed camptocormia underwent orthopedic spine treatment: in one case, the patient was a 69-year-old man, and in the second case, the patient was a 77-year-old man (5). The 69-year-old patient developed lower back pain and radiating pain in his left thigh five years after the onset of Parkinson's, and these symptoms were followed by postural disorders that forced him to give up his

exercise routine. He also had several falls, was unable to live independently, and used a wheelchair to move around. Although the onset of camptocormia occurred a couple of years later in the present case, some of the symptoms were similar, for example, lower back pain and radiating pain in the lower extremities. In the second reported case in the literature, the 77-year-old patient had a 5-year history of Parkinson's disease and a history of lumbar compression fracture. Similar to the second case, the patient in our case also had a history of lumbar compression fractures. Based on the symptoms in these reported cases, lower back pain and kyphotic deformity of the thoracolumbar region could be considered only as signs of camptocormia in patients with Parkinson's.

Camptocormia is usually surgically treated with transient external spinal stimulation, deep brain stimulation, and orthopedic spine surgery (5–9). In the previous case of the 69-year-old patient, after thoroughly evaluating the patient's condition and ruling out other causes of camptocormia, the surgeon recommended surgery. At the 5-year follow-up, the patient continued to use a walker for ambulation and his posture and gait had deteriorated, but he was satisfied with the results of the surgery because he was not dependent on a wheelchair. In the present case, the internal fixation had failed after the initial surgery in our hospital and had to be corrected by lengthening the fixation. In the case of the 77-year-old patient reported in the literature, only the first stage of surgery was performed without osteotomy on account of the poor general condition of the patient. However, left rod fracture occurred 24 months after surgery; the fracture may be related to mechanical stress caused by the absence of osteotomy. At follow-up, it was found that while his gait had initially improved after surgery, it gradually deteriorated over time to the same level as that before surgery. In comparison, in the present case, the patient was treated with vertebroplasty after the fall and was generally in good condition. However, the later complications probably occurred because the vertebral compression fractures that resulted from the fall were not optimally treated using vertebroplasty. At the time of writing this article, the patient had been followed up for 2 years and was recovering well. He was able to take care of himself and perform his daily exercises successfully. The patient was satisfied with the outcome of the treatment. Based on the findings in these three cases, surgical treatment might not always be appropriate in these patients due to their poor muscle strength and the high likelihood of the need for secondary revision surgery after internal fixation. Therefore, we recommend that patients with Parkinson's who develop camptocormia should be carefully considered for surgery and do not recommend surgery as a first option.

Although the patient in the present case seems to be benefiting from the surgical treatment, a longer follow-up period is needed to understand the long-term benefits of surgical treatment. Parkinson's associated with camptocormia is uncommon, but it severely affects the life of patients, some of whom have significant problems with activities of daily living. Importantly, there are no target treatment options, so the treatment options need to be carefully evaluated, especially the use of orthopedic spinal surgery.

CONCLUSION

This is a rare case of camptocormia in a Parkinson's patient that highlights the need for careful evaluation of whether internal spinal fixation surgery is beneficial in such patients.

DATA AVAILABILITY STATEMENT

The data are available from the corresponding author upon request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of Sichuan Orthopaedic 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

G-l M and H-t W contributed equally to the article. G-l M was responsible for writing the manuscript, H-t W revised the manuscript, and DW reviewed the manuscript. All authors read the final draft and agreed to its submission.

FUNDING

This research did not receive any specific grant from any funding agency in the public, commercial, or not-for-profit sector.

REFERENCES

1. Tiple D, Fabbrini G, Colosimo C, Ottaviani D, Camerota F, Defazio G, et al. Camptocormia in Parkinson disease: an epidemiological and clinical study. *J Neurol Neurosurg Psychiatry*. (2009) 80(2):145–8. doi: 10.1136/jnnp.2008.150011
2. Azher SN, Jankovic J. Camptocormia: pathogenesis, classification, and response to therapy. *Neurology*. (2005) 65(3):355–9. doi: 10.1212/01.wnl.0000171857.09079.9f
3. Yoritaka A, Shimo Y, Takanashi M, Fukae J, Hatano T, Nakahara T, et al. Motor and non-motor symptoms of 1453 patients with Parkinson's disease: prevalence and risks. *Parkinsonism Relat Disord*. (2013) 19(8):725–31. doi: 10.1016/j.parkreldis.2013.04.001
4. Chan AK, Chan AY, Lau D, Durcanova B, Miller CA, Larson PS, et al. Surgical management of camptocormia in Parkinson's disease: systematic review and meta-analysis. *J Neurosurg*. (2018) 131(2):368–75. doi: 10.3171/2018.4.JNS173032
5. Wadia PM, Tan G, Munhoz RP, Fox SH, Lewis SJ, Lang AE. Surgical correction of kyphosis in patients with camptocormia due to Parkinson's

disease: a retrospective evaluation. *J Neurol Neurosurg Psychiatry*. (2011) 82 (4):364–8. doi: 10.1136/jnnp.2009.176198
6. Srivanitchapoom P, Hallett M. Camptocormia in Parkinson's disease: definition, epidemiology, pathogenesis and treatment modalities. *J Neurol Neurosurg Psychiatry*. (2016) 87(1):75–85. doi: 10.1136/jnnp-2014-310049
7. Sarkiss CA, Fogg GA, Skovrlj B, Cho SK, Caridi JM. To operate or not? A literature review of surgical outcomes in 95 patients with Parkinson's disease undergoing spine surgery. *Clin Neurol Neurosurg*. (2015) 134:122–5. doi: 10.1016/j.clineuro.2015.04.022
8. Vanacore N, Suzzareddu G, Maggini M, Casula A, Capelli P, Raschetti R. Pisa syndrome in a cohort of Alzheimer's disease patients. *Acta Neurol Scand*. (2005) 111(3):199–201. doi: 10.1111/j.1600-0404.2005.00388.x
9. Lepoutre AC, Devos D, Blanchard-Dauphin A, Pardessus V, Maurage CA, Ferriby D, et al. A specific clinical pattern of camptocormia in Parkinson's disease. *J Neurol Neurosurg Psychiatry*. (2006) 77(11):1229–34. doi: 10.1136/jnnp.2005.083998

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.

frontiers | Frontiers in Surgery

TYPE Systematic Review
PUBLISHED 05 August 2022
DOI 10.3389/fsurg.2022.899538

OPEN ACCESS

EDITED BY
Hengxing Zhou,
Tianjin Medical University General Hospital, China

REVIEWED BY
Julius Dengler,
Brandenburg Medical School Theodor Fontane, Germany
Binay Biswas,
ESI-PGIMSR, Medical College and Hospital, India

*CORRESPONDENCE
Qinyi Liu
qinyi@jlu.edu.cn

†These authors have contributed equally to this work and share first authorship

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

RECEIVED 18 March 2022
ACCEPTED 22 July 2022
PUBLISHED 05 August 2022

CITATION
Li H, An J, Zhang J, Kong W, Yun Z, Yu T, Nie X and Liu Q (2022) Comparative efficacy of radiofrequency denervation in chronic low back pain: A systematic review and network meta-analysis.
Front. Surg. 9:899538.
doi: 10.3389/fsurg.2022.899538

Comparative efficacy of radiofrequency denervation in chronic low back pain: A systematic review and network meta-analysis

Han Li[1†], Junyan An[2†], Jun Zhang[2], Weijian Kong[2], Zhihe Yun[2], Tong Yu[2], Xinyu Nie[2] and Qinyi Liu[2*]

[1]Department of Respiratory and Critical Care Medicine, The Second Hospital of Jilin University, Changchun, China, [2]Department of Orthopedics, The Second Hospital of Jilin University, Changchun, China

Background: Facet joint pain is a common cause of chronic low back pain (CLBP). Radiofrequency (RF) denervation is an effective treatment option.
Purpose: A systematic review and network meta-analysis (NMA) was performed to evaluate and compare the efficacy and effectiveness of different RF denervation treatments in managing facet joint-derived CLBP.
Methods: The Cochrane Library, Embase, PubMed, and China Biology Medicine were searched to identify eligible randomized controlled trials (RCTs) from January 1966 through December 2021. Interventions included conventional radiofrequency denervation (CRF), pulsed radiofrequency denervation (PRF), pulsed radiofrequency treatment of the dorsal root ganglia (PRF-DRG), radiofrequency facet capsule denervation (RF-FC), and radiofrequency ablation under endoscopic guidance (ERFA). The outcome was the mean change in visual analog scale (VAS) score from baseline. A random-effects NMA was used to compare the pain relief effects of the interventions over the short term (≤6 months) and long term (12 months). The rank of effect estimation for each intervention was computed using the surface under the cumulative ranking curve.
Results: A total of 10 RCTs with 715 patients met the inclusion criteria. Moderate evidence indicated that CRF denervation had a greater effect on pain relief than sham control in the short term (standardized mean difference (SMD) −1.58, 95% confidence intervals (CI) −2.98 to −0.18) and the long term (SMD −4.90, 95% CI, −5.86 to −3.94). Fair evidence indicated that PRF denervation was more effective than sham control for pain over the long term (SMD −1.30, 95% CI, −2.17 to −0.43). Fair evidence showed that ERFA denervation was more effective for pain relief than sham control in the

Abbreviations
CI, confidence interval; CLBP, chronic low back pain; CRF, conventional radiofrequency denervation; CRF-sham, sham control of CRF after local anesthetic injection; ERFA, radiofrequency ablation under endoscopic guidance; IPM-QRB, Interventional Pain Management Techniques Quality Appraisal of Reliability and Risk of Bias Assessment; NMA, network meta-analysis; PRF, pulsed radiofrequency denervation; PRF-DRG, pulsed radiofrequency treatment of the dorsal root ganglia; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RCTs, randomized control trials; RF, radiofrequency; RF-FC, radiofrequency facet capsule denervation; RoB2, version 2 of the Cochrane tool for assessing risk of bias in randomized trial; SMD, standardized mean difference; SUCRA, the surface under the cumulative ranking curve; VAS, visual analog scale.

short term (SMD −3.07, 95% CI, −5.81 to −0.32) and the long term (SMD −4.00, 95% CI, −4.95 to −3.05). Fair evidence showed that RF-FC denervation was more effective for pain relief than sham control in the long term (SMD −1.11, 95% CI, −2.07 to −0.15). A fair level of evidence indicated that PRF-DRG denervation was more effective for pain relief than sham control in the short term (SMD −5.34, 95% CI, −8.30 to −2.39).

Conclusion: RF is an effective option for patients diagnosed with facet joint-derived CLBP.

Systematic Review Registration: Identifier: CRD42022298238.

KEYWORDS

zygapophyseal joint, low back pain, radiofrequency therapy, denervation, network meta-analysis

Introduction

Low back pain is a worldwide health care problem with significant social and economic consequences. Most patients can be successfully treated in primary health care, but approximately 10%–15% have persistent pain that transforms into chronic low back pain (CLBP) (1). CLBP may be secondary to changes in the intervertebral discs, sacroiliac joints, and facet joints of the lumbar spine (2). Facet joint pain, which represents 10%–40% of CLBP, is characterized by a diffuse distribution between the L1-S1 segments (3). A 50% decrease in pain intensity after injection of local anesthetic into the medial branch can provide a definitive diagnosis of facet joint-derived CLBP (4).

Radiofrequency (RF) denervation, an invasive therapy for CLBP, is a technique that reduces spinal pain by modulating the neurotransmission of nociceptive stimuli. The transmission of nociceptive impulses is blocked by applying an electric current to coagulate the sensory nerves, which deactivates the nerves (2). A recent systematic review supported the superiority of conventional radiofrequency (CRF) over sham controls and other treatments in terms of short-term (≤6 months) and long-term (>6 months) improvement (5). However, there has been no systematic review of the effectiveness evaluation of other emerging RF denervation treatments, such as pulsed RF denervation, RF facet capsule denervation, and RF ablation under endoscopic guidance. The current systematic review was performed to evaluate the efficacy and effectiveness of different RF denervation treatments in managing facet joint-derived CLBP, and the literature search was updated through December 2021.

Methods

A systematic review and network meta-analysis (NMA) was performed according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to evaluate and compare the efficacy and effectiveness of different RF denervation treatments in managing CLBP of facet joint origin.

Search strategies

Literature search

A comprehensive literature search was conducted to include randomized control trials (RCTs) published from all countries. Two experienced researchers (Han Li and Junyan An) comprehensively searched the Cochrane Library, Embase, PubMed, and China Biology Medicine independently by combining the following keywords: ("zygapophyseal joint" or "facet joint" or "facet osteoarthritis" or "back pain" or "backache" or "vertebrogenic pain" or "lumbago" or "lumbar pain") to identify related articles published in English or Chinese between January 1966 and December 2021. Searches were also conducted for previous systematic reviews and cross-references. A detailed search strategy is provided in the **Supplementary material**. The third researcher (Jun Zhang) resolved the disagreements.

Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) studies: RCTs; (2) participants: adult patients with low back pain lasting more than one month at the time of admission who were diagnosed with facet joint syndrome by a single or double diagnostic block and received at least three months of follow-up; (3) interventions: CRF, pulsed radiofrequency denervation (PRF), pulsed radiofrequency treatment of the dorsal root ganglia (PRF-DRG), radiofrequency facet capsule denervation (RF-FC), and radiofrequency ablation under endoscopic guidance (ERFA); and (4) outcome measures: the primary outcome measure was pain relief, and the outcome indicator was the visual analog scale (VAS). VAS represented 0 with no pain and 10 with the worst pain imaginable. The outcomes of 6 months or fewer of management were considered short-term, and 12 months was considered long-term. For RCTs with more than one follow-up, each follow-up period for VAS was categorized as short-term (≤6 months) and long-term (12 months) in this NMA.

The exclusion criteria were as follows: (1) studies in which the subject had an acute cause of low back pain, including fracture, osteoporosis, and malignancy; (2) letters, conference

abstracts, and commentaries; (3) different studies recruiting the same participants; and (4) studies from which we could not extract the essential data.

Data extraction

Two independent researchers (Han Li and Junyan An) extracted data from the included articles in a standardized data collection form, and a third researcher (Weijian Kong) validated the data extraction. Extracted data included (1) basic information: first author, region of study, study scale, study characteristic, and follow-up; (2) participants: gender distribution, age distribution, number of chronic low back pain patients, and duration of symptoms at enrollment; (3) therapy: protocol and target of interventions; and (4) outcomes: pain relief (the change in mean score on the VAS from baseline).

Quality assessment

RCTs meeting the inclusion criteria were evaluated with version 2 of the Cochrane tool for assessing risk of bias in randomized trial (RoB2, revised version 2019) and Interventional Pain Management Techniques Quality Appraisal of Reliability and Risk of Bias Assessment (IPM-QRB) criteria (6). RCTs with scores of 32–48 and 16–31 were assessed as high in quality and moderate in quality, respectively. RCTs with scores under 16 were considered low in quality and were excluded from the NMA. The methodological quality of the RCTs was assessed independently by two researchers (Han Li and Junyan An). When discrepancies appeared, a third researcher (Zhihe Yun) was involved to resolve the conflict.

The qualitative analysis of the evidence was performed based on best-evidence synthesis, modified, and collated using multiple criteria, as shown in the **Supplementary material** (7). The qualitative analysis was conducted using five levels of evidence ranging from strong to opinion- or consensus-based. Two independent researchers (Han Li and Junyan An) analyzed the evidence in a standardized manner. Any disagreements between researchers were resolved by a third researcher (Qinyi Liu), and consensus was attained.

Statistical analysis

The change in the mean VAS score from baseline extracted as the primary outcome was reported as the standardized mean difference (SMD) with 95% confidence interval (CI). The Higgins I^2 statistic was calculated and the Cochran Q test was conducted to evaluate heterogeneity. Random-effects NMA was performed using STATA (version 14.0; StataCorp) (8–10). Indirect and mixed comparisons of NMA were conducted using the mvmeta and network commands of STATA. Heterogeneity was evaluated using the restricted maximum likelihood method and assuming a common heterogeneity variable (tau value) for all comparisons. Global inconsistencies, representing the plausibility of inconsistency in the entire network, were assessed with a design-by-treatment model. Local inconsistencies, representing the plausibility of inconsistency in the loop network, were estimated by a node-splitting method. The rank of effect estimation for each intervention was computed using the surface under the cumulative ranking curve (SUCRA). Publication bias was evaluated by funnel plots.

Results

Search results

Our search yielded 8,771 records according to the predefined search strategy, of which 1,650 records were duplicates. A total of 7,078 studies were excluded after browsing the abstract. The full texts of 43 RCTs were retrieved for a detailed evaluation. Finally, we identified 10 RCTs for the NMA. The PRISMA flowchart is shown in **Figure 1**.

Study characteristics

The study sample size for 10 RCTs ranged from 30 to 150 patients (11–20). Overall, 715 patients were included in the final analysis, of which 319 patients received CRF, 76 patients received PRF, 50 patients received ERFA, 50 patients received PRF-DRG, 40 patients received RF-FC, and 180 patients received a sham control of CRF after local anesthetic injection (CRF-sham). All RCTs induced a CRF group, which performed radiofrequency denervation of the medial branch of the posterior primary ramus at 80°C–85°C for 60–90 s. The intervention group for the three RCTs was PRF treatment (two Hertz at 42°C for 120–240 s) (15, 18, 19). Two RCTs compared ERFA with CRF (12, 14). ERFA involves endoscopic dissection of the dorsal medial branch and ablation with a radiofrequency cutting head. A separate RCT evaluated the efficacy of PRF-DRG, a percutaneous pulsed radiofrequency treatment of the dorsal root ganglia (13). Of the included RCTs, six reported both short-term (≤6 months) and long-term (12 months) outcomes, and four reported only short-term outcomes. The

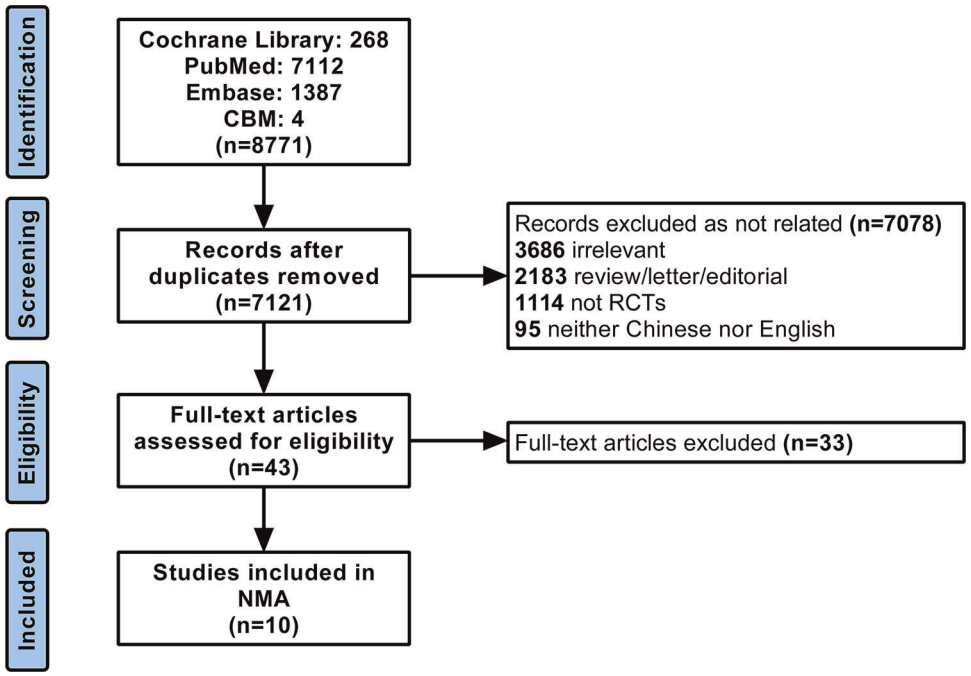


FIGURE 1
Flow chart of the literature search and selection of studies.

Supplementary material summarizes the details and the risk of bias of the included RCTs.

Efficacy of interventions measured in NMA

Figure 2 shows the network of eligible comparisons for the RF denervation options for CLBP. There was no evidence of heterogeneity or inconsistency in the NMA for short-term outcomes, but there was significant inconsistency in the NMA for long-term outcomes. Therefore, we fit an inconsistency model for long-term outcomes. Figure 3 shows the treatment rank probabilities for pain relief for short-term and long-term follow-up. Figure 4 shows a scatter plot based on the area under the SUCRA for each intervention. The results of the short-term and long-term effects of each intervention compared with other interventions are shown in Table 1. Moderate evidence indicated that CRF denervation had a greater effect on pain relief than sham control in the short term (SMD −1.58, 95% CI, −2.98 to −0.18) and the long term (SMD −4.90, 95% CI, −5.86 to −3.94). Fair evidence indicated that PRF denervation was more effective than sham control for pain over the long term (SMD −1.30, 95% CI, −2.17 to −0.43). Fair evidence showed that ERFA denervation was more effective for pain relief than sham control in the short term (SMD −3.07, 95% CI, −5.81 to −0.32) and the long term (SMD −4.00, 95% CI, −4.95 to −3.05). Fair evidence showed that RF-FC denervation was more effective for pain relief than sham control in the long term (SMD −1.11, 95% CI, −2.07 to −0.15). A fair level of evidence indicated that PRF-DRG denervation was more effective for pain relief than sham control in the short term (SMD −5.34, 95% CI, −8.30 to −2.39).

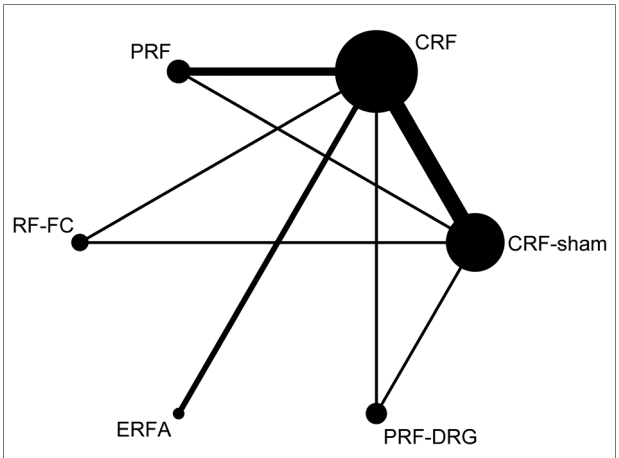


FIGURE 2
Network of eligible comparisons for the management of CLBP. The line indicates direct comparison of interventions, and the thickness of the line corresponds to the number of patients in the comparison. The size of the node corresponds to the number of studies that involve the intervention.

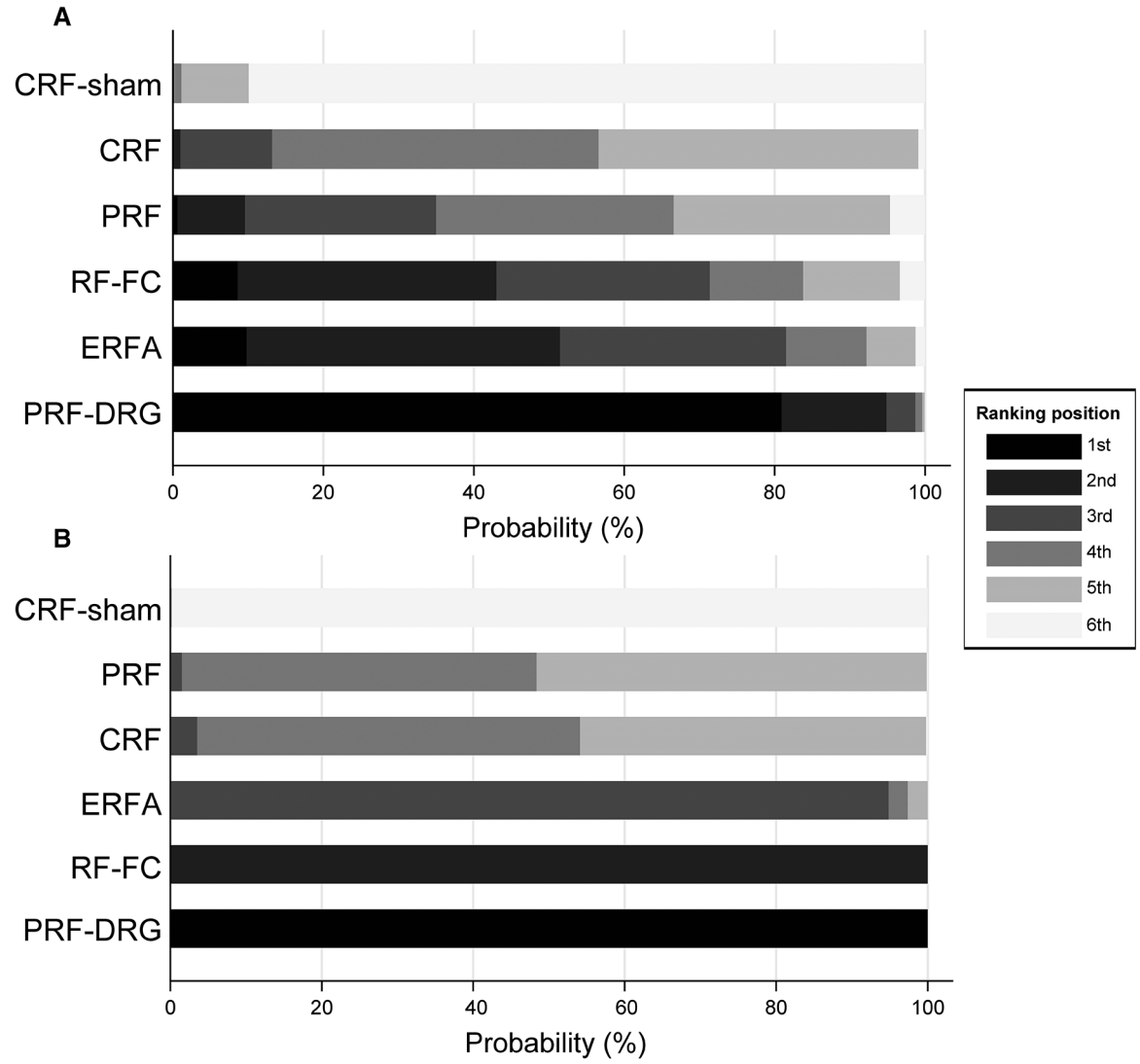


FIGURE 3
Treatment rank probabilities for pain relief for short-term (A) and long-term (B) follow-up. The order of the interventions on the vertical coordinate is based on the efficacy from lowest to highest. The horizontal coordinate is the probability of ranking 1st–6th.

Discussion

Summary of main results

The purpose of this systematic review and network meta-analysis (NMA) was to evaluate the effectiveness of different radiofrequency (RF) denervation procedures for the management of chronic low back pain (CLBP) based on information provided by randomized controlled trials (RCTs). We included 10 RCTs with five interventions: conventional radiofrequency denervation (CRF), pulsed radiofrequency denervation (PRF), pulsed radiofrequency treatment of the dorsal root ganglia (PRF-DRG), radiofrequency facet capsule denervation (RF-FC), and radiofrequency ablation under endoscopic guidance (ERFA). Of these, 60% were considered to have a low risk of bias. The reviewed RCTs provided evidence of fair to moderate quality, suggesting that CRF, ERFA, and PRF-DRG denervation could offer greater pain relief for short-term follow-up than sham surgery, whereas PRF, CRF, ERFA, and RF-FC could offer greater pain relief for long-term follow-up.

Agreements and disagreements with other studies or reviews

In 2021, Janapala et al. (5) published a systematic review on CRF in CLBP that included a dual-arm meta-analysis of pain relief with six RCTs and a single-arm meta-analysis of pain

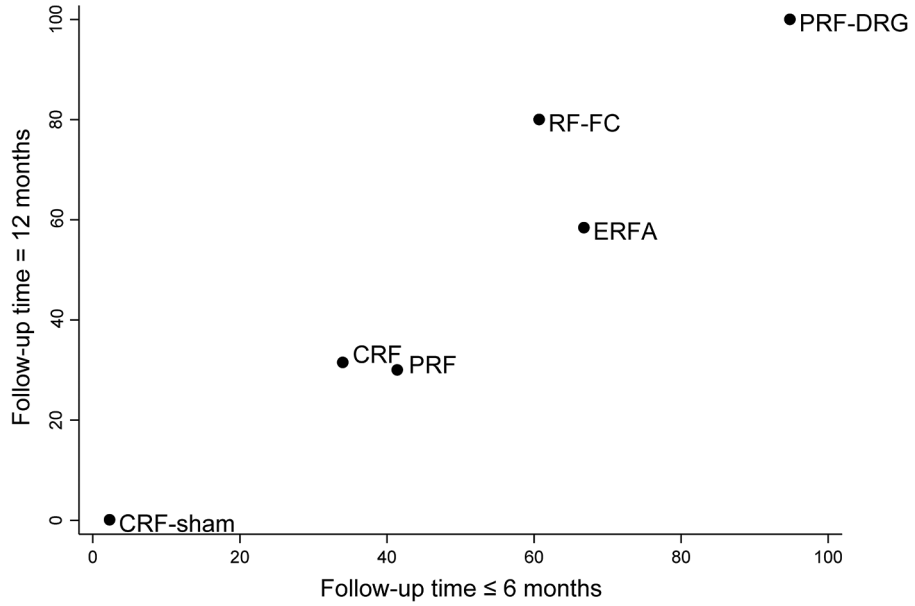


FIGURE 4
Scatter plot of the SUCRA for each intervention. The horizontal and vertical coordinates are the area under the SUCRA for each intervention at short-term and long-term follow-up, respectively. Higher values indicate higher efficacy ranking.

TABLE 1 League table for NMA of change in mean VAS score from baseline.

					Short-term (≤ 6 months)
CRF-sham	**−1.58 (−2.98, −0.18)**	−1.82 (−4.02, 0.37)	−2.85 (−5.81, 0.11)	**−3.07 (−5.81, −0.32)**	**−5.34 (−8.30, −2.39)**
4.90 (3.94, 5.86)	**CRF**	−0.24 (−2.16, 1.67)	−1.27 (−4.23, 1.69)	−1.49 (−3.85, 0.87)	**−3.76 (−6.72, −0.81)**
1.30 (0.43, 2.17)	**1.10 (0.20, 2.00)**	**PRF**	−1.03 (−4.50, 2.44)	−1.24 (−4.28, 1.80)	**−3.52 (−6.99, −0.06)**
1.11 (0.15, 2.07)	**5.10 (4.14, 6.06)**	**4.00 (3.07, 4.93)**	**RF-FC**	−0.21 (−4.00, 3.57)	−2.49 (−6.56, 1.57)
4.00 (3.05, 4.95)	**2.00 (1.62, 2.37)**	0.90 (−0.07, 1.87)	**−3.10 (−4.13, −2.07)**	**ERFA**	−2.28 (−6.06, 1.50)
0.20 (−0.70, 1.10)	**7.10 (6.15, 8.05)**	**6.00 (5.08, 6.92)**	**2.00 (1.56, 2.44)**	**5.10 (4.08, 6.12)**	**PRF-DRG**
Long-term (12 months)					

Short-term (upper right portion) and long-term (lower left portion) NMA results are presented for the mean change in VAS (from baseline) outcomes. Comparison should be made from left to right. Effect estimation is presented in standardized mean difference (SMD) with 95% confidence interval (CI), and the results are located between the column-defining intervention and row-defining intervention. For short-term (upper right portion) outcomes, an SMD less than 0 favors column-defining treatment. For long-term (lower left portion) outcomes, an SMD greater than 0 favors row-defining treatment. As a greater mean change in VAS score from baseline reflects greater pain relief, an increase in the absolute value of the SMD suggests better intervention for managing chronic low back pain. Significant results are marked in bold. CRF, conventional radiofrequency denervation; PRF, pulsed radiofrequency denervation; PRF-DRG, pulsed radiofrequency treatment of the dorsal root ganglia; RF-FC, radiofrequency facet capsule denervation; ERFA, radiofrequency ablation under endoscopic guidance; CRF-sham, a sham control of CRF.

relief with 10 RCTs. They concluded that moderate evidence could support CRF procedures over sham control and other treatments for both short-term (≤6 months) and long-term (>6 months) improvement. This finding was consistent with our results suggesting that CRF denervation was more effective than sham control in managing CLBP of facet joint origin. Although CRF is an effective therapy for pain relief, several adverse effects, including localized pain at the lesion site and neuritic pain, have been reported (21). Unfortunately, all previously published systematic reviews noted that adverse effects were not sufficiently reported. PRF uses less energy and lower temperature than CRF, which avoids neuronal tissue damage (22). In 2019, Contreras Lopez et al. (3) published a systematic review on PRF in CLBP including three RCTs. They indicated that PRF was less effective than CRF in relieving pain and restoring function and recommended the use of CRF with a high safety profile after conventional treatment. The results of our NMA showed that

there was no significant difference in pain relief in the short-term follow-up between CRF and PRF (SMD −0.24, 95% CI, −2.16 to 1.67). The results of long-term follow-up showed that CRF was less effective than PRF (SMD 1.10, 95% CI, 0.20 to 2.00). However, when compared with sham controls, CRF (SMD −4.90, 95% CI, −5.86 to −3.94) appeared to produce more significant pain relief than PRF (SMD −1.30, 95% CI, −2.17 to −0.43). In conclusion, our systematic review could not lead to any conclusions regarding the comparative efficacy of CRF and PRF.

Limitations of the systematic review

First, the low total number of patients included in the NMA resulted in a low overall completeness of the evidence. From a clinical point of view, the overall low number of patients is understandable due to the potential damage to patients from x-ray exposure with this invasive technique. However, this methodological shortcoming inevitably leads to a lower quality of evidence.

Second, while PRF-DRG denervation showed favorable outcomes in the short term, the result was measured from a single RCT (13), reflecting the value of further RCTs to substantiate this finding.

Third, of the 10 RCTs included in the NMA, only four reported indicators of pain and disorder-specific disability. In this systematic review, we did not include "disorder-specific disability", "treatment-related costs", or "ability to work" as required criteria. This was partly because these indicators are not always relevant in patients with CLBP and partly due to the limitations of the trial design of the included RCTs.

Fourth, we did not draw definitive conclusions about the risks of RF denervation due to the small size of the RCTs included in the NMA and the lack of assessment of adverse events.

Fifth, the follow-up time varied from three months to three years. Three RCTs had a follow-up of less than one year, resulting in missing long-term outcomes. Although two RCTs were performed with up to three years of follow-up, no data were extracted due to the inevitably large proportion of missed visits at the two- and three-year follow-ups. Nevertheless, longer follow-up periods are necessary to demonstrate the effectiveness of RF denervation.

Sixth, the lack of RCTs with low bias was a major limitation of this systematic review, although it is encountered in many other systematic reviews. In addition, in most of the RCTs included in the NMA, it was not clearly reported whether cointerventions or similar interventions were avoided. Methodologically sound RCTs with adequate sample sizes performed to assess the effectiveness of RF denervation are still rare.

Finally, we attempted to minimize the potential of publication bias through an extensive database search (through December 2021). Although the funnel plot showed no significant publication bias for the included RCTs, it was not possible to assess the impact of potential publication bias on the results.

Conclusion

In this systematic review, we analyzed current RCTs regarding different RF treatments in managing CLBP of facet joint origin. The evidence suggested that CRF, ERFA, and PRF-DRG denervation could offer greater pain relief for short-term follow-up than sham surgery, whereas PRF, CRF, ERFA, and RF-FC could offer greater pain relief for long-term follow-up. We concluded that RF is an effective option for patients diagnosed with facet joint-derived CLBP. However, high-quality RCTs with larger patient samples and long-term follow-up results are needed.

Data availability statement

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

Author contributions

Conceptualization: HL, JA, QL, Data curation: HL, JA, JZ, WK, ZY, QL, Formal analysis: HL, JA, QL, Funding acquisition: QL, Methodology: HL, JA, QL, Project administration: QL, Visualization: HL, JA, JZ, WK, ZY, TY, XN, Writing - original draft: HL, JA, Writing - review & editing: TY, XN, QL. All authors contributed to the article and approved the submitted version.

Funding

This study was supported by the Department of Finance of Jilin Province (ZXWSTZXEY041).

Acknowledgments

We would like to thank Elsevier for language editing services.

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

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsurg.2022.899538/full#supplementary-material.

References

1. Schwarzer AC, Wang SC, Bogduk N, McNaught PJ, Laurent R. Prevalence and clinical features of lumbar zygapophysial joint pain: a study in an Australian population with chronic low back pain. *Ann Rheum Dis*. (1995) 54 (2):100–6. doi: 10.1136/ard.54.2.100

2. Maas ET, Ostelo R, Niemisto L, Jousimaa J, Hurri H, Malmivaara A, et al. Radiofrequency denervation for chronic low back pain. *Cochrane Database Syst Rev*. (2015) 10:CD008572. doi: 10.1002/14651858.CD008572.pub2

3. Contreras Lopez WO, Navarro PA, Vargas MD, Alape E, Camacho Lopez PA. Pulsed radiofrequency versus continuous radiofrequency for facet joint low back pain: a systematic review. *World Neurosurg*. (2019) 122:390–6. doi: 10.1016/j.wneu.2018.10.191

4. Sehgal N, Dunbar EE, Shah RV, Colson J. Systematic review of diagnostic utility of facet (zygapophysial) joint injections in chronic spinal pain: an update. *Pain Physician*. (2007) 10(1):213–28. doi: 10.36076/ppj.2007/10/213

5. Janapala RN, Manchikanti L, Sanapati MR, Thota S, Abd-Elsayed A, Kaye AD, et al. Efficacy of radiofrequency neurotomy in chronic low back pain: a systematic review and meta-analysis. *J Pain Res*. (2021) 14:2859–91. doi: 10.2147/JPR.S323362

6. Manchikanti L, Hirsch JA, Cohen SP, Heavner JE, Falco FJ, Diwan S, et al. Assessment of methodologic quality of randomized trials of interventional techniques: development of an interventional pain management specific instrument. *Pain Physician*. (2014) 17(3):E263–90. doi: 10.36076/ppj.2014/17/E263

7. Manchikanti L, Falco FJ, Benyamin RM, Kaye AD, Boswell MV, Hirsch JA. A modified approach to grading of evidence. *Pain Physician*. (2014) 17(3):E319–25. doi: 10.36076/ppj.2014/17/E319

8. Dias S, Welton NJ, Caldwell DM, Ades AE. Checking consistency in mixed treatment comparison meta-analysis. *Stat Med*. (2010) 29(7–8):932–44. doi: 10.1002/sim.3767

9. Chaimani A, Higgins JPT, Mavridis D, Spyridonos P, Salanti G. Graphical tools for network meta-analysis in STATA. *PLoS One*. (2013) 8(10):e76654-e. doi: 10.1371/journal.pone.0076654

10. Shim S, Yoon BH, Shin IS, Bae JM. Network meta-analysis: application and practice using Stata. *Epidemiol Health*. (2017) 39:e2017047. doi: 10.4178/epih.e2017047

11. van Kleef M, Barendse GA, Kessels A, Voets HM, Weber WE, de Lange S. Randomized trial of radiofrequency lumbar facet denervation for chronic low back pain. *Spine (Phila Pa 1976)*. (1999) 24(18):1937–42. doi: 10.1097/00007632-199909150-00013

12. Xue Y, Ding T, Wang D, Zhao J, Yang H, Gu X, et al. Endoscopic rhizotomy for chronic lumbar zygapophysial joint pain. *J Orthop Surg Res*. (2020) 15(1):4. doi: 10.1186/s13018-019-1533-y

13. Moussa WM, Khedr W, Elsawy M. Percutaneous pulsed radiofrequency treatment of dorsal root ganglion for treatment of lumbar facet syndrome. *Clin Neurol Neurosurg*. (2020) 199:106253. doi: 10.1016/j.clineuro.2020.106253

14. Song K, Li Z, Shuang F, Yin X, Cao Z, Zhao H, et al. Comparison of the effectiveness of radiofrequency neurotomy and endoscopic neurotomy of lumbar medial branch for facetogenic chronic low back pain: a randomized controlled trial. *World Neurosurg*. (2019) 126:e109–e15. doi: 10.1016/j.wneu.2019.01.251

15. Çetin A, Yektaş A. Evaluation of the short- and long-term effectiveness of pulsed radiofrequency and conventional radiofrequency performed for medial branch block in patients with lumbar facet joint pain. *Pain Res Manag*. (2018) 2018:7492753. doi: 10.1155/2018/7492753

16. Moussa WM, Khedr W. Percutaneous radiofrequency facet capsule denervation as an alternative target in lumbar facet syndrome. *Clin Neurol Neurosurg*. (2016) 150:96–104. doi: 10.1016/j.clineuro.2016.09.004

17. Nath S, Nath CA, Pettersson K. Percutaneous lumbar zygapophysial (Facet) joint neurotomy using radiofrequency current, in the management of chronic low back pain: a randomized double-blind trial. *Spine (Phila Pa 1976)*. (2008) 33(12):1291–7. doi: 10.1097/BRS.0b013e31817329f0

18. Kroll HR, Kim D, Danic MJ, Sankey SS, Gariwala M, Brown M. A randomized, double-blind, prospective study comparing the efficacy of continuous versus pulsed radiofrequency in the treatment of lumbar facet syndrome. *J Clin Anesth*. (2008) 20(7):534–7. doi: 10.1016/j.jclinane.2008.05.021

19. Tekin I, Mirzai H, Ok G, Erbuyun K, Vatansever D. A comparison of conventional and pulsed radiofrequency denervation in the treatment of chronic facet joint pain. *Clin J Pain*. (2007) 23(6):524–9. doi: 10.1097/AJP.0b013e318074c99c

20. Leclaire R, Fortin L, Lambert R, Bergeron YM, Rossignol M. Radiofrequency facet joint denervation in the treatment of low back pain: a placebo-controlled clinical trial to assess efficacy. *Spine (Phila Pa 1976)*. (2001) 26(13):1411–6. doi: 10.1097/00007632-200107010-00003

21. Kornick C, Kramarich SS, Lamer TJ, Todd Sitzman B. Complications of lumbar facet radiofrequency denervation. *Spine (Phila Pa 1976)*. (2004) 29 (12):1352–4. doi: 10.1097/01.BRS.0000128263.67291.A0

22. Sluijter ME, Imani F. Evolution and mode of action of pulsed radiofrequency. *Anesth Pain Med*. (2013) 2(4):139–41. doi: 10.5812/aapm.10213

frontiers | Frontiers in Surgery

TYPE Original Research
PUBLISHED 08 August 2022
DOI 10.3389/fsurg.2022.906839

OPEN ACCESS

EDITED BY
Shibao Lu,
Capital Medical University, China

REVIEWED BY
Carlos A. Bagley,
University of Texas Southwestern Medical Center, United States
Reuben C. Soh,
Singapore General Hospital, Singapore

*CORRESPONDENCE
Shengjun Qian
qianshengjun@zju.edu.cn
Weishan Chen
chenweishan@zju.edu.cn

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

RECEIVED 29 March 2022
ACCEPTED 21 July 2022
PUBLISHED 08 August 2022

CITATION
Qian S, Wang Z, Ren Y, Chew I, Jiang G, Li W and Chen W (2022) The cervical sagittal curvature change in patients with or without PCSM after laminoplasty.
Front. Surg. 9:906839.
doi: 10.3389/fsurg.2022.906839

The cervical sagittal curvature change in patients with or without PCSM after laminoplasty

Shengjun Qian[1,2]*, Zhan Wang[1,2], Ying Ren[1], Ian Chew[3], Guangyao Jiang[2], Wanli Li[1,2] and Weishan Chen[1,2]*

[1]Department of Orthopedic Surgery, The Second Affiliated Hospital, Zhejiang University School of Medicine, Hangzhou China, [2]Department of Orthopedic Surgery, Orthopedics Research Institute of Zhejiang University, Hangzhou China, [3]Department of Orthopedic Surgery, Zhejiang University School of Medicine, Hangzhou China

Objective: After laminoplasty, the cervical sagittal curvature of some patients tend to be lordotic, this phenomenon cannot be explained by the theory of laminoplasty, and the reason remains unknown. We explored the possible role played by pinching cervical spondylotic myelopathy (PCSM) in the cervical sagittal curvature change in patients after laminoplasty.
Methods: From April 2017 to May 2019, we studied 122 patients undergoing laminoplasty with cervical spondylotic myelopathy (CSM). All patients were divided into Group A (anterior compression only, without PCSM) and Group B (both anterior and posterior compression, with PCSM). The visual analogue scale (VAS) was used to measure pain, and modified Japanese Orthopedic Association (mJOA) score was derived. The cervical global angle (CGA) and the range of cervical motion (ROM) were compared. The clinical and imaging results were compared between Group A and Group B.
Results: After laminoplasty, both the mean VAS and mJOA scores improved significantly in Group A and Group B, the mJOA recovery rate of Group B was better than that of Group A ($P < 0.05$). The mean CGA and ROM decreased in Group A, but increased in Group B. MRI revealed that the ligamentum flavum of Group A was significantly thinner than that of Group B ($P < 0.05$).
Conclusions: Because of the hypertrophic and folded ligamentum flavum compressing the dorsal spinal cord, patients with PCSM may maintain a compulsive kyphotic posture. After laminoplasty, the cervical sagittal curvature of these patients tend to be lordotic due to the release of dorsal spinal cord compression.

KEYWORDS
PCSM, ligamentum flavum, laminoplasty, lordosis, kyphosis

Introduction

Laminoplasty is widely used to treat patients with cervical spondylotic myelopathy (CSM) in recent years (1, 2). Although laminoplasty protects the vertebral lamina, it still destroys the posterior ligament and paravertebral muscle, which results in postoperative neck pain and kyphotic cervical sagittal curvature (3). Similar to laminectomy, laminoplasty is also unsuitable for patients with kyphotic cervical sagittal

curvature (4). However, recent studies have reported that the cervical sagittal curvature of some patients tend to be lordotic after laminoplasty, and the reason remains unknown (5).

Pinching cervical spondylotic myelopathy (PCSM) is a type of CSM with both anterior compression (herniated disc and osteophyte) and posterior compression (hypertrophic and folded ligamentum flavum). The ligamentum flavum is a member of the posterior ligamentous complex (PLC) located on the posterior edge of the spinal canal, which can reinforce the stability of the vertebrae (6). Many studies have found that a hypertrophic and folded ligamentum flavum can induce lumbar spinal canal stenosis and intermittent claudication (7–9). The neurological symptoms will be moderated when patients maintain a lumbar-flexed posture. We hypothesis that this situation may exist in patients with PCSM.

Materials and methods

Patient population

From April 2017 to May 2019, 251 patients undergoing laminoplasty with CSM in our hospital were analysed. Excluded from this study were 129 patients who had ossification of the posterior longitudinal ligament (OPLL), traumatic spinal injury, infection and tumor (**Figure 1**). The study enrolled a total of 95 men and 27 women with an average age of 59.0 years (range 38 to 79 years). Sixty five patients had three levels of cervical canal stenosis and 57 patients had four or five levels of cervical canal stenosis (**Table 1**). All patients were divided into two groups (**Figures 2A,B**): anterior compression only (Group A, 50 cases, without PCSM) and both anterior and posterior compression (Group B, PCSM, 72 cases, with PCSM). There was no significant difference in the factors of gender, age, BMI, basic diseases, intraoperative bleeding and surgical time between Group A and Group B ($P > 0.05$). The mean follow-up time was 27.32 months in Group A and 26.97 months in Group B.

Surgical technique

All patients were treated with unilateral open-door laminoplasty from C3 to C7. The paravertebral muscle was detached from each laminae. During this procedure, the muscles attached to the C2 and C7 spinous process were preserved as far as possible. A high-speed air drill was used to open the hemilamina on the dominant symptomatic side. A shallow gutter was scored on the contralateral hemilamina and used as a hinge. After opening the laminae, the hinged laminae was fixed with a titanium miniplate, and small screws were drilled through the plate holes into the lateral mass and the open laminae. Two drainage tubes were placed before incision suture, and a cervical collar was used for 2–4 weeks after surgery.

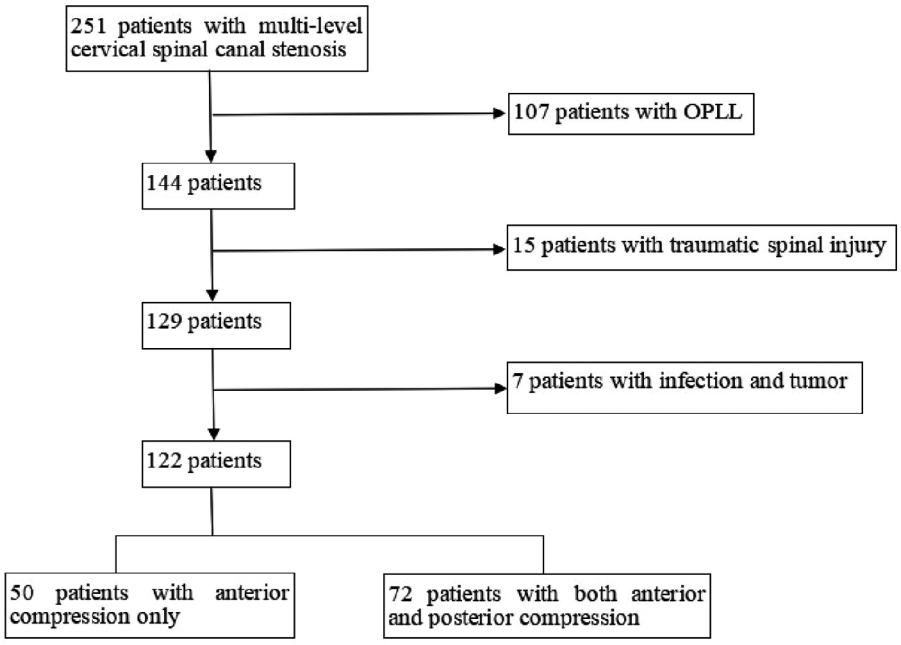


FIGURE 1
Flowchart of the collection of the study population.

TABLE 1 Clinical summary of 122 patients with CSM.

	Group A ($N = 50$)	Group B ($N = 72$)	*P*-value
Male, *N* (%)	37 (74.00)	58 (80.56)	0.391
Age, years, mean (SD)	58.82 (7.91)	59.24 (8.47)	0.261
BMI, kg/m^2, mean (SD)	27.34 (4.11)	26.91 (3.94)	0.561
Diabetes, *N* (%)	6 (12.00)	9 (12.50)	0.934
Hypertension, *N* (%)	23 (46.00)	37 (51.39)	0.558
Stenotic segments			
3 segments, *N* (%)	28 (56.00)	37 (51.39)	0.616
4–5 segments, *N* (%)	22 (44.00)	35 (48.61)	0.616
Intraoperative bleeding, ml, mean (SD)	211.34 (108.76)	232.89 (122.63)	0.320
Surgical time, min, mean (SD)	102.62 (36.42)	109.13 (30.92)	0.290
Follow-up time, mon, mean (SD)	27.32 (3.55)	26.97 (3.45)	0.587

CSM, cervical spondylotic myelopathy; BMI, body mass index.

Outcome measures

Clinical outcomes were assessed using a visual analogue scale (VAS) and modified Japanese Orthopedic Association (mJOA) score. The VAS measures pain on a scale of 0 (no pain) to 10 (maximal pain). The mJOA score is a 17-point rating instrument that evaluates sensory functions (of the trunk, upper and lower extremities), motor functions (of the upper and lower extremities), and the urinary bladder function. The mJOA recovery rate is defined as follows: mJOA recovery rate (%) = (postoperative mJOA−preoperative mJOA)/(17−preoperative mJOA) × 100%.

Cervical lateral radiographs (neutral, extension and flexion) were obtained and magnetic resonance imaging (MRI) was performed. We used the cervical global angle (CGA) to measure the angle of cervical sagittal curvature, which was measured between the posterior borders of the C2 and C7 vertebral bodies (10). The C2–7 ROM was the difference

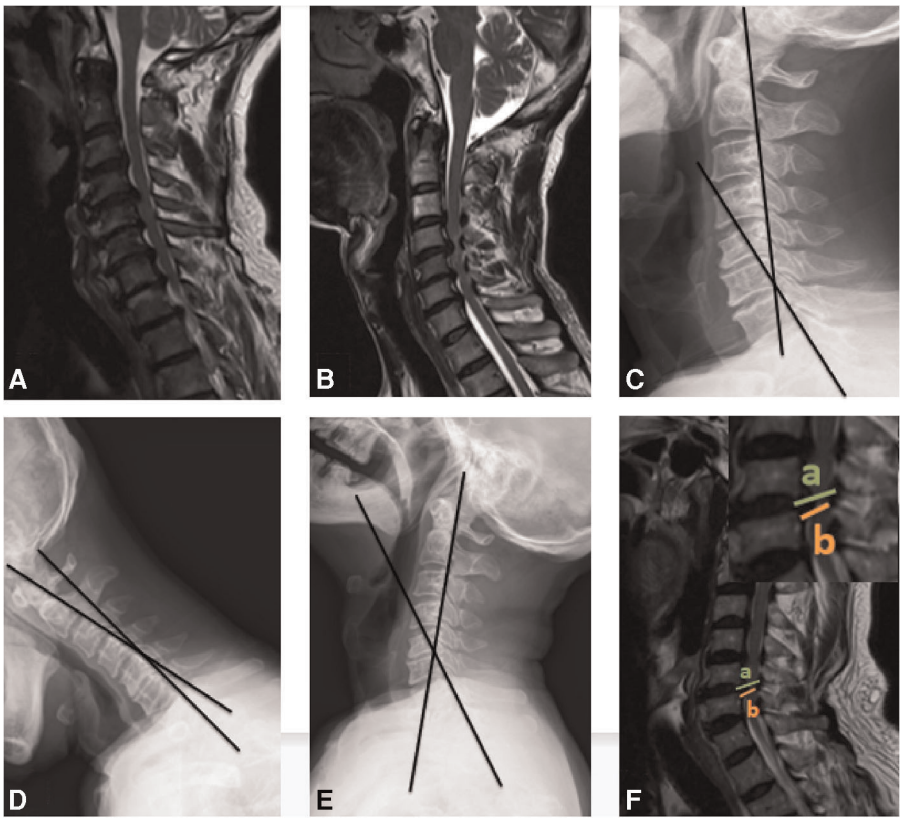


FIGURE 2
The schematic of Group A, Group B, CGA, ROM and thickness of ligamentum flavum. (**A**) Group A, anterior compression only, without PCSM. (**B**) Group B, both anterior and posterior compression, with PCSM. (**C**) The CGA is measured between the posterior border of the C2 and C7 vertebral body on neutral lateral radiograph. (**D**,**E**) The C2-7 ROM is calculated as the difference between the CGA measured during the maximal extension and flexion on the dynamic lateral radiographs. (**F**) The thickness of ligamentum flavum was measured as the length of (a,b) at the site where the spinal cord was most seriously compressed according to sagittal MR (a was the distance of the anterior border and the posterior border of the spinal canal, b was the distance of the anterior border of the spinal canal and the posterior border of the spinal cord).

between the CGAs measured during maximal extension and flexion on dynamic lateral radiographs (Figures 2C–E). Ligamentum flavum thickness was measured at the site where the spinal cord was most seriously compressed as indicated by sagittal MRI (11) (Figure 2F). All measurements were performed three times by one of the authors and independently by an experienced musculoskeletal radiologist.

Statistical analysis

T-tests, and chi-square tests were used for statistical analysis. The analysis was carried out by SPSS 20.0, and a *P* value of <0.05 was considered statistically significant.

Results

Clinical outcomes

The mean VAS score in Group A was 5.62 ± 1.76 before surgery and 3.18 ± 2.01 at the last follow-up. The mean VAS score in Group B was 5.57 ± 1.75 before surgery and 2.54 ± 1.46 at the last follow-up. The mean mJOA score in Group A was 9.06 ± 2.40 before surgery and 12.92 ± 2.69 at the last follow-up. The mean mJOA score in Group B was 9.32 ± 2.44 before surgery and 14.01 ± 2.08 at the last follow-up. Thus, both the mean VAS and mJOA scores improved significantly in Group A and Group B after surgery. Additionally, the VAS change in Group A was smaller than that in Group B (2.44 ± 1.15 vs. 3.03 ± 1.26, $P < 0.05$), the mJOA change in Group A was also smaller than that in Group B (3.86 ± 1.55 vs. 4.69 ± 1.94, $P < 0.05$). Correspondingly, the mJOA recovery rate of Group A was lower than that of Group B (0.52 ± 0.21 vs. 0.63 ± 0.19, $P < 0.05$; Table 2).

TABLE 2 Comparison of VAS, mJOA and the mJOA recovery rates between Group A and Group B.

	Group A	Group B	*P*-value
Pre-Op VAS	5.62 ± 1.76	5.57 ± 1.75	0.876
Post-Op VAS	3.18 ± 2.01	2.54 ± 1.46	0.058
VAS change	−2.44 ± 1.15	−3.03 ± 1.26	0.010
Pre-Op mJOA	9.06 ± 2.40	9.32 ± 2.44	0.562
Post-Op mJOA	12.92 ± 2.69	14.01 ± 2.08	0.013
mJOA change	3.86 ± 1.55	4.69 ± 1.94	0.013
mJOA recovery rate	0.52 ± 0.21	0.63 ± 0.19	0.005

VAS change = Post-Op VAS − Pre-Op VAS, mJOA change = Post-Op mJOA − Pre-Op mJOA. mJOA recovery rate (%) = (Post-Op mJOA−Pre-Op mJOA) / (17 −Pre-Op mJOA) × 100%. Values are displayed as a mean ± standard deviation. Significance between the two groups, $P < 0.05$. VAS,visual analogue scale; mJOA, modified japanese orthopedic association.

Radiologic assessments

The mean CGA of Group A was 19.52° ± 9.58° before surgery and 13.62° ± 9.74° at the last follow-up. The mean CGA of Group B was 17.49° ± 9.16° before surgery and 20.34° ± 8.35° at the last follow-up. The mean ROM of Group A was 45.68° ± 8.69° before surgery and 37.74° ± 8.01° at the last follow-up. The mean ROM of Group B was 39.56° ± 8.86° before surgery and 41.34° ± 8.81° at the last follow-up. Thus, for CGA, a kyphotic change (5.89° ± 4.22°) in Group A and a lordotic change (2.85° ± 6.24°) in Group B was observed ($P < 0.05$). For ROM, there was a decreased change (7.94° ± 3.15°) in Group A and an increased change (1.78° ± 6.32°) in Group B ($P < 0.05$). The different results may imply the different factors that influence the CGA and ROM before laminoplasty between Group A and B. MRI revealed that the ligamentum flavum of Group A was notably thinner than that of Group B (1.98 mm ± 0.43 mm vs. 3.42 mm ± 0.69 mm, $P < 0.05$, Table 3), indicating patients with PCSM had hypertrophic and folded ligamentum flavum.

Complication

Postoperative complications were noted during the study: such as incision infection (4.00% vs. 4.17%), hematoma (2.00% vs. 2.78%), cerebrospinal fluid leakage (2.00% vs. 1.39%), spinal cord injury (2.00% vs. 2.78%), persistent axial pain (12.00% vs. 11.11%), C5 paresis (6.00% vs. 4.17%) and postoperative thrombosis (2.00% vs. 2.78%) between Group A and Group B (Table 4). There were no statistical differences between Group A and Group B in postoperative complications.

Discussion

As first reported by Hirabayashi, laminoplasty is an effective treatment for patients with CSM (12). By enlarging the spinal

TABLE 3 Comparison of CGAs, ROMs and ligamentum flavum thicknesses between Group A and Group B.

	Group A	Group B	*P*-value
Pre-Op CGA (°)	19.52 ± 9.58	17.49 ± 9.16	0.240
Post-Op CGA (°)	13.62 ± 9.74	20.34 ± 8.35	<0.001
CGA change (°)	−5.89 ± 4.22	2.85 ± 6.24	<0.001
Pre-Op ROM (°)	45.68 ± 8.69	39.56 ± 8.86	<0.001
Post-Op ROM (°)	37.74 ± 8.01	41.34 ± 8.81	0.023
ROM change (°)	−7.94 ± 3.15	1.78 ± 6.32	<0.001
Thickness of LF (mm)	1.98 ± 0.43	3.42 ± 0.69	<0.001

CGA change = Post-Op CGA − Pre-Op CGA, ROM change = Post-Op ROM − Pre-Op ROM. Values are displayed as a mean ± standard deviation. Significance between the two groups, $P < 0.05$. CGA, cervical global angle; ROM, range of cervical motion.

canal volume, laminoplasty can provide direct posterior local decompression, by allowing the posterior migration of the spinal cord, laminoplasty can also create an indirect anterior decompression (13). However, it should be noted that laminoplasty destroys the posterior ligament and paravertebral muscle. Thus, in most patients, a decrease in cervical lordosis or an increase in cervical kyphosis occurs after laminoplasty (14, 15). Laminoplasty is thus suitable for patients with cervical lordosis, but not suitable for patients with cervical neutral or kyphosis (16). But, recent studies have reported that the cervical sagittal curvature of some patients tend to be lordotic after laminoplasty (17), and the reason remains unknown.

The ligamentum flavum is located on the posterior edge of the spinal canal, which reinforces the stability of cervical vertebrae (18). With age, the ligamentum flavum gradually degenerates, becoming hypertrophic and folded (19), reducing the volume of the cervical spinal canal and ultimately leads to the compression of the dorsal spinal cord. PCSM is defined as CSM with both anterior and posterior compression, and the posterior compression is usually due to the the hypertrophic and folded ligamentum flavum. Many previous studies found that a hypertrophic and folded ligamentum flavum could induce lumbar spinal canal stenosis (20). If the patient straightens the back, the hypertrophic and folded ligamentum flavum will compress the spinal cord or the nerve roots to a greater extent, inducing lower limb radiating pain and aggravating

TABLE 4 Postoperative complication between Group A and Group B.

	Group A	Group B
Incision infection, *N* (%)	2 (4.00)	3 (4.17)
Hematoma, *N* (%)	1 (2.00)	2 (2.78)
Cerebrospinal fluid leakage, *N* (%)	1 (2.00)	1 (1.39)
Spinal cord injury, *N* (%)	1 (2.00)	2 (2.78)
Persistent axial pain, *N* (%)	6 (12.00)	8 (11.11)
C5 paresis, *N* (%)	3 (6.00)	3 (4.17)
Postoperative thrombosis, *N* (%)	1 (2.00)	2 (2.78)

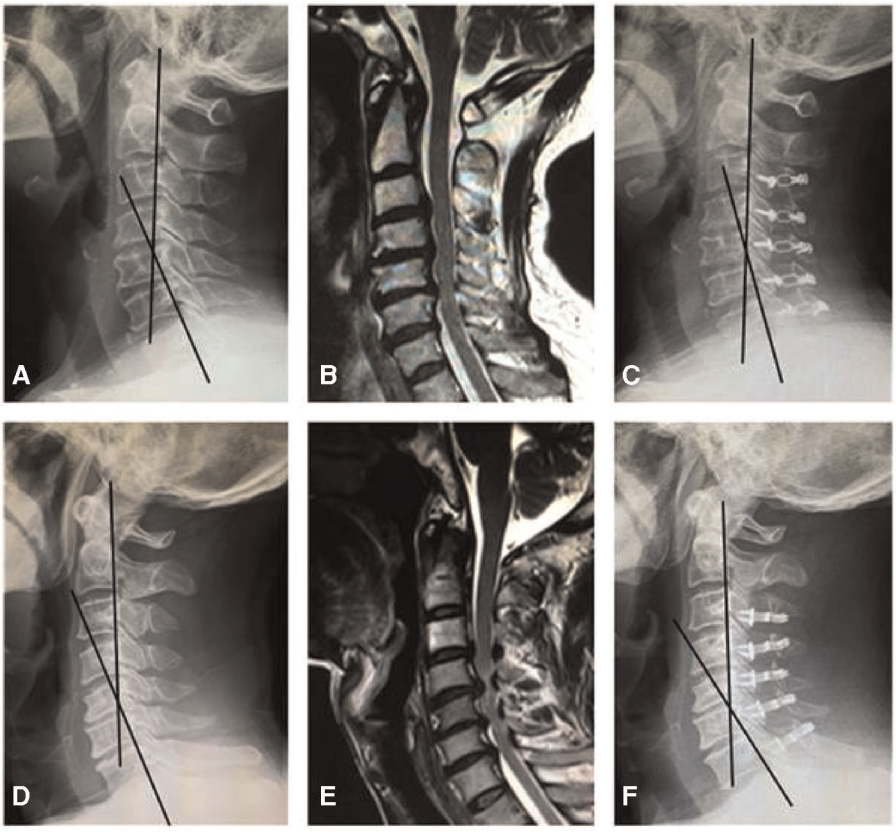


FIGURE 3
Radiological presentation of a 59 year-old man from Group A (**A–C**) and a 56 year-old man from Group B (**D–F**). (**A**) Preoperative lateral X-ray showed the CGA was 25.8°. (**B**) MR revealed the spinal cord had anterior compression only. (**C**) Postoperative lateral X-ray showed the CGA was 18.6°. (**D**) Preoperative lateral X-ray showed the CGA was 22.3°. (**E**) MR revealed spinal cord had both anterior and posterior compression. (**F**) Postoperative lateral X-ray showed the CGA was 31.8°.

intermittent claudication. Conversely, the neurological symptoms will be relieved if the patient maintains a lumbar-flexed posture. We hypothesise that the situation may exist in patients with PCSM, who have to maintain a cervical kyphotic posture to relieve the compression from posterior hypertrophic ligamentum flavum (21–23).

From April 2017 to May 2019, we analysed 122 patients who were diagnosed with CSM and treated with laminoplasty in our hospital. All patients were divided into two groups: anterior compression only (Group A, without PCSM) and both anterior and posterior compression (Group B, with PCSM). The ligamentum flavum of Group A (1.98 mm ± 0.43 mm) was notably thinner than that of Group B (3.42 mm ± 0.69 mm). After over 2 years follow-up, for the CGA measurements, there was a kyphotic change (5.89° ± 4.22°) in Group A and a lordotic change (2.85° ± 6.24°) in Group B. This suggests that the cervical sagittal curvature change of Group A tends to be kyphotic after laminoplasty (**Figures 3A–C**), whereas that of Group B tends to be lordotic (**Figures 3D–F**). Moreover, the VAS and mJOA changes, and the mJOA recovery rate of patients in Group A, were significantly lower than those of patients in Group B, which suggests a greater improvement in the clinical results of patients in Group B, as compared to patients in Group A. Considering the thickness difference of ligamentum flavum between Group A and B, we conjecture that patients with PCSM had a forced kyphotic posture before laminoplasty. Neck extension was restricted due to the hypertrophic and folded ligamentum flavum. Compared with patients in Group A, the clinical and imaging results of patients in Group B seemed worse before laminoplasty. After laminoplasty, the patients' spinal canal were enlarged and the posterior compressions were no longer visible. This relieved patients of the forced kyphotic posture and allowed them to extend their neck freely. As such, the patients had higher levels of comfort. This corresponds with the improved results seen in Group B after laminoplasty.

Interestingly, compared with Group A (45.68° ± 8.69°), the mean preoperative ROM in Group B (39.56° ± 8.86°) was much smaller, implying that patients with PCSM had stiff necks. The theory of laminoplasty cannot account for the increased ROM (41.34° ± 8.81°) of Group B patients after laminoplasty, but is well explained by our hypothesis. Thus, the ROM may be useful when evaluating whether a patient has a compulsive kyphotic posture before laminoplasty.

Our study had certain limitations. First, this was a single-center study. Second, the number of cases was not large, and the follow-up time was short. As time goes on, a patent cervical spinal canal may appear in some patients, and leads to a compulsive kyphotic posture again. More cases will be included and the follow-up period will be lengthened in our future study.

Conclusions

In conclusion, a hypertrophic and folded ligamentum flavum may force patients with PCSM to maintain a compulsive kyphotic posture. For these patients, the cervical sagittal curvature tend to become lordotic with the release of dorsal spinal cord compression after laminoplasty.

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 ethical committee of The Second Affiliated Hospital, School of Medicine, Zhejiang University. 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

QSJ and CWS were the main writers and designers of the paper. RY and LWL made substantial contributions to the study. WZ, Ian and JGY contributed to literatures collection and language corrections. All authors contributed to the article and approved the submitted version.

Funding

This work was supported by the Zhejiang Provincial Natural Science Foundation (LQ22H160040) and National Natural Science Foundation of China (82103499).

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

All claims expressed in this article are solely those of the authors and do not necessarily represent those of

their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsurg.2022.906839/full#supplementary-material.

References

1. Mesregah MK, Buchanan IA, Formanek B, Wang JC, Buser Z. Intra- and post-complications of cervical laminoplasty for the treatment of cervical myelopathy: an analysis of a nationwide database. *Spine*. (2020) 45(20): E1302–11. doi: 10.1097/BRS.0000000000003574

2. Takeuchi K, Yokoyama T, Wada K, Kumagai G, Kudo H, Tanaka S, et al. Modified K-line in neck extension is a prognostic indicator of the surgical outcome at 5 years after cervical laminoplasty for cervical spondylotic myelopathy. *Spine*. (2021) 46(19):E1031–41. doi: 10.1097/BRS.0000000000003982

3. Bartels RH, van Tulder MW, Moojen WA, Arts MP, Peul WC. Laminoplasty and laminectomy for cervical sponydylotic myelopathy: a systematic review. *Eur Spine J*. (2015) 24(2):160–7. doi: 10.1007/s00586-013-2771-z

4. Liang G, Liang C, Zheng X, Xiao D, Zeng S, Yin D, et al. Sagittal alignment outcomes in lordotic cervical spine: does three-level anterior cervical discectomy and fusion outperform laminoplasty? *Spine*. (2019) 44(15):E882–8. doi: 10.1097/BRS.0000000000003016

5. Machino M, Yukawa Y, Hida T, Ito K, Nakashima H, Kanbara S. Cervical alignment and range of motion after laminoplasty: radiographical data from more than 500 cases with cervical spondylotic myelopathy and a review of the literature. *Spine*. (2012) 37(20):E1243–50. doi: 10.1097/BRS.0b013e3182659d3e

6. Sairyo K, Biyani A, Goel V, Leaman D, Booth RJ, Thomas J. Pathomechanism of ligamentum flavum hypertrophy: a multidisciplinary investigation based on clinical, biomechanical, histologic, and biologic assessments. *Spine*. (2005) 30 (23):2649–56. doi: 10.1097/01.brs.0000188117.77657.ee

7. Hansson T, Suzuki N, Hebelka H, Gaulitz A. The narrowing of the lumbar spinal canal during loaded MRI: the effects of the disc and ligamentum flavum. *Eur Spine J*. (2009) 18(5):679–86. doi: 10.1007/s00586-009-0919-7

8. Tamai K, Kaneda K, Iwamae M, Terai H, Katsuda H, Shimada N, et al. The short-term outcomes of minimally invasive decompression surgery in patients with lumbar ossification or calcification of the ligamentum flavum. *J Neurosurg Spine*. (2020) :1–8. doi: 10.3171/2020.6.SPINE20946

9. Hori Y, Suzuki A, Hayashi K, Ohyama S, Yabu A, Maruf MH, et al. Long-term, time-course evaluation of ligamentum Flavum hypertrophy induced by mechanical stress: an experimental animal study. *Spine*. (2021) 46(9):E520–7. doi: 10.1097/BRS.0000000000003832

10. Grob D, Frauenfelder H, Mannion AF. The association between cervical spine curvature and neck pain. *Eur Spine J*. (2007) 16(5):669–78. doi: 10.1007/s00586-006-0254-1

11. Sayit E, Daubs MD, Aghdasi B, Montgomery SR, Inoue H, Wang CJ, et al. Dynamic changes of the ligamentum flavum in the cervical spine assessed with kinetic magnetic resonance imaging. *Global Spine*. (2013) 3(2):69–74. doi: 10.1055/s-0033-1337121

12. Hirabayashi K, Toyama Y, Chiba K. Expansive laminoplasty for myelopathy in ossification of the longitudinal ligament. *Clin Orthop Relat Res*. (1999) 359:35–48. doi: 10.1097/00003086-199902000-00005

13. Liu G, Buchowski JM, Bunmaprasert T, Yeom JS, Shen H, Riew KD. Revision surgery following cervical laminoplasty: etiology and treatment strategies. *Spine*. (2009) 34(26):2760–8. doi: 10.1097/BRS.0b013e3181b11ee1

14. Li X, Yu H, Welle K, Gathen M, Zhang L, Xiao J, et al. Comparative effectiveness and safety of open-door laminoplasty, French-door laminoplasty, laminectomy and fusion, and laminectomy alone for multilevel degenerative cervical myelopathy: a Bayesian network analysis. *Adv The*. (2022) 39 (1):117–39. doi: 10.1007/s12325-021-01980-8

15. Miyamoto H, Maeno K, Uno K, Kakutani K, Nishida K, Sumi M. Outcomes of surgical intervention for cervical spondylotic myelopathy accompanying local kyphosis (comparison between laminoplasty alone and posterior reconstruction surgery using the screw-rod system). *Eur Spine J*. (2014) 23(2):341–6. doi: 10.1007/s00586-013-2923-1

16. Lee CH, Lee J, Kang JD, Hyun SJ, Kim KJ, Jahng TA, et al. Laminoplasty versus laminectomy and fusion for multilevel cervical myelopathy: a meta-analysis of clinical and radiological outcomes. *J Neurosurg Spine*. (2015) 22 (6):589–95. doi: 10.3171/2014.10.SPINE1498

17. Suk KS, Kim KT, Lee JH, Lee SH, Lim YJ, Kim JS. Sagittal alignment of the cervical spine after the laminoplasty. *Spine*. (2007) 32(23):E656–60. doi: 10.1097/BRS.0b013e318158c573

18. Li Z, Xue Y, He D, Tang Y, Ding H, Wang Y, et al. Extensive laminectomy for multilevel cervical stenosis with ligamentum flavum hypertrophy: more than 10 years follow-up. *Eur Spine J*. (2015) 24(8):1605–12. doi: 10.1007/s00586-014-3459-8

19. Yabe Y, Hagiwara Y, Ando A, Tsuchiya M, Minowa T, Takemura T, et al. Chondrogenic and fibrotic process in the ligamentum flavum of patients with lumbar spinal canal stenosis. *Spine*. (2015) 40(7):429–35. doi: 10.1097/BRS.0000000000000795

20. Moojen WA, Schenck CD, Lycklama À, Nijeholt GJ, Jacobs WCH, Van der Kallen BF, et al. Preoperative MRI in patients with intermittent neurogenic claudication: relevance for diagnosis and prognosis. *Spine*. (2018;1) 43 (5):348–55. doi: 10.1097/BRS.0000000000001301

21. Kotani Y, Takahata M, Abumi K, Ito M, Sudo H, Minami A. Cervical myelopathy resulting from combined ossification of the ligamentum flavum and posterior longitudinal ligament: report of two cases and literature review. *Spine J*. (2013) 13(1):e1–6. doi: 10.1016/j.spinee.2012.10.038

22. Zeng C, Xiong J, Wang JC, Inoue H, Tan Y, Tian H. The evaluation and observation of "hidden" hypertrophy of cervical ligamentum Flavum, cervical canal, and related factors using kinetic magnetic resonance imaging. . *Global Spine*. (2016) 6(2):155–63. doi: 10.1055/s-0035-1557140

23. Gu R, Zhu Q, Lin Y, Yang X, Gao Z, Tanaka Y. Dynamic canal encroachment of ligamentum flavum: an in vitro study of cadaveric specimens. *J Spinal Disord Tech*. (2006) 19(3):187–90. doi: 10.1097/01.bsd.0000190816.28682.83

frontiers | Frontiers in Surgery

TYPE Original Research
PUBLISHED 18 August 2022
DOI 10.3389/fsurg.2022.911514

OPEN ACCESS

EDITED BY
Luca Ricciardi,
Sapienza University of Rome, Italy

REVIEWED BY
Suyash Singh,
All India Institute of Medical Sciences, India
Javier Quillo-Olvera,
The Brain and Spine Care, Minimally Invasive Spine Surgery Group, Mexico

*CORRESPONDENCE
Chien-Chou Pan
adonisvgh@gmail.com

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

RECEIVED 02 April 2022
ACCEPTED 08 July 2022
PUBLISHED 18 August 2022

CITATION
Tseng S-C, Lin Y-H, Wu Y-C, Shih C-M, Chen K-H, Lee C-H and Pan C-C (2022) Indirect decompression *via* oblique lumbar interbody fusion is sufficient for treatment of lumbar foraminal stenosis. Front. Surg. 9:911514. doi: 10.3389/fsurg.2022.911514

Indirect decompression *via* oblique lumbar interbody fusion is sufficient for treatment of lumbar foraminal stenosis

Sheng-Chieh Tseng[1], Yu-Hsien Lin[1], Yun-Che Wu[1], Cheng-Min Shih[1,2], Kun-Hui Chen[1,3,4,5,6], Cheng-Hung Lee[1,6,7] and Chien-Chou Pan[1,8]*

[1]Department of Orthopedic Surgery, Taichung Veterans General Hospital, Taichung, Taiwan, [2]Department of Physical Therapy, HungKuang University, Taichung, Taiwan, [3]Department of Nursing, Jenteh Junior College of Medicine, Nursing and Management, Miaoli, Taiwan, [4]Department of Computer Science and Information Engineering, College of Computing and Informatics, Providence University, Taichung, Taiwan, [5]Department of Biomedical Engineering, College of Intelligent Technology, HungKuang University, Taichung, Taiwan, [6]College of Medicine, National Chung Hsing University, Taichung, Taiwan, [7]Department of Food Science and Technology, Hungkuang University, Taichung, Taiwan, [8]Department of Rehabilitation Science, Jenteh Junior College of Medicine, Nursing and Management, Miaoli, Taiwan

Oblique lumbar interbody fusion (OLIF) is a popular technique for the treatment of degenerative lumbar spinal disease. There are no clear guidelines on whether direct posterior decompression (PD) is necessary after OLIF. The purpose of this study was to analyze the effect of the indirect decompression obtained from OLIF in patients with lumbar foraminal stenosis. We retrospectively reviewed 33 patients who underwent OLIF surgery for degenerative lumbar spinal disease between 1 January 2018, and 30 June 2019. The inclusion criteria included patients who were diagnosed with lumbar foraminal stenosis by preoperative MRI. The exclusion criteria included the presence of central canal stenosis, spinal infection, vertebral fractures, and spinal malignancies. The clinical results, evaluated using the visual analogue scale of back pain (VAS-Back), VAS of leg pain (VAS-Leg), and Oswestry disability index (ODI), were recorded. The radiologic parameters were also measured. The VAS-Back, VAS-Leg, and ODI showed significant improvement in both the PD and non-posterior decompression (Non-PD) groups postoperatively (all, $p < 0.05$). Patients in the Non-PD group showed better results than those in the PD group in the VAS-Back at 12- and 24 months postoperatively (0.00 vs. 3.00 postoperatively at 12 months, $p = 0.030$; 0.00 vs. 4.00 postoperatively at 24 months, $p = 0.009$). In addition, the ODI at 24 months postoperatively showed better improvement in the Non-PD group (8.89 vs. 24.44, $p = 0.038$). The disc height in both the PD and the Non-PD groups increased significantly postoperatively (all, $p < 0.05$), but the restoration of foraminal height was significantly different only in the Non-PD group. There was no statistically significant difference in cage

Abbreviations: ADH, anterior disc height; DH, average disc height; DLIF, direct lateral interbody fusion; FH, foraminal height; FS, foraminal stenosis; LL, lumbar lordosis; LLIF, lateral lumbar interbody fusion; Non-PD, non-posterior decompression; ODI, Oswestry disability index; OLIF, oblique lumbar interbody fusion; PD, Posterior decompression; PDH, posterior disc height; PLIF, posterior lumbar interbody fusion; SL, segmental lordosis; TLIF, transforaminal lumbar interbody fusion; VAS-Back, visual analogue scale of back pain; VAS-Leg, visual analogue scale of leg pain; XLIF, extreme lateral interbody fusion

position, cage subsidence, fusion grade, or screw loosening between the PD and the Non-PD groups. Indirect decompression *via* OLIF for lumbar foraminal stenosis showed favorable outcomes. The use of interbody cages and posterior instrumentation was sufficient for relieving symptoms in patients with lumbar foraminal stenosis. Additional direct posterior decompression may deteriorate results in the follow-up period.

KEYWORDS

oblique lumbar interbody fusion, lumbar foraminal stenosis, indirect decompression, direct decompression, laminotomy, laminectomy

Introduction

Spinal fusion is a popular surgical treatment for degenerative lumbar spinal disease such as spinal stenosis, spondylolisthesis, or disc herniation (1). There are various lumbar spinal fusion techniques, including anterior lumbar interbody fusion, posterior lumbar interbody fusion (PLIF), and transforaminal lumbar interbody fusion (TLIF). The retroperitoneal approach, which was first introduced by Mayer in 1997, is a minimally invasive technique for decreasing surgery-related comorbidities (2). Several modifications of this technique were developed in subsequent years. Silvestre et al. used a similar approach, which is referred to as oblique lumbar interbody fusion (OLIF), and presented the first results about complications and morbidities (3). OLIF has the advantages of less blood loss, shorter hospital stays, and faster recovery when compared with conventional posterior approaches (4). Previous studies have confirmed its achievement of indirect neural decompression through the restoration of disc height and extension of the thecal sac (5). Shimizu et al. demonstrated that OLIF had good short-term clinical outcomes, comparable to those obtained with TLIF and PLIF, for severe degenerative lumbar stenosis (6). Some authors have stated that indirect decompression could achieve adequate neural decompression through direct lateral interbody fusion (DLIF), lateral lumbar interbody fusion (LLIF), or extreme lateral interbody fusion (XLIF) (7–9). The fundamental concept of these lateral interbody fusion techniques is the "indirect decompression" effect through the restoration of intervertebral disc height and foraminal height (FH). Shimizu et al. confirmed that lateral interbody fusion without posterior decompression (PD) achieved expansion of the thecal sac and restoration of disc height in severe canal stenosis (7). However, most of these studies have focused on DLIF, LLIF, and XLIF and it remains unclear whether indirect decompression alone is sufficient to relieve low back pain or radicular pain in patients receiving OLIF. Furthermore, 0%–60% of patients who received these indirect decompression procedures underwent additional posterior laminectomy (10, 11). The posterior decompression procedures have the advantage of the direct decompression of the nerve root. However, they may cause iatrogenic injuries to the paravertebral muscles and disruption of the posterior tension mechanism (12). There are no clear guidelines on whether direct posterior decompression is necessary after OLIF.

Therefore, the aim of this study was to analyze the effect of the indirect decompression obtained from OLIF in patients with lumbar foraminal stenosis (FS), in terms of clinical and radiologic outcomes. We also investigated whether additional direct posterior decompression affected the outcomes in these patients.

Methods

We retrospectively reviewed 33 patients who underwent OLIF surgery for degenerative lumbar spinal disease between 1 January 2018 and 30 June 2019. The inclusion criteria included patients who were diagnosed with lumbar FS by preoperative MRI. The radiologic criteria of lumbar spinal stenosis were summarized in a systematic review article (13). FS is diagnosed by nerve root compression in the foraminal zone with obliteration of the perineural intraforaminal fat (14). The exclusion criteria included the presence of central canal stenosis, spinal infection, vertebral fractures, and spinal malignancies. These patients were divided into posterior decompression (PD) or non-posterior decompression (Non-PD) groups according to whether direct posterior decompression was performed. The minimum follow-up period was at least 24 months. All the surgeries were performed by experienced spine surgeons at our institute.

We performed the OLIF procedure as described by Woods et al. (15). The Clydesdale cage (Medtronic, TN, USA) was used, and a morselized bone allograft or synthetic bone graft substitute (Actifuse, Baxter, IL, USA) was packed into the cage to enable fusion. After the performance of the OLIF procedures, posterior instrumentation with pedicle screws was used in all cases. Importantly, the surgeons informed patients of the pros and cons of additional posterior decompression procedure before the operation. Proper suggestions were provided by the surgeons, and the patients made the final

decision on whether the posterior decompression procedure was performed. If direct posterior decompression was planned, the surgeons decided the exact procedure, including laminectomy, laminotomy, or discectomy according to their experience and preference. All the posterior decompression procedures were performed before the insertion of pedicle screws. Adequate decompression of the dural sac and nerve roots at lateral recess and neuroforamen was checked meticulously, and hemostasis was performed (**Figure 1**).

The clinical outcomes were evaluated using the visual analogue scale of back pain (VAS-Back), VAS of leg pain (VAS-Leg), and Oswestry disability index (ODI), which were recorded preoperatively and at the postoperative 1-, 3-, 6-, 12-,and 24-month follow-ups. The minimum clinically important difference (MCID) for the patient-reported outcome measures in this study was defined as a 30% reduction from baseline of pain and disabilities (16). The radiologic parameters, including the index level of the anterior disc height (ADH), posterior disc height (PDH), average disc height (DH), FH, lumbar lordosis (LL), and segmental lordosis (SL), were measured preoperatively, postoperatively, and at the last follow-up in the outpatient clinic (**Figure 2**). Additionally, we analyzed the cage position and cage-related parameters at the last follow-up time. The normalized mean cage center position was defined as the value of the distance between the cage center to the posterior vertebral border divided by the width of inferior end plate on the lateral view of the x-ray (17). The grading of cage subsidence was determined according to Marchi et al. (18): Grade 0, 0%–24%; Grade I, 25%–49%; Grade II, 50%–74%; and Grade III, 75%–100% collapse of the vertebral end plate. The fusion grade was classified according to Ailon et al. (19): Grade I, definite union; Grade II, probable union; Grade III, probable non-union; Grade IV, definite non-union. Finally, the perioperative parameters and postoperative complications were recorded by chart review.

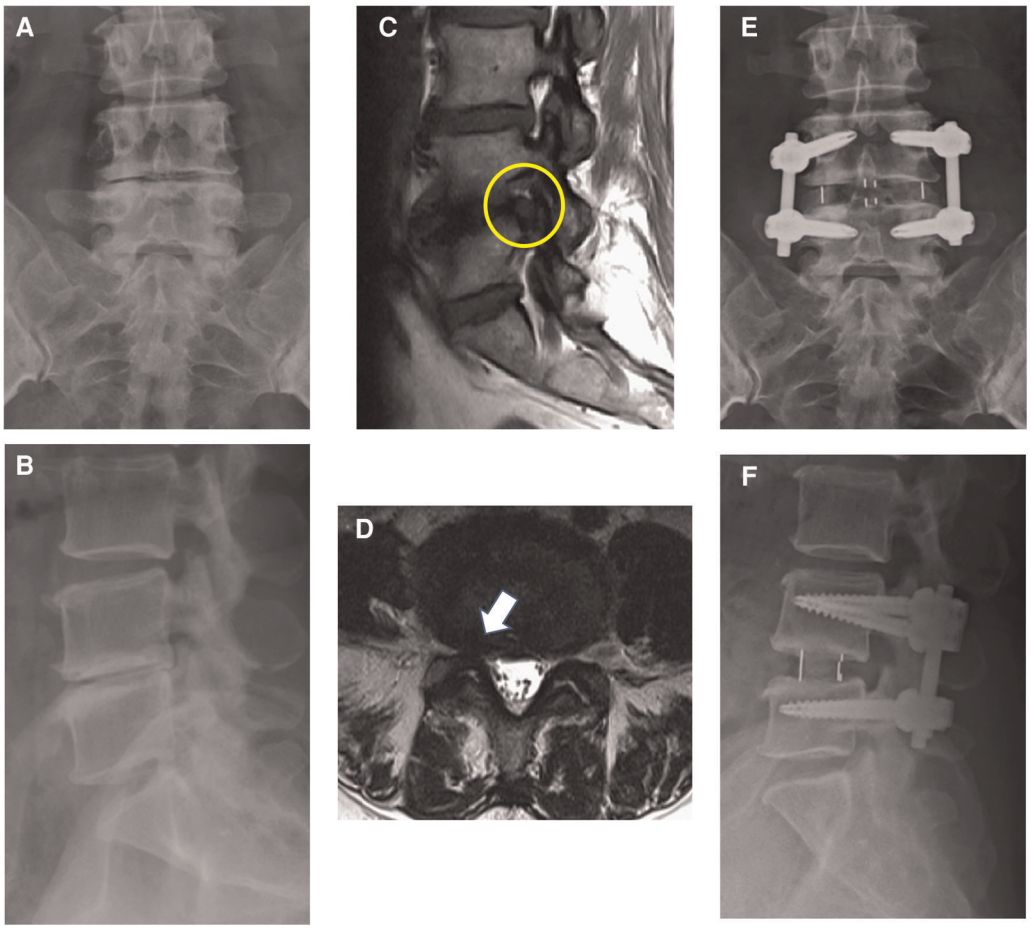


FIGURE 1
Anterior–posterior view (A) and lateral view (B) of a 67-year-old woman with degenerative disc disease. Sagittal T1-weighted MRI (C) and axial T2-weighted MRI (D) showed foraminal stenosis of L4/L5 (yellow circle and white arrow). Postoperative anterior–posterior view (E) and lateral view (F) of this patient. OLIF, L4/L5, with posterior instrumentation was done.

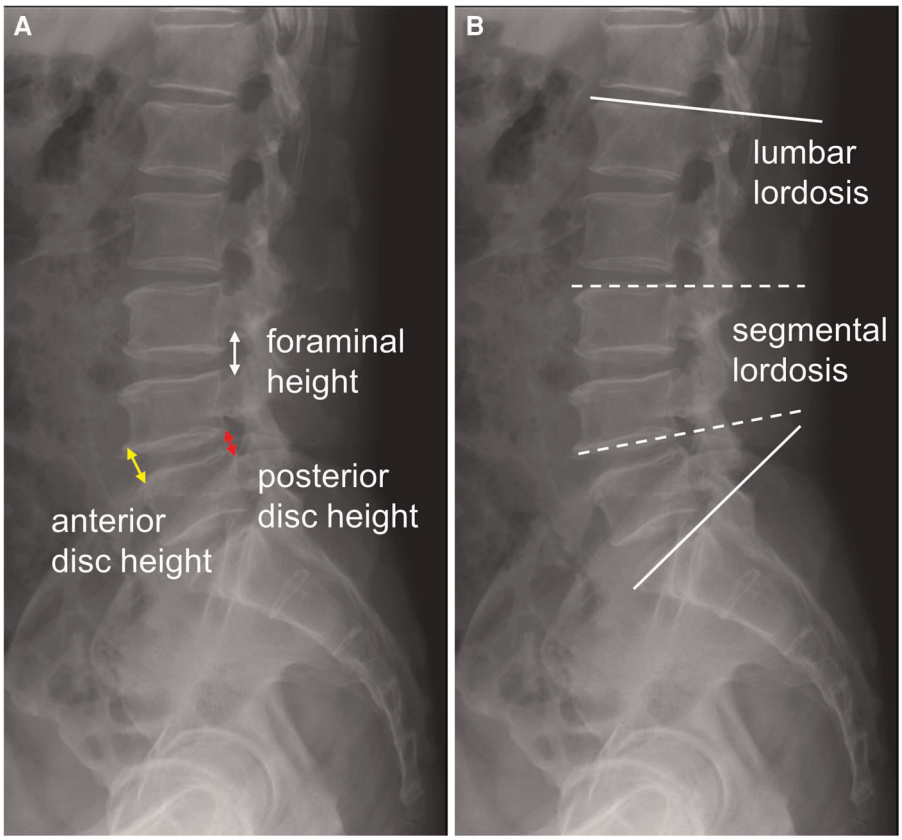


FIGURE 2
The radiologic parameters (A) anterior disc height (ADH, yellow arrow): the distance of the anterior disc space; posterior disc height (PDH, red arrow): the distance of the posterior disc space; average disc height (DH): (ADH + PDH)/2; foraminal height (FH, white arrow): the distance between the pedicles of upper and lower levels; (B) lumbar lordosis (LL, solid line): the angle of L1 to S1 upper endplate; segmental lordosis (SL, dotted line): the angle of the upper endplate of the upper vertebra and the lower endplate of the lower vertebra of the index level.

Statistical analyses

Statistical analyses were performed using the Statistical Package for the Social Sciences (IBM SPSS version 22.0; International Business Machines Corp., New York, USA). The Friedman test was used for comparison of the postoperative values of each clinical and radiologic outcome with the preoperative values. The Bonferroni test was used for the *post hoc* analysis. The chi-square test was used to compare the qualitative variables between the groups, and the Mann–Whitney *U* test to compare the quantitative variables between the groups. A p-value < 0.05 was statistically significant.

Results

A total of 33 patients were included in this study, with 16 patients in the Non-PD group and 17 patients in the PD

TABLE 1 The patient demographics.

	Non-PD ($n = 16$)	PD ($n = 17$)	p-Value
Age (years), median (Q1–Q3)	64.0 (53.5–70.5)	64.0 (56.5–72.0)	0.857
Gender, *n* (%)			0.225
Female	14 (87.5)	11 (64.7)	
Male	2 (12.5)	6 (35.3)	
BMI (kg/m^2), median (Q1–Q3)	24.8 (22.9–26.6)	23.9 (22.7–26.8)	0.471
Level, *n* (%)			0.460
Single level	10 (62.5)	12 (70.6)	
Two levels	6 (37.5)	4 (23.5)	
Three levels	0 (0.0)	1 (5.9)	
Follow-up time, months, median (Q1–Q3)	33.0 (26.7–35.2)	34.8 (29.5–37.2)	0.428

Non-PD, non-posterior decompression; PD, posterior decompression; BMI, body mass index. The chi-square test was used to compare the qualitative variables between the groups. The Mann–Whitney U test was used to compare the quantitative variables between the groups.

group. There were no significant differences between the two groups in terms of age, sex, BMI, operative levels, and follow-up time. The patient demographics are given in Table 1.

TABLE 2 Comparison of the clinical outcomes between the Non-PD and PD groups.

	Non-PD ($n = 16$) median (Q1–Q3)	PD ($n = 17$) median (Q1–Q3)	p-Value
VAS-Back			
Preop	7.50 (6.25–8.00)	8.00 (7.00–8.00)	0.384
Postop-1M	3.50 (2.25–5.00)	4.00 (2.25–5.75)	0.593
Postop-3M	2.50 (2.00–5.00)	3.00 (2.00–4.75)*	0.703
Postop-6M	1.00 (0.00–3.00)*	3.00 (2.00–4.75)*	0.105
Postop-12M	0.00 (0.00–2.00)*	3.00 (1.25–4.75)*	0.030†
Postop-24M	0.00 (0.00–2.25)*	4.00 (2.00–6.00)*	0.009†
VAS-Leg			
Preop	6.50 (1.25–8.00)	8.00 (6.00–8.50)	0.282
Postop-1M	0.00 (0.00–0.00)*	0.00 (0.00–3.75)*	0.096
Postop-3M	0.00 (0.00–0.00)*	0.00 (0.00–2.75)*	0.583
Postop-6M	0.00 (0.00–0.00)*	0.00 (0.00–1.50)*	0.796
Postop-12M	0.00 (0.00–0.00)*	0.00 (0.00–0.00)*	0.728
Postop-24M	0.00 (0.00–0.00)*	0.00 (0.00–0.00)*	0.141
ODI			
Preop	55.56 (42.22–63.89)	55.56 (44.44–65.56)	0.538
Postop-1M	43.33 (38.89–56.67)	46.67 (44.44–55.56)	0.238
Postop-3M	32.23 (22.22–37.78)	42.22 (32.22–48.34)*	0.123
Postop-6M	22.23 (11.11–28.89)*	37.78 (22.22–48.34)*	0.094
Postop-12M	11.11 (6.67–20.00)*	32.23 (11.67–48.34)*	0.162
Postop-24M	8.89 (8.34–16.11)*	24.44 (8.89–46.67)*	0.038†

Non-PD, non-posterior decompression; PD, posterior decompression; VAS, visual analogue scale; ODI, Oswestry disability index; Preop, preoperative; Postop, postoperative; M, month. Intragroup difference compared with Preop: the Friedman test, the Bonferroni test (the post-hoc analysis). Intergroup difference: the Mann–Whitney U test.
*$p < 0.05$.
†$p < 0.05$.

The VAS-Back, VAS-Leg, and ODI showed significant improvement in both the PD and Non-PD groups postoperatively (all, $p < 0.05$) (Table 2). All the pain scales achieved MCID (a reduction of 2.4 points for the VAS of the back and leg) postoperatively at the 1-month follow-up. The disability scores achieved MCID (a reduction of 16.67 points for ODI) at 3 months postoperatively in the Non-PD group and at 6 months postoperatively in the PD group.

Patients in the Non-PD group showed better results than those in the PD group in the VAS-Back at 12 months and 24 months postoperatively (0.00 vs. 3.00 postoperatively at 12 months, $p = 0.030$; 0.00 vs. 4.00 postoperatively at 24 months, $p = 0.009$) (Figure 3). In addition, the ODI at 24 months postoperatively showed better improvement in the Non-PD group (8.89 vs. 24.44, $p = 0.038$).

The ADH, PDH, and DH in both the PD and Non-PD groups increased significantly postoperatively (all, $p < 0.05$) (Table 3). The results were obtained at the last follow-up. The restoration of FH was significantly different only in the Non-PD group. However, the LL and SL had no significant increase after OLIF in both groups.

A comparison of the PD and Non-PD groups showed that the latter had a better improvement ratio in terms of ADH, PDH, and DH than the former. There was no significant difference in FH, LL, and SL between the two groups.

There was no statistically significant difference in cage position, cage subsidence, fusion grade, or screw loosening between the PD and the Non-PD groups (Table 4). High-grade cage subsidence (Grades II and III) occurred in 18.2% patients of the Non-PD group and 13% patients of the PD group. Importantly, all the patients achieved adequate spinal fusion on image presentation at the last follow-up time.

The estimated blood loss was similar in both groups (Table 5). Regarding postoperative minor complications, only one patient in each group experienced postoperative ileus. Numbness of the thigh occurred in three patients (18.8%) in

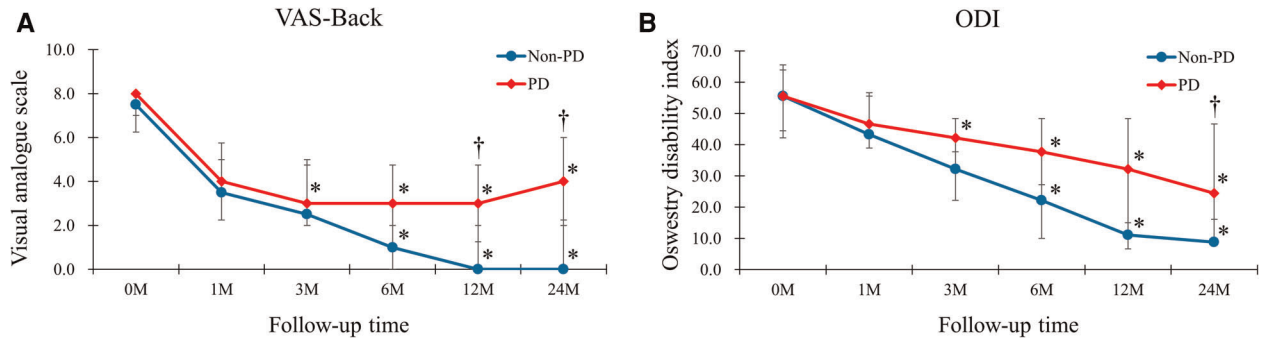


FIGURE 3
The VAS-Back and ODI of the Non-PD and PD groups. (A) Patients in the Non-PD group had better results than those of PD group in the VAS-Back at 12-months and 24-months postoperatively (0.00 vs. 3.00 postoperatively at 12-months, $p = 0.030$; 0.00 vs. 4.00 postoperatively at 24-months, $p = 0.009$). (B) The ODI at 24-months postoperatively showed better improvement in the Non-PD group (8.89 vs. 24.44, $p = 0.038$).

TABLE 3 Comparison of the radiologic outcomes between the Non-PD and the PD groups.

	Non-PD ($n = 22$) median (Q1, Q3)	PD ($n = 23$) median (Q1, Q3)	p-Value
ADH (mm)			
Preop	6.80 (5.10, 10.45)	10.45 (7.45, 12.30)	
Postop −Preop	4.10 (2.20, 5.60)*	3.35 (2.10, 4.70)*	0.318
Last−Preop	5.45 (3.15, 7.80)*	3.30 (0.15, 5.15)*	0.019†
PDH (mm)			
Preop	5.40 (4.50, 5.70)	6.80 (5.40, 7.70)	
Postop −Preop	3.70 (2.90, 3.90)*	1.95 (0.95, 3.20)*	0.008†
Last−Preop	3.40 (3.00, 5.55)*	1.80 (0.80, 3.10)*	0.001†
DH (mm)			
Preop	6.00 (5.10, 7.85)	9.08 (7.00, 10.00)	
Postop −Preop	3.70 (2.95, 5.00)*	2.85 (1.75, 4.05)*	0.048†
Last−Preop	4.60 (3.20, 5.70)*	2.60 (0.60, 3.93)*	0.002†
FH (mm)			
Preop	16.70 (13.10, 18.80)	19.20 (16.45, 21.65)	
Postop −Preop	2.90 (−2.10, 6.40)*	1.60 (−0.10, 2.75)	0.453
Last−Preop	1.00 (−1.20, 3.60)	0.30 (−1.75, 3.10)	0.317
LL (degree)			
Preop	35.95 (27.98, 42.98)	31.65 (23.63, 48.45)	
Postop −Preop	3.45 (−3.28, 8.25)	1.50 (−7.25, 9.70)	0.801
Last−Preop	3.40 (−3.23, 12.43)	2.20 (−5.28, 13.43)	0.943
SL (degree)			
Preop	11.20 (4.86, 8.30)	12.60 (7.18, 22.85)	
Postop −Preop	2.25 (−0.85, 4.26)	2.20 (−0.50, 5.58)	0.885
Last−Preop	0.80 (−3.39, 5.73)	2.30 (−2.23, 4.98)	0.857

Non-PD, non-posterior decompression; PD, posterior decompression; ADH, anterior disc height; PDH, posterior disc height; DH, average disc height; FH, foraminal height; LL, lumbar lordosis; SL, segmental lordosis; Preop, preoperative; Postop, postoperative; Last, last follow-up. Intragroup difference: the Friedman test, the Bonferroni test (the post-hoc analysis). Intergroup difference: the Mann–Whitney U test.
*$p < 0.05$.
†$p < 0.05$.

TABLE 4 Cage position and cage-related parameters.

	Non-PD ($n = 22$)	PD ($n = 23$)	p-Value
Normalized mean cage center position, median (Q1–Q3)	0.58 (0.51–0.65)	0.57 (0.55–0.62)	0.982
Cage subsidence, n (%)			0.446
Grade 0	8 (36.4)	12 (52.2)	
Grade I	10 (45.5)	8 (34.8)	
Grade II	4 (18.2)	2 (8.7)	
Grade III	0 (0)	1 (4.3)	
Fusion grade, n (%)			1.000
Grade I	18 (81.8)	19 (82.6)	
Grade II	4 (18.2)	4 (17.4)	
Grade III	0 (0)	0 (0)	
Grade IV	0 (0)	0 (0)	
Screw loosening, n (%)	4 (18.2)	3 (13.0)	0.688

Non-PD, non-posterior decompression; PD, posterior decompression. The chi-square test was used to compare the qualitative variables between the groups. The Mann–Whitney U test was used to compare the quantitative variables between the groups.

TABLE 5 Perioperative parameters and postoperative complications.

	Non-PD ($n = 16$)	PD ($n = 17$)	p-Value
Estimated blood loss (ml), median (Q1–Q3)	300 (212.50–475.00)	320 (225.00–475.00)	0.800
Complications, n (%)			
Postoperative ileus	1 (6.3)	1 (5.9)	1.000
Numbness of thigh	3 (18.8)	2 (11.8)	0.656
Delirium	1 (6.3)	0 (0)	0.485
Dural tear	0 (0)	1 (5.9)	1.000
Superficial wound infection	0 (0)	1 (5.9)	1.000

Non-PD, non-posterior decompression; PD, posterior decompression. The chi-square test was used to compare the qualitative variables between the groups. The Mann–Whitney U test was used to compare the quantitative variables between the groups.

the Non-PD group and two patients (11.8%) in the PD group. Besides, in the PD group, one patient had dural tear and another one had superficial wound infection. No major complication or reoperation was recorded in either group.

Discussion

Lumbar interbody fusion techniques such as TLIF and PLIF have become well-developed methods for treating degenerative lumbar spinal disease (1). These posterior approaches could decompress the neural elements directly and provide initial stability through the use of interbody cages and pedicle screws. Nevertheless, the posterior structures would be damaged simultaneously (12). OLIF is a lateral-approach technique using the corridor between the psoas muscle and the aorta. It avoids violations of the psoas and lumbosacral plexus injuries and has a high fusion rate (15). It has been shown to significantly improve clinical outcomes, and its fusion rate was 97.9% at 6 months (15). Our data showed a comparatively high fusion rate, with all patients having achieved successful fusion at the 2-year follow-up period. Another study showed that stand-alone minimally invasive lateral interbody fusion could relieve neurologic symptoms and improve the quality of life in selected patient populations

(20). Furthermore, the rate of high-grade cage subsidence was 9% and not related directly to the clinical outcomes (20). According to our results, 15% of patients exhibited high-grade cage subsidence. The phenomenon of subsidence was multifactorial, including bone mineral density, disc height, and cage position (21). There was no difference in the ratio of cage subsidence between the Non-PD and the PD groups. Additional posterior decompression procedure may not affect the probability of cage subsidence. Also, the cage was inserted a little anterior to the center of the lower end plate in both groups without intergroup difference in cage position. Yao et al. considered that anterior placement of the TLIF cage may reduce the risk of cage subsidence (21). A systematic review reported that the cage position had no influence on the indirect decompression effect in XLIF (22). More evidence is needed to confirm the relationship between cage position and indirect decompression effect.

Recently, some studies demonstrated that the "indirect decompression" effect *via* OLIF showed good short-term clinical and radiologic outcomes (5, 23). Kim et al. found that OLIF increased the DH and sagittal angle significantly at the 1-year follow-up. However, the FH did not change (24). Shimizu et al. demonstrated similar clinical outcomes between OLIF and conventional TLIF/PLIF in the treatment of severe spinal stenosis, while OLIF was shown to have better radiographic outcomes (6). For adjacent segment disease after posterior lumbar fusion, OLIF has better short-term clinical outcomes and DH restoration than PLIF (4).

In our study, the neurologic symptoms caused by foraminal stenosis were much improved after OLIF. This means the radicular pain caused by nerve root compression at neuroforamen was efficiently relieved by means of the "indirect decompression" effect obtained from OLIF. In addition, the Non-PD patients showed better clinical results than those in the PD group in the VAS score for back pain at 12- and 24 months postoperatively and ODI at 24 months postoperatively. Theoretically, direct posterior decompression such as laminectomy or laminotomy could decompress the neural elements directly. The osteophytes and redundant ligamentum flavum can be removed meticulously, and the nerve root can be released. However, some authors have found that a posterior decompression procedure may cause iatrogenic injuries to the paraspinal musculature and disruptions of the posterior bony structure (12, 25). These additional procedures may contribute to paraspinal muscle atrophy and compromise the result of the index procedure (26). Besides, the integrity of the posterior complex between the fused segments and the adjacent segments could be damaged in laminectomy or laminotomy after lumbar spinal fusion (27). The development of adjacent instability would deteriorate the outcomes of spinal fusion and may lead to adjacent segment disease in the future. This is the reason why the patients in the PD group still had back pain in the 24-month follow-up period. In our opinion, the efficacy of indirect decompression is sufficient for lumbar FS. Additional direct posterior decompression is not necessary in these cases.

On the other hand, OLIF restored the ADH, PDH, and DH effectively by the implantation of a larger interbody cage *via* the lateral approach. This result is compatible with previous studies. Sato et al. confirmed that OLIF can significantly improve the DH and spinal canal area (28). The clinical symptoms were relieved by reducing the bulging disc and stretching the redundant ligamentum flavum. Furthermore, the improvement ratio of these parameters is greater in the Non-PD group than in the PD group. The reason may be that the collapse of intervertebral discs was more severe in the Non-PD group preoperatively. More potential restoration of DH is expected. Surprisingly, the FH was increased only in the Non-PD group postoperatively. Chang et al. stated that OLIF showed favorable outcomes in the restoration of FH and that the improvement ratio of the FH was correlated with radicular pain and disability (29). This may explain why patients in the Non-PD group had better clinical outcomes than those in the PD group.

There is no significant improvement in LL and SL after OLIF in this study. Previous literature stated that LLIF had great capacity for coronal deformity correction, but the ability to achieve sagittal plane correction is limited (30). Recently, some studies showed marked sagittal deformity correction in OLIF (31, 32). More studies are needed to discuss the change in sagittal parameters in OLIF.

There are some debates on the indirect decompression effect of the lateral interbody fusion technique. Wang et al. described evidence that bony lateral recess stenosis is an independent risk factor for the failure of the indirect decompression in XLIF (33). Oliveira et al. concluded that congenital stenosis or locked facets may limit the efficacy of indirect decompression in XLIF (10). XLIF is relatively contraindicated for severe central spinal stenosis due to a risk of the need for secondary operation. In addition, a previous study suggested open laminectomy in the presence of fused facet joints or large herniated discs (34). However, some studies had the opposite opinion about these points. Malham et al. and Park et al. reported that facet degeneration does not impair the amount of direct decompression in XLIF (25, 35). Another study announced that locked facets are not a relative contraindication for XLIF (36). A recent systematic review found that only severe central canal stenosis in preoperative images is likely to cause failure of indirect decompression in XLIF (22). In contrast to the experience in XLIF, most articles about OLIF excluded these factors (6, 7, 29). According to our reports, the indirect decompression effect *via* OLIF is sufficient for lumbar FS. If the patients' symptoms were mainly caused by neural compression at neuroforamen, OLIF without direct posterior decompression is a reasonable treatment. Additional direct decompression may be not beneficial in these cases,

irrespective of whether facet degeneration is present. However, if the patients are diagnosed with severe central canal stenosis, obvious osteophyte compromising lateral recess, or large disc herniation, direct posterior decompression is considered.

OLIF is a relatively safe procedure with few postoperative minor complications. Postoperative ileus occurred in two patients due to a manipulation of the retroperitoneum. The symptoms improved during hospitalization. About 15% of patients experienced numbness of the anterior thigh after operation with intact motor function. The sensory deficit may be caused by a retraction of the genitofemoral nerve (24), and it was relieved spontaneously within three months of follow-up at the outpatient clinic. Dural tear happened in one patient when laminectomy was performed. The tear site was repaired by tissue glue and CSF leakage was checked meticulously. The patient had no associated complication afterward.

This study had some limitations. First, this was a retrospective study. The plan for additional direct posterior decompression depended on the patients' decision and the surgeons' preference. This may have led to a patient selection bias. Second, this was a mid-term follow-up study, with a median follow-up time of 31.69 months. Third, this was a single-center study, and thus, its generalizability may be inadequate. Fourth, the number of patients was limited, and a larger sample size is necessary in further studies.

The use of OLIF for lumbar FS showed favorable clinical and radiologic outcomes during the 2-year follow-up period. Moreover, the use of interbody cages and posterior instrumentation without direct decompression was sufficient for the relief of symptoms in patients with lumbar FS. Additionally, direct posterior decompression may not be necessary in these patients.

Data availability statement

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

Ethics statement

The studies involving human participants were reviewed and approved by The Ethics Committee of Taichung Veterans General Hospital (protocol code: CE21055A). Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

S-CT, C-CP, and Y-HL contributed to the conception and design of the study. Y-CW and C-MS organized the database. S-CT wrote the first draft of the manuscript. K-HC, C-HL, C-CP, and S-CT wrote sections of the manuscript. All authors contributed to the article and approved the submitted version.

Funding

This research received no external funding.

Acknowledgments

The authors thank the Biostatistics Task Force of Taichung Veterans General Hospital and Mr. Chen Jun-Peng for statistical analysis.

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. de Kunder SL, Rijkers K, Caelers I, de Bie RA, Koehler PJ, van Santbrink H. Lumbar interbody fusion: a historical overview and a future perspective. *Spine*. (2018) 43(16):1161–8. doi: 10.1097/BRS.0000000000002534

2. Mayer HM. A new microsurgical technique for minimally invasive anterior lumbar interbody fusion. *Spine*. (1997) 22(6):691–9; discussion 700. doi: 10.1097/00007632-199703150-00023

3. Silvestre C, Mac-Thiong JM, Hilmi R, Roussouly P. Complications and morbidities of mini-open anterior retroperitoneal lumbar interbody fusion: oblique lumbar interbody fusion in 179 patients. *Asian Spine J*. (2012) 6 (2):89–97. doi: 10.4184/asj.2012.6.2.89

4. Zhu G, Hao Y, Yu L, Cai Y, Yang X. Comparing stand-alone oblique lumbar interbody fusion with posterior lumbar interbody fusion for revision of rostral adjacent segment disease: a strobe-compliant study. *Medicine (Baltimore)*. (2018) 97(40):e12680. doi: 10.1097/MD.0000000000012680

5. Fujibayashi S, Hynes RA, Otsuki B, Kimura H, Takemoto M, Matsuda S. Effect of indirect neural decompression through oblique lateral interbody fusion for degenerative lumbar disease. *Spine*. (2015) 40(3):E175–82. doi: 10.1097/BRS.0000000000000703

6. Shimizu T, Fujibayashi S, Otsuki B, Murata K, Matsuda S. Indirect decompression via oblique lateral interbody fusion for severe degenerative lumbar spinal stenosis: a comparative study with direct decompression transforaminal/posterior lumbar interbody fusion. *Spine J*. (2021) 21(6):963–71. doi: 10.1016/j.spinee.2021.01.025

7. Shimizu T, Fujibayashi S, Otsuki B, Murata K, Matsuda S. Indirect decompression with lateral interbody fusion for severe degenerative lumbar spinal stenosis: minimum 1-year MRI follow-up. *J Neurosurg Spine*. (2020) 33(1): 27–34. doi: 10.3171/2020.1.SPINE191412

8. Scherman DB, Rao PJ, Phan K, Mungovan SF, Faulder K, Dandie G. Outcomes of direct lateral interbody fusion (DLIF) in an Australian cohort. *J Spine Surg*. (2019) 5(1):1–12. doi: 10.21037/jss.2019.01.08

9. Formica M, Quarto E, Zanirato A, Mosconi L, Vallerga D, Zotta I, et al. Lateral lumbar interbody fusion: what is the evidence of indirect neural decompression? A systematic review of the literature. *Hss J*. (2020) 16 (2):143–54. doi: 10.1007/s11420-019-09734-7

10. Oliveira L, Marchi L, Coutinho E, Pimenta L. A radiographic assessment of the ability of the extreme lateral interbody fusion procedure to indirectly decompress the neural elements. *Spine*. (2010) 35(26 Suppl):S331–7. doi: 10.1097/BRS.0b013e3182022db0

11. Wang MY, Vasudevan R, Mindea SA. Minimally invasive lateral interbody fusion for the treatment of rostral adjacent-segment lumbar degenerative stenosis without supplemental pedicle screw fixation. *J Neurosurg Spine*. (2014) 21 (6):861–6. doi: 10.3171/2014.8.Spine13841

12. Mobbs RJ, Phan K, Malham G, Seex K, Rao PJ. Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. *J Spine Surg*. (2015) 1 (1):2–18. doi: 10.3978/j.issn.2414-469X.2015.10.05

13. Andreisek G, Imhof M, Wertli M, Winklhofer S, Pfirrmann CW, Hodler J, et al. A systematic review of semiquantitative and qualitative radiologic criteria for the diagnosis of lumbar spinal stenosis. *AJR Am J Roentgenol*. (2013) 201(5): W735–46. doi: 10.2214/AJR.12.10163

14. Lee S, Lee JW, Yeom JS, Kim KJ, Kim HJ, Chung SK, et al. A practical MRI grading system for lumbar foraminal stenosis. *AJR Am J Roentgenol*. (2010) 194 (4):1095–8. doi: 10.2214/AJR.09.2772

15. Woods KR, Billys JB, Hynes RA. Technical description of oblique lateral interbody fusion at L1–L5 (OLIF25) and at L5–S1 (OLIF51) and evaluation of complication and fusion rates. *Spine J*. (2017) 17(4):545–53. doi: 10.1016/j.spinee.2016.10.026

16. Asher AM, Oleisky ER, Pennings JS, Khan I, Sivaganesan A, Devin CJ, et al. Measuring clinically relevant improvement after lumbar spine surgery: is it time for something new? *Spine J*. (2020) 20(6):847–56. doi: 10.1016/j.spinee.2020.01.010

17. Siu TL, Najafi E, Lin K. A radiographic analysis of cage positioning in lateral transpsoas lumbar interbody fusion. *J Orthop*. (2017) 14(1):142–6. doi: 10.1016/j.jor.2016.10.028

18. Marchi L, Abdala N, Oliveira L, Amaral R, Coutinho E, Pimenta L. Radiographic and clinical evaluation of cage subsidence after stand-alone lateral interbody fusion. *J Neurosurg Spine*. (2013) 19(1):110–8. doi: 10.3171/2013.4.Spine12319

19. Ailon T, Hamilton DK, Klineberg E, Daniels AH, Lafage V, Bess S, et al. Radiographic fusion grade does not impact health-related quality of life in the absence of instrumentation failure for patients undergoing posterior instrumented fusion for adult spinal deformity. *World Neurosurg*. (2018) 117: e1–7. doi: 10.1016/j.wneu.2018.04.127

20. Ahmadian A, Bach K, Bolinger B, Malham GM, Okonkwo DO, Kanter AS, et al. Stand-alone minimally invasive lateral lumbar interbody fusion: multicenter clinical outcomes. *J Clin Neurosci*. (2015) 22(4):740–6. doi: 10.1016/j.jocn.2014.08.036

21. Yao YC, Chou PH, Lin HH, Wang ST, Liu CL, Chang MC. Risk factors of cage subsidence in patients received minimally invasive transforaminal lumbar interbody fusion. *Spine*. (2020) 45(19):E1279–e85. doi: 10.1097/brs.0000000000003557

22. Lang G, Perrech M, Navarro-Ramirez R, Hussain I, Pennicooke B, Maryam F, et al. Potential and limitations of neural decompression in extreme lateral interbody fusion: a systematic review. *World Neurosurg*. (2017) 101:99–113. doi: 10.1016/j.wneu.2017.01.080

23. Beng TB, Kotani Y, Sia U, Gonchar I. Effect of indirect neural decompression with oblique lateral interbody fusion was influenced by preoperative lumbar lordosis in adult spinal deformity surgery. *Asian Spine J*. (2019) 13(5):809–14. doi: 10.31616/asj.2018.0283

24. Kim D, Choi B, Kim HY, Lee S. Clinical and radiographic outcomes of oblique lumbar interbody fusion at 1 year: a preliminary report of a single institution experience. *J Min Inv Spine Surg Techn*. (2020) 5(1):1–7. doi: 10.21182/jmisst.2020.00087

25. Park D, Mummaneni PV, Mehra R, Kwon Y, Kim S, Ruan HB, et al. Predictors of the need for laminectomy after indirect decompression via initial anterior or lateral lumbar interbody fusion. *J Neurosurg Spine*. (2020) 32(6): 781–7. doi: 10.3171/2019.11.SPINE19314

26. Pourtaheri S, Issa K, Lord E, Ajiboye R, Drysch A, Hwang K, et al. Paraspinal muscle atrophy after lumbar spine surgery. *Orthopedics*. (2016) 39(2):e209–14. doi: 10.3928/01477447-20160129-07

27. . Lai PL, Chen LH, Niu CC, Fu TS, Chen WJ. Relation between laminectomy and development of adjacent segment instability after lumbar fusion with pedicle fixation. *Spine*. (2004) 29(22):2527–32; discussion 32. doi: 10.1097/01.brs.0000144408.02918.20

28. Sato J, Ohtori S, Orita S, Yamauchi K, Eguchi Y, Ochiai N, et al. Radiographic evaluation of indirect decompression of mini-open anterior retroperitoneal lumbar interbody fusion: oblique lateral interbody fusion for degenerated lumbar spondylolisthesis. *Eur Spine J*. (2017) 26(3):671–8. doi: 10.1007/s00586-015-4170-0

29. Chang SY, Nam Y, Lee J, Chang BS, Lee CK, Kim H. Clinical significance of radiologic improvement following single-level oblique lateral interbody fusion with percutaneous pedicle screw fixation. *Orthopedics*. (2020) 43(4):e283–e90. doi: 10.3928/01477447-20200521-02

30. Taba HA, Williams SK. Lateral lumbar interbody fusion. *Neurosurg Clin N Am*. (2020) 31(1):33–42. doi: 10.1016/j.nec.2019.08.004

31. Park SW, Ko MJ, Kim YB, Le Huec JC. Correction of marked sagittal deformity with circumferential minimally invasive surgery using oblique lateral interbody fusion in adult spinal deformity. *J Orthop Surg Res*. (2020) 15(1):13. doi: 10.1186/s13018-020-1545-7

32. Cho MS, Seo EM. Efficacy and radiographic analysis of oblique lumbar interbody fusion in treating lumbar degenerative spondylolisthesis with sagittal imbalance. *Neurosurg Rev*. (2021) 44(4):2181–9. doi: 10.1007/s10143-020-01390-4

33. Wang TY, Nayar G, Brown CR, Pimenta L, Karikari IO, Isaacs RE. Bony lateral recess stenosis and other radiographic predictors of failed indirect decompression via extreme lateral interbody fusion: multi-institutional analysis of 101 consecutive spinal levels. *World Neurosurg*. (2017) 106:819–26. doi: 10.1016/j.wneu.2017.07.045

34. Castellvi AE, Nienke TW, Marulanda GA, Murtagh RD, Santoni BG. Indirect decompression of lumbar stenosis with transpsoas interbody cages and percutaneous posterior instrumentation. *Clin Orthop Relat Res*. (2014) 472 (6):1784–91. doi: 10.1007/s11999-014-3464-6

35. Malham GM, Parker RM, Goss B, Blecher CM, Ballok ZE. Indirect foraminal decompression is independent of metabolically active facet arthropathy in extreme lateral interbody fusion. *Spine*. (2014) 39(22):E1303–10. doi: 10.1097/brs.0000000000000551

36. Navarro-Ramirez R, Lang G, Moriguchi Y, Elowitz E, Corredor JA, Avila MJ, et al. Are locked facets a contraindication for extreme lateral interbody fusion? *World Neurosurg*. (2017) 100:607–18. doi: 10.1016/j.wneu.2016.11.059

frontiers | Frontiers in Surgery

TYPE Original Research
PUBLISHED 29 September 2022
DOI 10.3389/fsurg.2022.899438

OPEN ACCESS

EDITED BY
Hengxing Zhou,
Tianjin Medical University General Hospital, China

REVIEWED BY
Jinwei Xie,
Sichuan University, China
Gregory Schmale,
University of Washington, United States

*CORRESPONDENCE
Feng Guo
gkgf100@sina.com

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

RECEIVED 18 March 2022
ACCEPTED 13 September 2022
PUBLISHED 29 September 2022

CITATION
Xu X, Wang H, Cui F and Guo F (2022) Clinical effect of day case arthroscopic surgery in tibial-eminence fracture in adults using button plates. Front. Surg. 9:899438.
doi: 10.3389/fsurg.2022.899438

Clinical effect of day case arthroscopic surgery in tibial-eminence fracture in adults using button plates

Xiaohui Xu[1], Huayi Wang[2], Fengguo Cui[1] and Feng Guo[3]*

[1]Department of Orthopaedics, QiLu Hospital of ShanDong University, Dezhou Hospital, Dezhou, China, [2]Department of Orthopaedics, Xijing Hospital, Air Force Military Medical University, Xi'an, China, [3]Department of Orthopaedics, Beijing Rehabilitation Hospital, Capital University of Medical Sciences, Beijing, China

Background: The tibial-eminence fracture (TEF) is an anterior cruciate-ligament avulsion fracture with a low incidence. Many surgical techniques have been described, but none of them allow early functional exercise, and there are many postoperative complications.
Purposes: This study aimed to evaluate the early clinical efficacy and complications of day case arthroscopic-surgery treatment of adult TEF with button plates.
Methods: We retrospectively analyzed patients with TEF treated with arthroscopic surgery. Clinical subjective evaluation included International Knee Documentation Committee (IKDC) subjective score, Lysholm Knee Score, and Visual Analog Scale (VAS) score. Knee joint scores were evaluated by Lysholm score. Clinical objective assessment included the Lachman test, anterior-drawer test (ADT), IKDC, and range of motion. We assessed patient quality of life using a life summary table. Assessment of fracture healing and internal fixation was based on lateral x-rays of the knee joint. We measured and evaluated patient satisfaction at the last follow-up in accordance with Marsh criteria.
Results: At final follow-up (average follow-up time, 28.23 ± 3.14 months), we evaluated results from 22 patients (22 knees). Average patient age during surgery was 33.64 ± 6.96 years. Average time from injury to surgery was 6.59 ± 1.47 h. Postoperative function was better than pre-operative function in all patients. IKDC subjective score, Lysholm score, and VAS score were better at final follow-up than before surgery. Differences in Lachman test and ADT scores before and after surgery were statistically significant. According to Intra-articular button position classification, 6 patients (6 knees) showed ideal position (A), 16 patients (16 knees) showed nearly ideal position (B), and none of the patients had nonideal position (C). The fractures of 22 patients healed completely; 2 patients had a 5°–10° knee joint dysfunction, and 1 had an abnormal knee sound. According to intra-articular button position classification, the rate of ideal position was 100%. Patient satisfaction rate was 81.8%.
Conclusion: Day surgery using double-button plates to treat TEF could achieve anatomical reduction, power and stability, as well as good clinical efficacy.

KEYWORDS

arthroscopic fixation, fracture, tibial eminence, clinical efficacy, patient satisfaction, button plates (TightRope)

Introduction

The tibial-eminence fracture (TEF) is an anterior cruciate-ligament (ACL) avulsion fracture with a low incidence. Previous studies have reported that TEF commonly occurs in children and adults (1). Currently, up to 40% of these fractures occur in adults (2). TEFs were first described by Meyers and McKeever in 1959. They are divided into four types: type 1, which is nonreducible; type 2; and types 3 and 4, which require surgical treatment (1, 3). The current treatment plan for displaced TEFs involves anatomical reduction of the fracture, reconstruction of the ACL, early functional exercise, restoration of knee joint function, and quality of life (QoL) improvement.

Fracture treatment options in adults include incision or arthroscopic screws, steel wires, metal sutures, or metal-free sutures (4). Regardless of fixation type, the purpose is to achieve stability, reconstruction, and early functional exercise. However, none of the above methods permit early functional exercise, and there are many postoperative complications. Therefore, developing a better surgical plan to facilitate patient recovery is crucial. In this study, we adopted a new fracture treatment plan based on double-button fixation to evaluate the clinical efficacy of day surgery.

Materials and methods

This study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of our institution. Enrolled patients signed their informed consent (Approval No. 2020042).

We retrospectively analyzed the clinical efficacy and complications of double-button plate surgical treatment in TEF patients from April 2017 to April 2019. All patients were operated on by the same group of surgeons. The sole inclusion criterion was no obvious contusion of the skin over the knee joint. Exclusion criteria were as follows: (1) no closed epiphyses; (2) arteriovenous injury; (3) previous meniscal resection; (4) abnormal imaging findings; (5) lack of consent to participate in the study; (6) multiple-ligament injury; (7) ACL rupture; and (8) previous knee dislocation or old TEF.

All patients received clinical and radiological examinations before surgery, including computed-tomography (CT) and magnetic-resonance imaging examination.

Clinical evaluation

Postoperatively, we followed up on patients in the outpatient department at 1 week, 4 weeks, 6 weeks, 3 months, 6 months, and annually thereafter. Clinical results were evaluated by Visual Analog Scale (VAS) score, Lysholm Knee Score, International Knee Documentation Committee (IKDC) subjective score, range of motion (ROM), Lachman test score, and ACL stretch test [anterior-drawer test (ADT)] score. Lysholm scores were graded as excellent (87–100), good (77–86), general (67–76), or poor (<67) (5). Lachman test scores were graded as 0 (no difference), 1 (1–5 mm laxity), 2 (5–10 mm laxity), or 3 (>10 mm laxity). We evaluated radiographs using anteroposterior and lateral x-rays. These outcome measures are regarded as essential for evaluating fracture healing and knee function in patients with TEF. Disappearance of the fracture line indicated healing.

Quality of life

Patients' QoL was evaluated using Short Form 12 (SF-12) profiles, including a physical-component summary (PCS) and a mental-component summary (MCS).

Satisfaction

Patient satisfaction, evaluated at the last follow-up, was based on Marsh's six-level classification (6): extremely satisfied, satisfied, partly satisfied, neither satisfied nor dissatisfied, somewhat dissatisfied, and very dissatisfied.

Surgical technique

Depending on the patient's condition, we performed the arthroscopic procedure under general or epidural anesthesia. The patient was placed in the supine position, and a lower-extremity tourniquet was used.

The first step was using the arthroscopic anterolateral, anteromedial, and patellar approaches to explore the joint cavity. Arthroscopy was continued to flush the joint cavity. We used an electric scalpel and radiofrequency electrocautery to clean up the blood clots and clean the synovium of the fractured end. First, the fracture was cleaned; then, if it was type 4, we tied it with a non-absorbable thread to modify it into a type 3 fracture. The second step was to carefully explore the surroundings and use the rear-drawer test to facilitate reduction. After resetting the bone block, we used a 1.0-mm Kirschner wire for temporary fixation (**Figure 1**).

A C-type (point-to-point) guide positioner was placed on the tibial intercondylar eminence to maintain the reset simultaneously into the guide pin. (We suggest that the intra-articular plate be placed in the first half to first third of the free bone to prevent "seesawing.") In the third step, we introduced a 2.4-mm threaded needle through the guide,

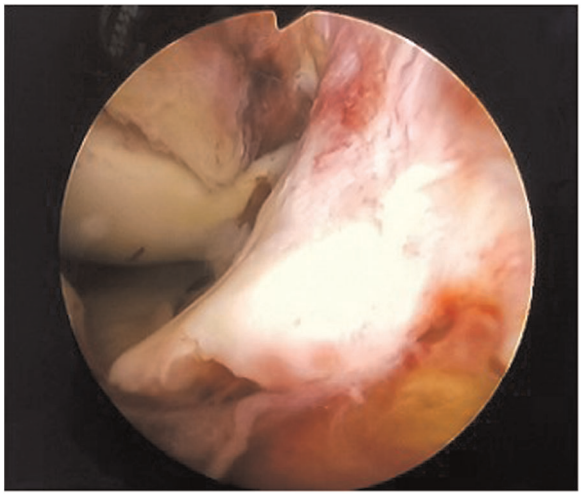


FIGURE 1
Arthroscopic view: type III fracture with ligament being obstacle to reduction.

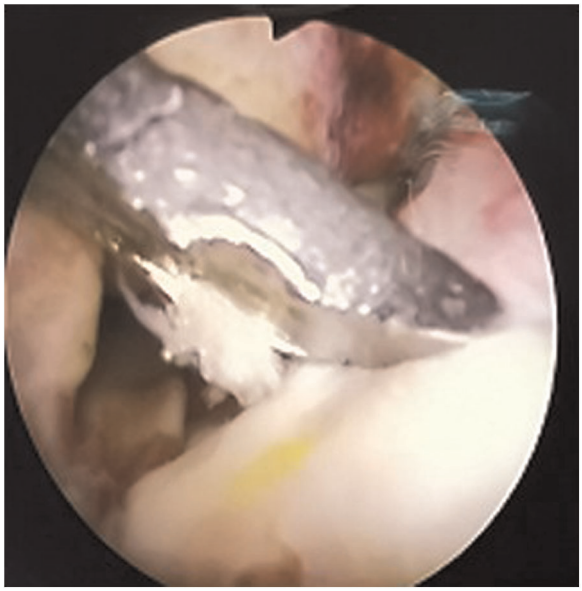


FIGURE 2
Arthroscopic view: reduction of fracture block with reducer.

crossing the tibial cortex and tibial eminence, and terminating at the ACL insertion. A 4.5-mm tunnel was drilled along this threaded needle, which allowed the surgeon to insert the oblong button down through the osseous tunnels. A guidewire was successively passed through the cannulated drill, which we used to prepare passage for an intra-articular button (TightRope; Arthrex, Inc., Naples, FL, USA) (Figures 2–4). The button was turned and placed over the tibial eminence under arthroscopic guidance. Then, we tightened the traction

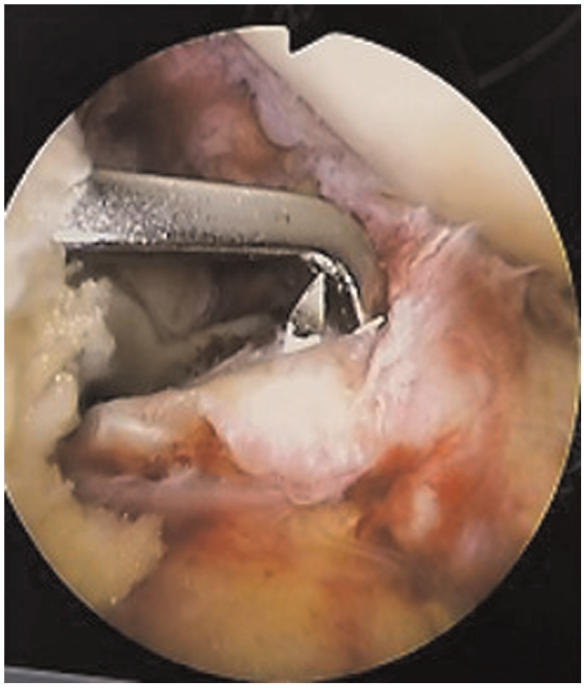


FIGURE 3
Arthroscopic view: the guide hole the reduction and determines the pain placement, insert the guide needle into the guide to set the position.

sutures. These sutures were tied on the round extra-articular metal button, which was created to keep the fracture fragment reduced (Figures 5, 6).

Postoperative treatment plan

Knee joints were treated postoperatively with rehabilitation program. Patients wore a knee brace for adjustable knee flexion and extension for the first day. Full-weight–bearing exercise was prescribed at 0°–30° for the remainder of the first week, 0°–50° for the second week, 0°–60° for the third week, 0°–75° for the fourth and fifth weeks, and 0°–90° for the sixth week. Six weeks after surgery, the brace was removed, and knee flexion and extension were strengthened *via* unrestricted functional exercise.

Statistical analysis

All data were analyzed using SPSS version 18.0 (IBM Corp., Armonk, NY, USA). We calculated means and standard deviations for IKDC, VAS, SF-12, and Lysholm scores. Ratios were calculated for categorical variables (Lachman grade, ADT, and overall IKDC grade) and compared using the χ^2

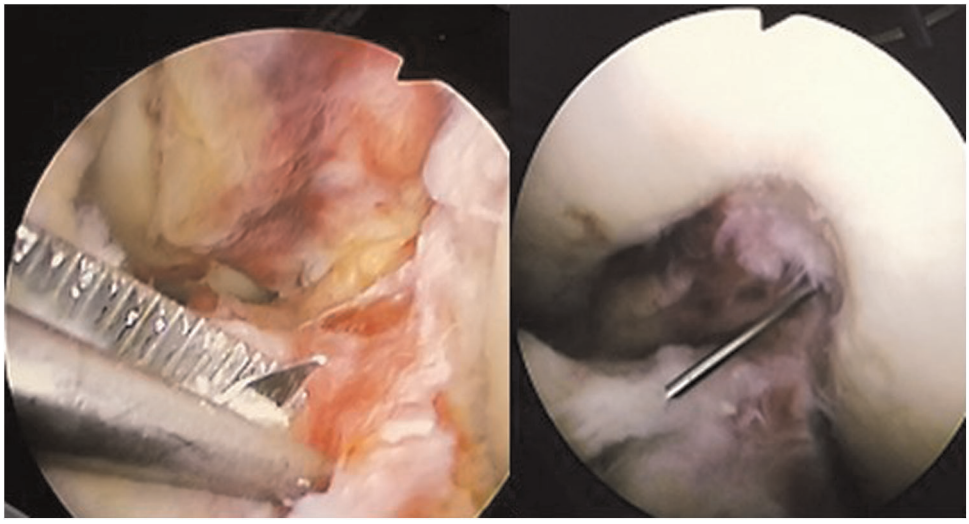


FIGURE 4
Arthroscopic view: maintain the position of the guide needle and insert the hollow drill.

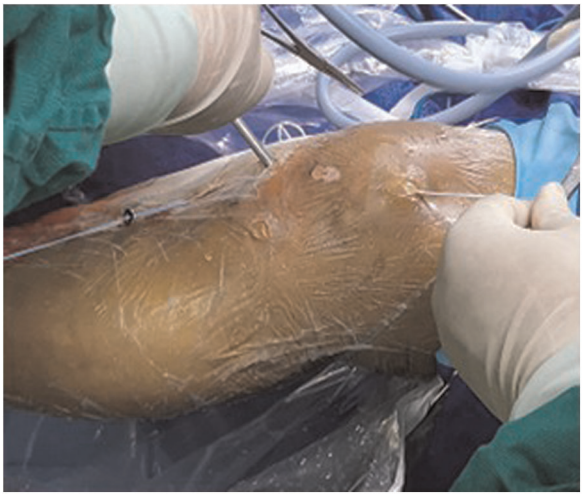


FIGURE 5
The assistant pulls the white cord in order to pull the button plate out through the hole.

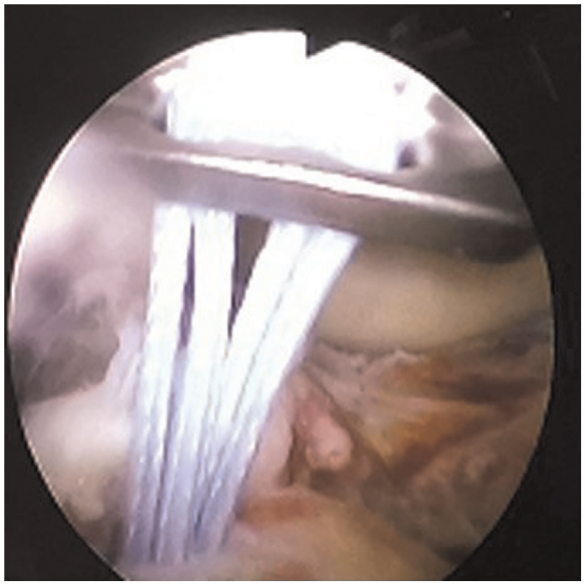


FIGURE 6
Arthroscopic view: pull and flip button plate.

test. We used a paired *t*-test to compare Constant score before surgery with that at the last follow-up. The level of significance was set at $P < 0.05$.

Results

We included a total of 32 patients (32 knees) with TEF types 2–4 according to Meyers and McKeever classification. Ten patients (10 knees) were lost to follow-up; a total of 22 patients (22 knees) with displaced TEFs who had undergone arthroscopic treatment between April 2017 and April 2019 completed the study at the last follow-up.

Average follow-up duration was 28.23 ± 3.14 months (range, 25–36 months). This study included 12 men and 10 women, with a mean age of 33.64 ± 6.96 years. Mean time interval between injury and surgery was 6.59 ± 1.47 h. Twenty patients (90.91%) had Meyers and McKeever type 3 avulsion fractures, and two (9.1%) had type 4 fractures; 20 out of 22 patients had concomitant meniscal and cartilage injuries (7), and

seven had simple fractures. At the last follow-up, two patients had 5° and 10° loss of normal knee joint function compared with the normal contralateral knee joint.

All patients restored the ROM of the involved knee to a completely normal range or a range with an acceptable deficit of <10° compared with that of the normal contralateral knee. One patient had sporadic abnormal sound in the knee, but function was not affected.

Subjective function assessment

VAS score

VAS score declined significantly from 7.00 ± 1.35 before surgery to 1.55 ± 0.86 at the last follow-up ($t = 25.31$, $P < 0.001$; Table 1).

IKDC subjective score

Mean IKDC score improved from 37.36 ± 4.75 perioperatively to 90.09 ± 2.27 postoperatively ($t = 47.02$, $P < 0.001$; Table 1).

Lysholm knee score

Lysholm score increased from 6.41 ± 4.32 points before surgery to 96.41 ± 0.59 points at the last follow-up ($P < 0.05$), and this difference was statistically significant ($t = 96.86$, $P < 0.001$). According to Lysholm knee score, the excellent or good knee joint score had a rate of 100%.

Quality of life and patient satisfaction

Mean PCS score increased from 32.47 ± 3.71 before surgery to 41.61 ± 8.36 at the last follow-up ($t = -4.27$, $P < 0.001$), while mean MCS score increased from 43.69 ± 2.96 before surgery to 54.60 ± 2.75 at final follow-up ($t = -16.54$, $P < 0.001$; Table 1).

Patient satisfaction was measured as suggested by Marsh (6). Six (27.3%) patients felt extremely satisfied, 12 (54.5%) felt very satisfied, 3 (13.6%) felt somewhat satisfied, and 1 (4.5%) felt neither satisfied nor dissatisfied. The satisfaction rate was 81.8%.

TABLE 1 Scores differences between perioperatively and postoperatively.

	VAS	IKDC Subjective	Lysholm Score	SF-12 PCS	SF-12 MCS
Perioperatively	7.00 ± 1.35	37.36 ± 4.75	6.41 ± 4.32	32.47 ± 3.71	43.69 ± 2.96
Postoperatively	1.55 ± 0.86	90.09 ± 2.27	96.41 ± 0.59	41.61 ± 8.36	54.60 ± 2.75
t	25.31	47.02	96.86	−4.27	−16.54
P	***	***	***	***	***

Values are reported as Means ± SD.
***Means $P < 0.001$.

Objective function assessment

Anterior-drawer test

Out of 20 patients (20 knees) with positive perioperative ADT scores, only 3 knees showed positive ADT at the last follow-up (difference between before and after: $\chi^2 = 26.33$, $P < 0.0001$; Table 2).

Lachman test

Out of 18 patients (18 knees) with preoperative positive Lachman test scores, only one knee had a positive Lachman score at final follow-up, and the difference between before and after surgery was statistically significant ($\chi^2 = 26.77$, $P < 0.0001$; Table 2).

Range of motion

The ROM of patients with serious functional limitations to knee extension/flexion increased from 11.77 ± 6.10 to 130.45° ± 9.55°, and no patients needed arthroscopic-release therapy. Knee movement returned to an acceptable normal range in 20 patients. One patient had a deformity of approximately 10° at the last follow-up.

Radiographic results

According to our evaluation of lateral–knee joint x-ray results, all patients achieved anatomical reduction of the bone block, and the fracture block healed within 3 months after the operation.

TABLE 2 Patients with objective results of differences between perioperatively and postoperatively (ADT and Lachman test).

	ADT		Lachman test	
	(+)	(−)	(+)	(−)
Perioperatively	20	3	18	1
Postoperatively	2	19	4	21
χ^2	26.33		26.77	
P	<0.0001		<0.0001	

Values are reported as the number of patients (%).

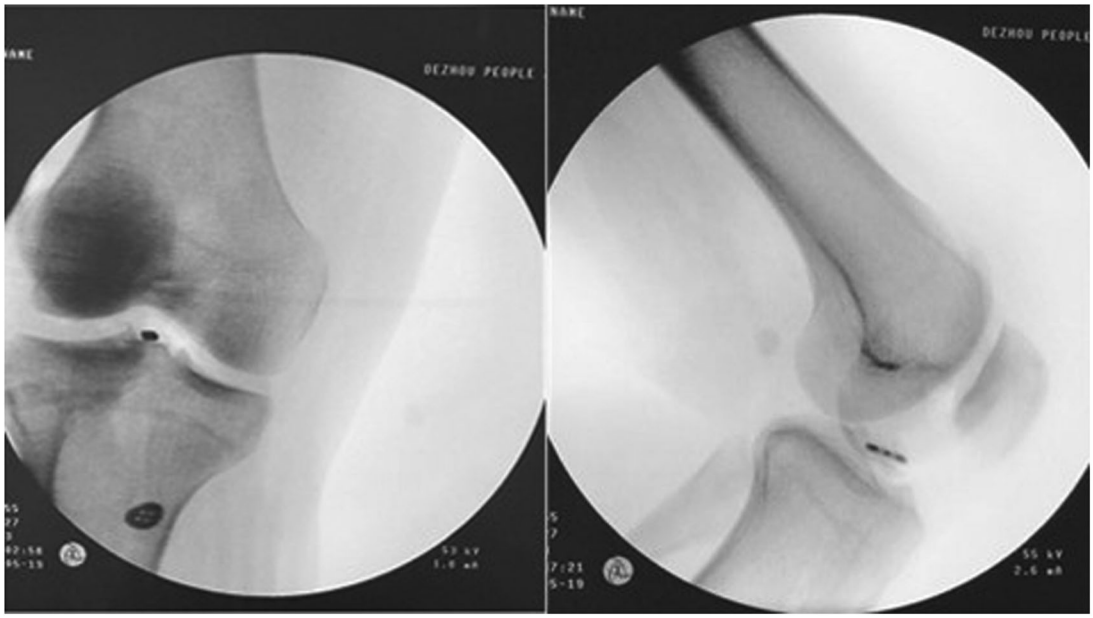


FIGURE 7
Postoperative anterior-posterior and lateral view radiographs. The ideal position (A).

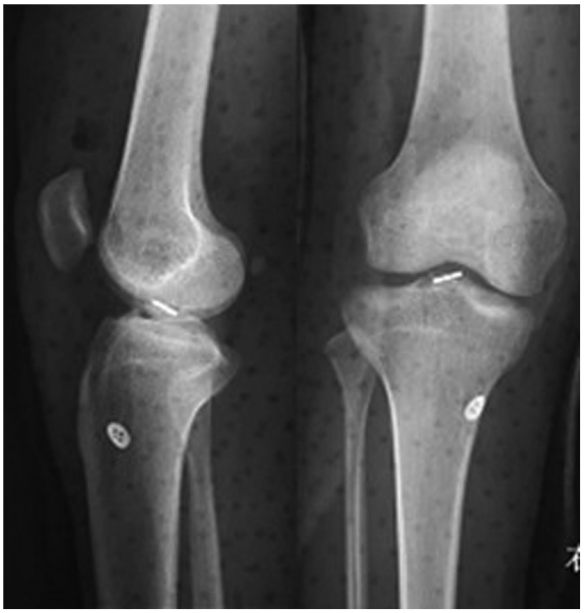


FIGURE 8
Postoperative anterior-posterior and lateral view radiographs. The nearly ideal position (B).

Intra-articular button position

Lateral–knee joint x-rays indicated that the relationship between the long axis of the rectangular button loop in the joint and the sagittal plane of the human body could be categorized into three states: ideal, nearly ideal, and nonideal. The ideal position (A) was the long axis of the steel plate being parallel to the sagittal plane of the human body (Figure 7). The nearly ideal position (B) implied that an angle existed between the long axis of the plate and the sagittal plane of the body (Figure 8). The nonideal position (C) was the plate's long axis being perpendicular to the body's sagittal plane. According to this classification, 6 patients (6 knees) showed ideal position (A), 16 patients (16 knees) showed nearly ideal position (B), and none of the patients had nonideal position (C).

Complications

Two patients showed a loss of 5° and 10° knee joint motion compared with the normal contralateral knee joint at the last follow-up. One patient (1 knee) had twisting pronunciation or abnormal sound, without alteration of knee function. There was no infection in any of the 22 patients.

Discussion

Most adult TEFs are caused by trauma, especially the high-energy traumata of car accidents, falls, and certain other injuries (2, 8); these fractures are often accompanied by ligament and/or meniscal damage. The treatment plan for these patients is to provide elastic quality, tough stitching, and rigid hard-metal,

fork-fixed avulsion reconstruction of the bone and ligament. All treatment regimens attempt to rebuild ACL tension and ligament proprioceptive function.

The tensile force of the native ACL (9, 10) during normal human activities is 500 N. The mean force of TEF is about 2500 N (10, 11). Based on the biomechanical properties of two metal buttons (TightRope; Arthrex, Inc., Naples, FL, USA), the mean vertical force in static load leading to failure is 982 N, and the mean anterior force in static load leading to failure is 627 N (12). The ultimate tensile force of this button system is strong enough to fix the fracture and restore the ACL (13, 14). It also illustrates the biomechanical properties and thus the feasibility of the button plates that can be used to treat TEF.

The treatment plan includes conservative management for type 1 nondisplaced TEFs. Surgical treatment is required for type 2 TEFs if the reduction is not anatomical (7, 15) and for all type 3 and 4 fractures (16, 17). Successful arthroscopic reduction and fixation have been described in recent studies (14).

With the use of arthroscopy in treatment, early activity and rapid recovery can be achieved, and hospital stay can be shortened. Treatment options reported so far include purse nails, cancellous bone screws, Kirschner wires, U-shaped nails, threaded rivets, sutures, and wire fixation. However, previous studies have reported that using suture fixation technology can help achieve good results.

Suture and rivet technology can achieve fixation of tibial intercondylar-ridge fractures and reconstruction of anterior-fork ligament tension (7, 18, 19). It has been reported that suture and screw fixation techniques are very effective in fixing fractures and reconstructing anterior-fork ligaments (7, 18, 19). However, the strength of these tools is not sufficient to favor the healing of fractures; most of them require a fixed full-knee extension position and non–weight-bearing exercise for a long time, which leads to knee joint adhesion and low activity. After treatment with these technologies, patients have low QoL and poor satisfaction.

The Chinese Ambulatory Surgery Alliance defines "day surgery" as a planned surgery other than outpatient surgery, 24 h after which the patient is discharged. We performed the arthroscopic double-button fixation technique on day cases, achieving good function and relatively excellent knee joint scores; this technique yielded the same or better results than other approaches (5, 13, 20, 21). There have been reports of this treatment plan in the literature, but few evaluation indicators are included (9, 22). In this day surgery study, patients received a double-button plate, which has both rigid and elastic characteristics. They were instructed to perform early functional exercises and put their full weight on the affected leg starting on day 2 after surgery. In contrast to the available literature, arthrofibrosis can be effectively avoided by continuously increasing the range of activities (20), and we

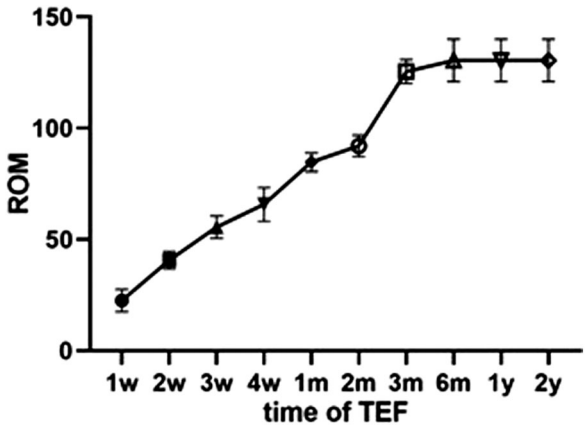


FIGURE 9
Changes of range of motion of knee joint after TEF operation.

suggest such an aggressive regimen to secure the fixation (**Figure 9**). At the last follow-up, average knee mobility was about 130.45° (range, 118–145°), which was comparable to or better than previously reported results (13, 20, 21). We believe that early day case arthroscopic surgery of TEF achieves better immediate surgical effect with more-favorable cost effectiveness.

At the same time, the SF-12 scores (PCS, MCS) of our patients increased significantly. This treatment allowed them to perform knee joint functional-rehabilitation exercises early, which can effectively reduce postoperative adhesion and stiffness caused by braking and increase the confidence of postoperative knee joint rehabilitation.

We believe that TEF patients often have ACL injuries, such as traction, which can affect the stability of the knee joint after surgery (2). In previous studies, in TEF carinal fractures, ACL injury was caused by traction during the fracture, causing >50% of the injury. However, this injury does not cause ligament rupture (2, 3), and there is no injury that could make the knee unstable.

Nonetheless, previous studies have reported that 44% of TEF patients with screw and wire fixation had physical and knee instability, requiring re-reconstruction of the ACL after this type of fracture. The re-reconstruction rate of the ACL in adults is reported to range from 7% (5 years after surgery) to 12% (15 years after surgery) (5, 6, 8). None of our patients needed ACL reconstruction. The injury composition was different from that in the previous report (5, 6, 8), which might have influenced the results at the last follow-up. Before performing the fixation, we thoroughly inspected the joint to exclude ligament rupture by arthroscopy. The satisfaction rate, which we measured as suggested by Marsh (6), was 81.8%.

Knee flexion and extension activities of all patients were severely restricted before surgery. Imaging examinations of all patients after 3 months showed that anatomical reduction of the bone block and fracture healing were achieved. At the last

follow-up, ADT score was positive in three patients (3 knees, 13.63%), and Lachman score was positive in one (1 knee, 4.54%); our overall results were better than those of a previous study on screw or suture fixation (4). We considered that the reason for the positive ADT and Lachman scores might be postoperative anterior-fork ligament relaxation; in 10 of the 22 patients, there was also meniscal-ligament compression and cartilage injury. The meniscal-injury rate in our study was consistent with that reported in the literature; our patients were less involved in sports involving vigorous knee joint exercise such as football, basketball, or long-distance running. During follow-up, none of the patients had obvious discomfort, and none underwent secondary knee arthroscopy.

It is well known that no matter whether incision or arthroscopic surgery is performed for tibial intercondylar-ridge fractures, complications such as adhesion, fracture nonunion, dysfunction, loss, and relaxation occur (3, 13, 15, 20). Early rehabilitation exercises after fracture surgery can effectively restore knee function but can also increase the risks of refracture, non-union fracture displacement, increased bleeding, increased inflammatory response, and repeated knee swelling (13, 20). The postoperative recovery process for our patients was different from that described in previous similar reports (9, 22). In this study, we included more evaluation indicators, and we asked patients to bear their full weight on the affected leg on day 2 after surgery. Functional exercise was within the adjustment range of the brace. We believe that early functional exercise is conducive to knee rehabilitation and improves knee mobility (i.e., ROM). Steel-button plate fixation offers elastic fixation and promotes fracture healing (10, 11). Postoperative complications with this treatment protocol are significantly less common than have been previously reported in similar studies (7, 12–16). In this study, two patients had knee joint extension loss at the last follow-up, which was similar to findings in the existing literature; there was no joint release or joint ROM release under anesthesia. After discharge from the hospital, patients were urged to perform strengthening functional exercises of the knee joint at home in a timely manner, which could significantly improve the restricted movement of the joint. The proportion of patients with car accident trauma in this study was high, and there were often soft-tissue injuries around the knee joint. These injuries led to easy adhesion, causing knee joint dysfunction. Patients undergoing day case arthroscopic surgery do not need to wait long before the operation, and they can exercise earlier afterward.

The direction of the tunnel and the placement of intra-articular buttons can affect fracture healing and knee functional rehabilitation. The button plate requires anatomical reduction and fixation of the bone block and the combined-force direction of the ACL for the nail path during treatment, which can achieve maximum mechanical fixation. We suggest that the intra-articular plate be placed in the first half to first third of the free bone to prevent "seesawing." If the plate is placed too far forward, such as at one third of the free bone, "excessive reduction" will occur in the front of the block and tilt will occur in the back, resulting in poor reduction. Moreover, the internal and external diameters of the free-bone fragments are larger when the intra-articular plate is placed backward, which is more advantageous to preventing the fragments from breaking during drilling. In addition, rotation of the plate can be prevented by placing it in the ACL. The nail path of our patients' bone block was designed to follow the direction of force (**Figure 10**).

Femoral intercondylar presence is different in men and women; differences in femoral intercondylar width have been previously reported in the literature, with an average femoral intercondylar-terminus width of 14.5–24 mm (17, 20). However, the width of the intercondylar fossa in patients with osteoarthritis is narrower. The length of the long axis of the intra-articular loop plate is about 10 mm. We recommend that this axis be parallel to the sagittal plane of the knee joint, which can effectively avoid the impact of the button plate on the narrower intercondylar fossa and reduce damage. We routinely sutured and reinforced the intra-articular button into the ACL. However, during postoperative follow-up, we found that the button had rotated. This resulted in a risk of collision between the button plate and the intercondylar fossa.

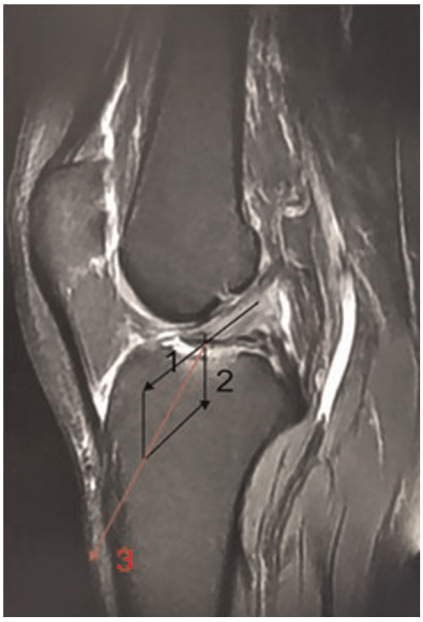


FIGURE 10
(1) The direction of the force line represents the tension direction of the anterior bifurcate ligament. (2) The direction of the force line represents the pressure direction of the fracture block. (3) The direction of the button where was fixed at the combind force direction, which was between the bone mass and the ACL.

However, according to Intra-articular button position classification, 16 patient follow-ups were found in the continuous presence of loop rotation button, intra-articular rectangular loop into a fixed-position B type. 0 patient developed a C-type and had no knee discomfort during follow-up. During follow-up, 1 patient had postoperative bouncing weakness and abnormal noise when the knee joint moved, but knee flexion and extension function was good.

We do not recommend secondary surgery to remove the internal-fixation device because it is covered by soft tissue and ligament fibers after fracture healing. It is difficult to find and remove under arthroscopy. Secondary surgery increases costs and pain; however, if the intra-articular button body becomes loose in the knee, it must be removed.

Conclusions

Day surgery for TEF using a double-button plate could significantly reduce hospital stay and preoperative waiting time. It could also accelerate rehabilitation of knee joint function, reduce rehabilitation time, and significantly improve patients' early postoperative exercise capability.

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 DeZhou Hospital Institutional Review Board. The patients/participants provided their written informed consent to participate in this study.

Author contributions

XX participated in the design of the study and drafted the manuscript. FG participated in the design of the study and coordinationand helped draft the manuscript. HW and FC participated in the radiological evaluation and performed the statistical analysis. All authors contributed to the article and approved the submitted version.

Acknowledgments

We thank LetPub (www.letpub.com) for its linguistic assistance 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. Meyers MH, McKeever FM. Fracture of the intercondylar eminence of the tibia. *J Bone Joint Surg Am*. (1970) 52:1677–84. doi: 10.2106/00004623-197052080-00024

2. Noyes FR, DeLucas JL, Torvik PJ. Biomechanics of anterior cruciate ligament failure: an analysis of strain-rate sensitivity and mechanisms of failure in primates. *J Bone Joint Surg Am*. (1974) 56:236–53. doi: 10.2106/00004623-197456020-00002

3. Kocher MS, Foreman ES, Micheli LJ. Laxity and functional outcome after arthroscopic reduction and internal fixation of displaced tibial spine fractures in children. *Arthroscopy*. (2003) 19:1085–90. doi: 10.1016/j.arthro.2003.10.014

4. Pan RY, Yang JJ, Chang JH, Shen HC, Lin LC, Lian YT. Clinical outcome of arthroscopic fixation of anterior tibial eminence avulsion fractures in skeletally mature patients: a comparison of suture and screw fixation technique. *J Trauma Acute Care Surg*. (2012) 72:E88–93. doi: 10.1097/TA.0b013e3182319d5a

5. Wiggins AJ, Grandhi RK, Schneider DK, Stanfield D, Webster KE, Myer GD. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Am J Sports Med*. (2016) 44:1861–76. doi: 10.1177/0363546515621554

6. Bourke HE, Salmon LJ, Waller A, Patterson V, Pinczewski LA. Survival of the anterior cruciate ligament graft and the contralateral ACL at a minimum of 15 years. *Am J Sports Med*. (2012) 40:1985–92. doi: 10.1177/0363546512454414

7. Vega JR, Irribarra LA, Baar AK, Iniguez M, Salgado M, Gana N. Arthroscopic fixation of displaced tibial eminence fractures: a new growth plate-sparing method. *Arthroscopy*. (2008) 24:1239–43. doi: 10.1016/j.arthro.2008.07.007

8. Leie M, Heath E, Shumborski S, Salmon L, Roe J, Pinczewski L. Midterm outcomes of arthroscopic reduction and internal fixation of anterior cruciate ligament tibial eminence avulsion fractures with K-wire fixation. *Arthroscopy*. (2019) 35:1533–44. doi: 10.1016/j.arthro.2018.11.066

9. Faivre B, Benea H, Klouche S, Lespagnol F, Bauer T, Hardy P. An original arthroscopic fixation of adult's tibial eminence fractures using the tightrope device: a report of 8 cases and review of literature. *Knee*. (2014) 21:833; (2017) 165. doi: 10.1016/j.knee.2014.02.007

10. Yamanishi Y, Yamaguchi S, Imazato S, Nakano T, Yatani H. Effects of the implant design on peri-implant bone stress and abutment micromovement:

three-dimensional finite element analysis of original computer-aided design models. *J Periodontol*. (2014) 85:e333–8. doi: 10.1902/jop.2014.140107

11. Betts DC, Muller R. Mechanical regulation of bone regeneration: theories, models, and experiments. *Front Endocrinol*. (2014) 5:211. doi: 10.3389/fendo.2014.00211

12. Wiegand N, Naumov I, Vámhidy L, Nöt LG. Arthroscopic treatment of tibial spine fracture in children with a cannulated Herbert screw. *Knee*. (2014) 21(2):481–5. doi: 10.1016/j.knee.2013.12.004

13. Doral MN, Atay OA, Leblebicioğlu G, Tetik O. Arthroscopic fixation of the fractures of the intercondylar eminence via transquadricipital tendinous portal. *Knee Surg Sports Traumatol Arthrosc*. (2001) 9(6):346–9. doi: 10.1007/s001670100235

14. Bonin N, Jeunet L, Obert L, Dejour D. Adult tibial eminence fracture fixation: arthroscopic procedure using K-wire folded fixation. *Knee Surg Sports Traumatol Arthrosc*. (2007) 15(7):857–62. doi: 10.1007/s00167-006-0284-6

15. Schneppendahl J, Thelen S, Gehrmann S, Twehues S, Eichler C, Koebke J, et al. Biomechanical stability of different suture fixation techniques for tibial eminence fractures. *Knee Surg Sports Traumatol Arthrosc*. (2012) 20:2092–7. doi: 10.1007/s00167-011-1838-9

16. Verdano MA, Pellegrini A, Lunini E, Tonino P, Ceccarelli F. Arthroscopic absorbable suture fixation for tibial spine fractures. *Arthrosc Tech*. (2014) 3:e45–8. doi: 10.1016/j.eats.2013.08.016

17. Shelbourne KD, Facibene WA, Hunt JJ. Radiographic and intraoperative intercondylar notch width measurements in men and women with unilateral and bilateral anterior cruciate ligament tears. *Knee Surg Sports Traumatol Arthrosc*. (1997) 5:229–33. doi: 10.1007/s001670050055

18. Wagih AM. Arthroscopic treatment of avulsed tibial spine fractures using a transosseous sutures technique. *Acta Orthop Belg*. (2015) 81:141–6. PMID: 26280867

19. Tudisco C, Giovarruscio R, Febo A, Savarese E, Bisicchia S. Intercondylar eminence avulsion fracture in children: long-term follow-up of 14 cases at the end of skeletal growth. *J Pediatr Orthop B*. (2010) 19(5):403–8. doi: 10.1097/BPB.0b013e32833a5f4d

20. Van Eck CF, Martins CAQ, Kopf S, Lertwanich P, Fu FH, Tashman S. Correlation between the 2-dimensional notch width and the 3-dimensional notch volume: a cadaveric study. *Arthrosc J Arthrosc Relat Surg*. (2011) 27(2):207–12. doi: 10.1016/j.arthro.2010.06.027

21. Memisoglu K, Muezzinoglu US, Atmaca H, Sarman H, Kesemenli CC. Arthroscopic fixation with intra-articular button for tibial intercondylar eminence fractures in skeletally immature patients. *J Pediatr Orthop B*. (2016) 25:31–6. doi: 10.1097/BPB.0000000000000223

22. Ballal M, Joseph C, Chidanand KJC, Vinay HS, Shankar SU. Tightrope-suture button fixation for type III tibial eminence fractures – Case series and review of literature. *J Arthrosc Jt Surg*. (2014) 1(2):87–90. doi: 10.1016/j.jajs.2014.07.004

frontiers | Frontiers in Surgery

TYPE Original Research
PUBLISHED 10 November 2022
DOI 10.3389/fsurg.2022.905946

OPEN ACCESS

EDITED BY
Luca Ricciardi,
Sapienza University of Rome, Italy

REVIEWED BY
Alessandro Frati,
Sapienza University of Rome, Italy
Yuzeng Liu,
Capital Medical University, China

*CORRESPONDENCE
Hao Liu
liuhaodoctor@163.com
Zhonglai Qian
szqzlspine@163.com

†These authors have contributed equally to this work

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

RECEIVED 28 March 2022
ACCEPTED 17 October 2022
PUBLISHED 10 November 2022

CITATION
Deng L, Zhang J, Zhou Q, Zheng Y, Hua X, Hu X, Liu H and Qian Z (2022) Effect of the intermediate pedicle screws and their insertion depth on sagittal balance and functional outcomes of lumbar fracture.
Front. Surg. 9:905946.
doi: 10.3389/fsurg.2022.905946

Effect of the intermediate pedicle screws and their insertion depth on sagittal balance and functional outcomes of lumbar fracture

Lei Deng[1†], Junxin Zhang[1†], Quan Zhou[1†], Yifei Zheng[2†], Xi Hua[1], Xiayu Hu[1], Hao Liu[1*] and Zhonglai Qian[1*]

[1]Department of Orthopaedics, The First Affiliated Hospital of Soochow University, Soochow University, Suzhou, China, [2]Department of Orthopaedics, The Affiliated Suzhou Science & Technology Town Hospital of Nanjing Medical University, Suzhou, China

Objective: This study aimed to examine the effect of the intermediate pedicle screws and their insertion depth on sagittal balance and functional outcomes of lumbar fracture.

Methods: This study reviewed 1,123 patients with lumbar fractures between January 2015 and June 2019, and 97 patients were ultimately enrolled in this study: Group A: 32 patients in the four-pedicle screws fixation group; Group B: 28 patients in the six-pedicle screws fixation with long intermediate pedicle screws group; Group C: 37 patients in the six-pedicle screws fixation with short intermediate pedicle screws group. The radiographic outcomes were assessed with lumbar lordosis (LL), segmental lordosis (SL), fractured vertebral lordosis (FL), sacral slope (SS), pelvic incidence (PI), and pelvic tilt (PT). The visual analog scale (VAS) and the Oswestry disability index (ODI) scores were used for assessing functional outcomes.

Results: The PI, PT, and SS showed no significant differences between the three groups ($P > 0.05$). Compared with Group A, Groups B and C showed better FL, SL, and LL 1 month after operation ($5.96 \pm 1.67/4.81 \pm 1.49$ vs. 8.78 ± 2.90, $24.39 \pm 3.80/23.70 \pm 4.10$ vs. 20.09 ± 3.33, $39.07 \pm 3.61/39.51 \pm 3.23$ vs. 36.41 ± 3.11, $P < 0.05$) and at final follow-up ($8.75 \pm 1.40/6.78 \pm 1.70$ vs. 11.31 ± 2.61, $22.11 \pm 3.39/23.70 \pm 4.10$ vs. 17.66 ± 2.60, $38.04 \pm 3.49/39.51 \pm 3.23$ vs. 35.41 ± 3.11, $P < 0.05$). The FL of Group C were significantly better than those of Group B 1 month after operation (4.81 ± 1.49 vs. 5.96 ± 1.67, $P < 0.05$) and at final follow-up (6.78 ± 1.70 vs. 8.75 ± 1.40, $P < 0.05$). No significant differences in VAS and ODI were found between Group A and Group B ($P > 0.05$). There were also no significant differences in VAS and ODI between Group A and Group C ($P > 0.05$). However, The VAS and ODI of Group C showed better than Group B 1 month after operation (3.05 ± 0.70 vs. 3.54 ± 0.79, 17.65 ± 3.41 vs. 19.71 ± 2.35, $P < 0.05$) and at final follow-up (2.19 ± 0.46 vs. 2.57 ± 0.57, 13.81 ± 2.20 vs. 15.57 ± 1.73, $P < 0.05$).

Conclusions: Both four-pedicle screw fixation and six-pedicle screw fixation were effective in treating lumbar fracture. However, six-pedicle screw fixation

Abbreviations
LL, lumbar lordosis; SL, segmental lordosis; FL, fractured vertebral lordosis; SS, sacral slope; PI, pelvic incidence; PT, pelvic tilt; VAS, visual analog scale; ODI, Oswestry disability index; BMD, bone mineral density.

with short intermediate pedicle screws showed better radiographic and functional outcomes after surgery. Therefore, we recommend six-pedicle screws fixation with short intermediate pedicle screws for the long-term recovery of sagittal balance and function.

KEYWORDS

lumbar fracture, intermediate pedicle screws, insertion depth, sagittal balance, lumbar pedicle screw fixation

Introduction

Lumbar fracture is a common clinical fracture of the spine; it accounts for approximately 10% of total body fractures. It is mainly caused by severe external trauma, such as car accidents and falls. Clinical symptoms are mainly manifested as local pain, swelling, and dysfunction of the lumbar vertebra, which have a serious impact on the daily life of patients. The lumbar vertebra is the part of the spine with the greatest endurance and mobility. It is of great significance to restore and rebuild the sequence and stability of the injured lumbar vertebra.

For some patients with slight compressive lumbar fractures, conservative treatment can be adopted, but for severe compressive and burst lumbar fractures, surgery is preferred to restore vertebral height, correct kyphosis, and restore lumbar sequence and sagittal balance (1). The conventional surgery technique is posterior short-segment four-pedicle screws fixation, which constructs with pedicle screws inserted above and below the injured vertebral body. However, studies have shown that in this type of surgery, implant failure, loss of reduction, and spinal nonunion can occur after surgery (2–4). In 1994, Dick et al. first reported the posterior short-segment six-pedicle screws fixation with two additional screws at the injured vertebral body (5). Two additional screws at the injured vertebral body were defined as intermediate pedicle screws. This surgery has become a common method to treat lumbar fractures.

In recent years, more and more research has reported the importance of paying attention to the stability of sagittal spinal and pelvic parameters during clinical follow-up after spinal surgery (6, 7). Key sagittal balance parameters of spinal and pelvic including pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), and spinal curvature, especially fractured vertebral lordosis (FL), lumbar lordosis (LL), and segmental lordosis (SL), were used to assess and analyze global sagittal balance (8). In the process of treating lumbar vertebral fractures, patients often received posterior short-segment six-pedicle screws or four-pedicle screws fixation. Selecting six-pedicle screws or four-pedicle screws fixation tends to depend on the surgeon's experience. We wonder whether the additional two intermediate pedicle screw insertion affects the sagittal balance of spinal and functional outcomes. Among the patients who received posterior short-segment six-screw fixation, we found that the length of the additional intermediate pedicle screws often accounts for less than 50% of the anteroposterior diameter of the vertebral body. However, we also found that the length of the additional intermediate pedicle screws sometimes accounts for 50%–90% of the anteroposterior diameter of the vertebral body. Some intermediate pedicle screws even reach the anterior edge of the vertebra. We suspect whether the depth of intermediate pedicle screw insertion affects the sagittal balance of spinal and functional outcomes. Nowadays, many research studies have reported the effects of pedicle screw number and insertion depth on spinal balance and functional outcomes (9, 10). However, few studies have examined the effect of intermediate pedicle screw insertion depth on spinal balance and functional outcomes. Therefore, this study aims to compare the radiographic and clinical functional improvement of lumbar fracture patients with or without intermediate pedicle screws and different insertion depths of intermediate pedicle screws.

Methods

General information

The inclusion criteria were as follows: (1) A trauma-induced single-level lumbar (L1-L5) compressive or a burst fracture. (2) According to the AO classification, the degree of lumbar fracture belongs to the A3 type. (3) All patients received posterior short-segment pedicle screw fixation from the Medtronic Spine system, including the superior and inferior segment with or without two additional screws at fracture vertebra. (4) The follow-up time was no less than 1 year and all the information of interest was available. (5) All patients and their families signed informed consent forms and were approved by the medical ethics committee.

The exclusion criteria were as follows: (1) Patients had previous fractures or surgical interventions in the fractured vertebra and in the upper and lower of the fractured vertebra. (2) Patients have symptoms of nerve damage and paralysis caused by fracture. (3) Pathological lumbar vertebra fracture. (4) Patients who were lost to follow-up.

This study retrospectively reviewed 1,123 patients with lumbar fractures in our institute between January 2015 and June 2019, 97 patients who received a posterior lumbar open

reduction and a pedicle screw internal fixation operation met the selection criteria. In our study, both the four-pedicle screws and the six-pedicle screws were only internal fixation and did not involve intervertebral fusion. Finally, 32 patients were divided into Group A because there were no pedicle screws on the injured vertebra (Figure 1), 28 patients were divided into Group B because the anterior edge of intermediate pedicle screws was more than 50% of the anteroposterior diameter of the injured vertebra (Figure 2) and 37 patients were divided into Group C because the anterior edge of intermediate pedicle screws were less than 50% of the anteroposterior diameter of the injured vertebra (Figure 3). The detailed screening flowchart is presented in the Supplementary material.

All patients underwent preoperative x-ray, computed tomography (CT), and magnetic resonance imaging (MRI). In clinical practice, we use a combination of x-ray, CT, and MRI to diagnose lumbar fractures. The fractured vertebra can be identified as the responsible vertebra for pain according to the T2-weighted MRI. The preoperative and follow-up x-rays for each patient were complete and available. The demographic data of patients included age, gender, surgical segment, bone mineral density (BMD), and follow-up time.

Surgical technique

The surgical area was routinely disinfected and covered with towels. With the spinous process of the injured vertebra as the center, the skin and subcutaneous tissue were dissected along the posterior midline, fascia and supraspinal ligament were removed, and surrounding tissues were removed along the spinous process and lamina subperiosteum. The bilateral lamina and facet joints of the injured vertebra and its adjacent upper and lower vertebrae were exposed. A total of six-pedicle

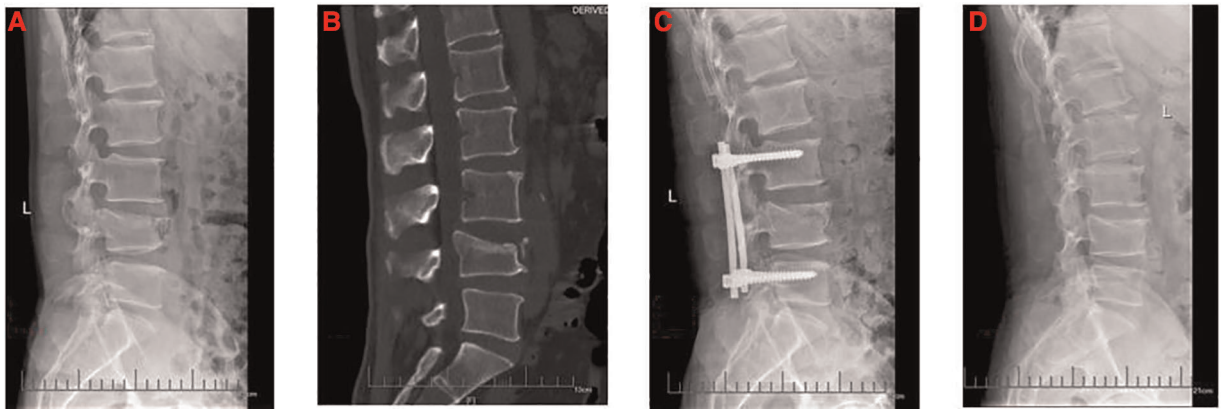


FIGURE 1
The preoperative and postoperative radiographs of four-pedicle screw fixation group. (A) Preoperative lateral x-ray. (B) Preoperative lateral computed tomography. (C) Lateral x-ray 1 month after surgery. (D) Lateral x-ray at final follow-up.

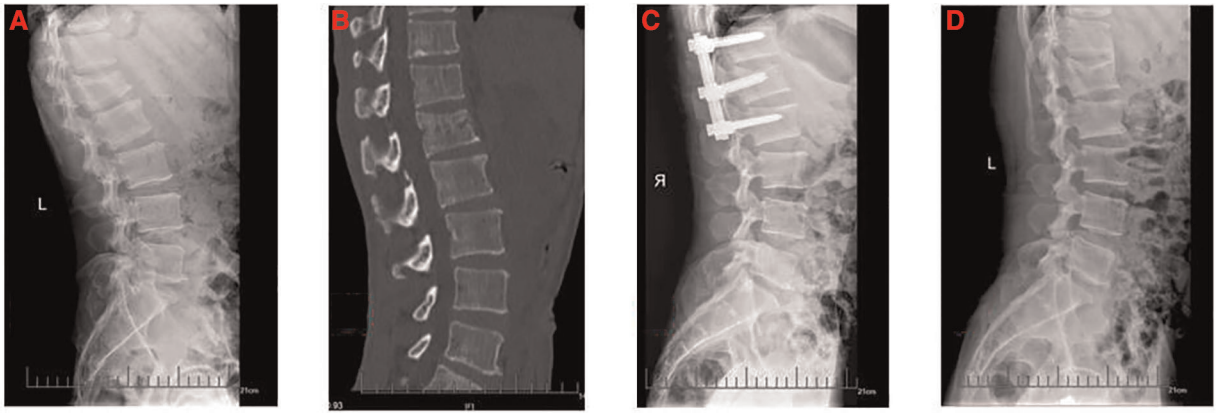


FIGURE 2
The preoperative and postoperative radiographs of six-pedicle screws fixation with long intermediate pedicle screws group. (A) Preoperative lateral x-ray. (B) Preoperative lateral computed tomography. (C) Lateral x-ray 1 month after surgery. (D) Lateral x-ray at final follow-up.

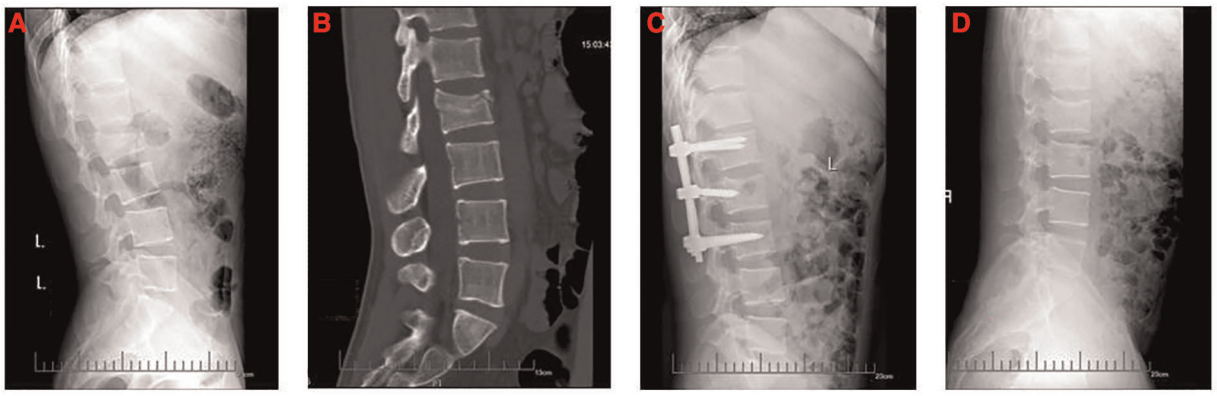


FIGURE 3
The preoperative and postoperative radiographs of six-pedicle screws fixation with short intermediate pedicle screws group. (A) Preoperative lateral x-ray. (B) Preoperative lateral computed tomography. (C) Lateral x-ray 1 month after surgery. (D) Lateral x-ray at final follow-up.

screws were inserted into the bilateral pedicles of the injured vertebrae and its adjacent vertebrae. In the control group, the injured vertebra was exposed, and four-pedicle screws were inserted into the bilateral pedicles of the injured vertebra and its adjacent vertebrae respectively. The screw placement effect was confirmed to be satisfactory by the c-arm machine. The rod was prebent and installed. The pedicle screw nut of the normal vertebral body was locked first, and the remaining screw nut was tightened after the fractured vertebral body was detached. Fluoroscopy showed good results of fracture reduction and all pedicle tail caps were locked. Then, the operative area was adequately irrigated, drainage tubes were routinely placed, and the incisions were sutured layer by layer.

Assessed parameters

Clinical assessment

A visual analog scale (VAS) was used to assess patients' subjective pain perception before surgery, 1 month after surgery, and at the final follow-up (0–10 scale, with 0 being painless and 10 being the most painful) (11). In addition, the Oswestry disability index (ODI) was used to assess improvements in quality of life before surgery, 1 month after surgery, and at the final follow-up (12).

Radiographic evaluation

The patient underwent anteroposterior and lateral radiographs before surgery, 1 month postoperatively, and at the final follow-up. All radiological parameters were measured by three spinal surgeons. The evaluation was conducted by blind method. The radiological parameters of the same patient were measured three times by three observers, and the data differences of each parameter were all less than 5%, indicating that the measurements of the three observers were stable and reliable. An average of the results measured for each parameter was used for analysis. The following radiographic parameters were measured. FL is the angle between the upper endplate and lower endplate plane of injured vertebral body. SL is the angle between the upper endplate of the superior vertebral body and lower endplate of the inferior vertebral body. LL is the angle between the superior endplate of L1 vertebra and the sacral plate. SS is the angle formed between the sacral plate and the horizontal line. PI is the angle between the line perpendicular to the midpoint of the sacral plate and the line connecting the midpoint of the femoral heads to the midpoint of the sacral plate. PT is the angle between the vertical line of the line between the midpoint of the sacral plate and the axis of the femoral heads (**Figure 4**).

Statistical methods

SPSS26.0 software was used to analyze the data in our study. Statistic values are presented as mean ± standard deviation. ANOVA test was used to compare differences between the three groups, followed by the least significant difference (LSD) for pair-wise comparisons to estimate any significant differences between groups. The χ^2 test was used for categorical data. $P < 0.05$ indicated the difference was statistically significant.

Results

Demographics

The demographic data of the three groups was shown in **Table 1**. Ninety-seven patients who received surgical treatment

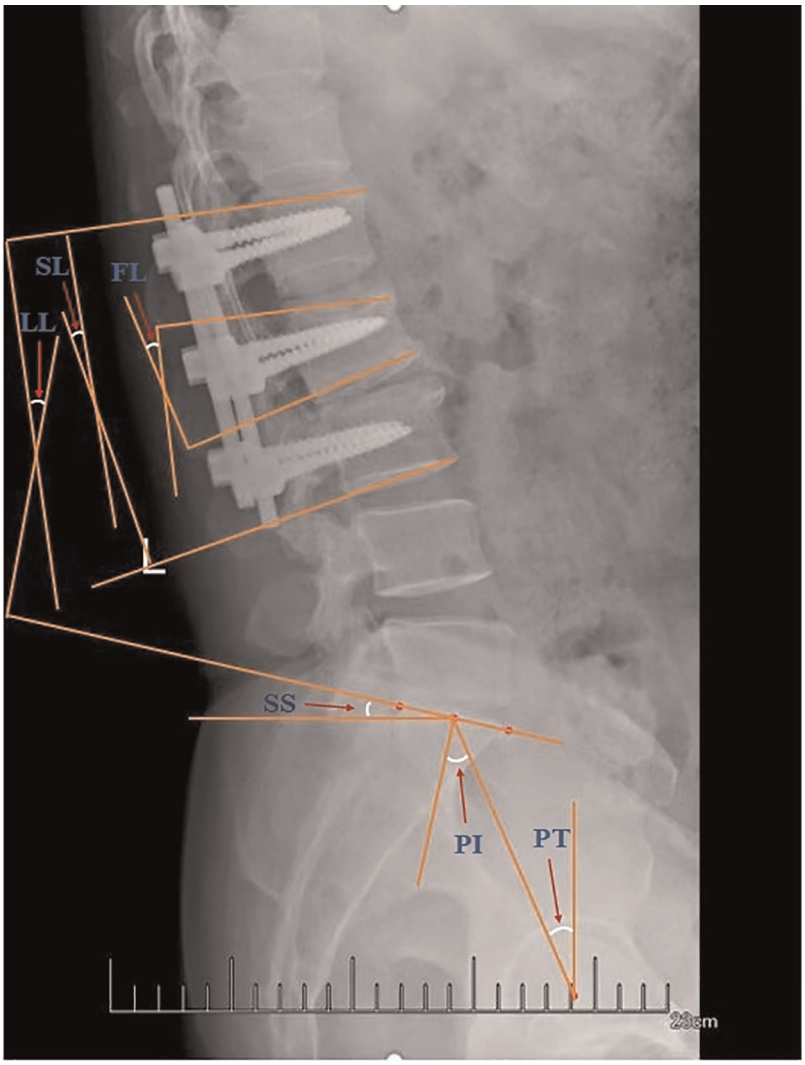


FIGURE 4
Plain lateral radiograph for measuring radiographic parameters. LL, lumbar lordosis; SL, segmental lordosis; FL, fractured vertebral lordosis; SS, sacral slope; PI, pelvic incidence; PT, pelvic tilt.

in our institution were enrolled in this study, and all these patients have completed final follow-up. The mean follow-up of Group A was 14.06 ± 4.30 months, the mean follow-up of Group B was 13.36 ± 3.89 months, and the mean follow-up of Group C was 13.54 ± 3.10 months ($P > 0.05$). There were no significant differences in terms of age, gender, BMD, operational segment, and follow-up time between the three groups ($P > 0.05$).

Radiographic outcomes

All the radiographic outcomes are shown in Table 2. The FL, SL, and LL at 1 month after surgery and at the final follow-up all showed significant differences compared with the preoperative values in all three groups ($P > 0.05$). Compared with Group A, Groups B and C all had better FL, SL, and LL 1 month after operation and at the final follow-up ($P < 0.05$). For the comparison between Groups B and C, SL and LL at 1 month after surgery and at the final follow-up all showed no significant differences ($P > 0.05$). Group C showed significantly better FL than Group B 1 month after operation and at the final follow-up ($P < 0.05$). Meanwhile, when all three groups were compared, all the SS, PT, and PI were not significantly different before and after surgery ($P > 0.05$).

Functional outcomes

The functional outcomes of the three groups are shown in Table 3. Compared with the preoperative results, the VAS

TABLE 1 The demographic data of groups.

	Group A	Group B	Group C	*P*-value
Number of patients	32	28	37	—
Gender (male/female)	13/19	15/13	18/19	0.643
Age (years)	48.59 ± 8.33	47.07 ± 8.24	49.14 ± 7.67	0.583
BMD (T-score)	−1.79 ± 0.27	−1.86 ± 0.29	−1.83 ± 0.27	0.604
Injured vertebra (*n*)				0.999
L1	16	15	19	
L2	10	9	11	
L3	2	1	3	
L4	2	2	3	
L5	2	1	1	
Follow-up (months)	14.06 ± 4.30	13.36 ± 3.89	13.54 ± 3.10	0.746

BMD, bone mineral density.

TABLE 2 The radiographic data of groups.

	Group A	Group B	Group C	*P*-value
FL (°)				
Pre	18.84 ± 3.59	18.21 ± 2.47	18.14 ± 3.12	0.367
1 month	8.78 ± 2.90[a]	5.96 ± 1.67[ab]	4.81 ± 1.49[abc]	**<0.001**
Final	11.31 ± 2.61[a]	8.75 ± 1.40[ab]	6.78 ± 1.70[abc]	**<0.001**
SL (°)				
Pre	13.44 ± 2.51	12.86 ± 2.07	13.30 ± 2.62	0.635
1 month	20.09 ± 3.33[a]	24.39 ± 3.80[ab]	23.70 ± 4.10[ab]	**<0.001**
Final	17.66 ± 2.60[a]	22.11 ± 3.39[ab]	21.16 ± 3.28[ab]	**<0.001**
LL (°)				
Pre	30.97 ± 3.54	29.82 ± 3.54	30.62 ± 3.05	0.408
1 month	36.41 ± 3.11[a]	39.07 ± 3.61[ab]	39.51 ± 3.23[ab]	**<0.001**
Final	35.41 ± 3.11[a]	38.04 ± 3.49[ab]	38.19 ± 3.51[ab]	**0.002**
SS (°)				
Pre	35.91 ± 4.39	36.11 ± 4.52	35.05 ± 3.65	0.547
1 month	35.75 ± 4.08	35.14 ± 4.14	36.11 ± 4.26	0.652
Final	36.09 ± 3.76	35.57 ± 3.53	35.81 ± 4.01	0.867
PT (°)				
Pre	18.81 ± 3.95	18.04 ± 3.94	18.43 ± 3.85	0.745
1 month	17.59 ± 3.64	16.82 ± 3.54	16.22 ± 3.51	0.256
Final	16.15 ± 3.57	15.93 ± 4.59	16.30 ± 3.63	0.932
PI (°)				
Pre	54.72 ± 5.67	54.14 ± 5.62	53.46 ± 4.40	0.604
1 month	53.34 ± 4.67	51.96 ± 4.19	52.32 ± 4.06	0.430
Final	52.22 ± 4.38	51.50 ± 5.34	52.11 ± 4.65	0.824

FL, fractured vertebral lordosis; SL, segmental lordosis; LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence.
Bold represents there is statistical significance between the three groups, P < 0.05.
[a]Statistically significant compared with the preoperative, P < 0.05.
[b]Statistically significant compared with Group A, P < 0.05.
[c]Statistically significant compared with Group B, P < 0.05.

TABLE 3 The functional outcomes of groups.

	Group A	Group B	Group C	*P*-value
VAS				
Pre	7.31 ± 0.97	7.32 ± 0.90	7.38 ± 0.86	0.948
1 month	3.25 ± 0.72[a]	3.54 ± 0.79[a]	3.05 ± 0.70[ab]	**0.037**
Final	2.38 ± 0.55[a]	2.57 ± 0.57[a]	2.19 ± 0.46[ab]	**0.018**
ODI				
Pre	38.41 ± 7.30	37.00 ± 9.12	37.86 ± 4.92	0.746
1 month	18.59 ± 3.14[a]	19.71 ± 2.35[a]	17.65 ± 3.41[ab]	**0.029**
Final	14.97 ± 3.56[a]	15.57 ± 1.73[a]	13.81 ± 2.20[ab]	**0.025**

VAS, visual analog scale; ODI, the Oswestry disability index; Pre, preoperative.
Bold represents there is statistical significance between the three groups, P < 0.05.
[a]Statistically significant compared with the preoperative, P < 0.05.
[b]Statistically significant compared with Group B, P < 0.05.

and ODI scores 1 month after operation and at the final follow-up all showed significant differences in all three groups ($P < 0.05$). No significant differences in VAS and ODI were found between Group A and Group B ($P > 0.05$). There were also no significant differences in VAS and ODI between Group A and Group C ($P > 0.05$). However, Group C showed better VAS and ODI than Group B 1 month after operation and at the final follow-up ($P < 0.05$).

Discussion

During the past several decades, posterior four-pedicle screw fixation has been one of the most popular surgeries for treating lumbar fractures (13, 14). With the development of posterior six-pedicle screw fixation, this has resulted in more sophisticated posterior pedicle screw fixation techniques and more options for surgeons. Currently, there are conflicting opinions about the advantages and disadvantages of four-pedicle screw fixation and six-pedicle screw fixation (15–18). In our clinical operation for lumbar fracture, the choice of whether to insert two additional screws in the injured vertebra and how long the screws should insert in the injured vertebra is often made freely according to the surgeon's clinical experience. These questions constantly confused our surgeons. This study conducted a systematic review to explore which type of surgery is better for sagittal balance and functional recovery of the spine after surgery.

Lumbar sagittal balance is an independent risk factor for clinical outcomes in patients undergoing spinal surgery. Studies have shown that postoperative restoration of sagittal balance improves long-term clinical outcomes and reduces the risk of sagittal imbalance (19). Therefore, key parameters such as FL, SL, LL, PI, PT, and SS were used in this study to evaluate and analyze which type of surgery is better for

sagittal balance. Pelvic sagittal parameters include PI, PT, and SS. Local spinal sagittal parameters include LL, SL, and FL.

In this study, comparing the three groups, there were no significant differences for the three pelvic sagittal balance parameters of PI, PT, and SS, which reveals that with or without intermediate pedicle screws do not affect the pelvic sagittal plane of spinal alignment before and after the surgery. Our results are in agreement with those of Liu et al. They concluded that the number of pedicle screws inserted did not affect pelvic sagittal balance parameters of PI, PT, and SS after surgery (9). Furthermore, this study reveals that the depth of intermediate pedicle screws also did not affect the pelvic sagittal plane of spinal alignment before and after the surgery. Many researchers believe that the placement of intermediate pedicle screws can lead to better postoperative radiographic outcomes, including recovery of injured vertebral height and kyphotic angle (20–23). In this study, when comparing four-pedicle screw fixation group and two six-pedicle screw fixations groups, the latter showed better local spine sagittal balance parameters of FL, SL, and LL at two postoperative follow-ups. The six-pedicle screws fixation group could reconstruct better in the FL, SL, and LL after surgery. It is generally agreed that intermediate pedicle screws allow for greater stability if stabilization at the dorsolumbar junction is desired with fewer screws. Extra pedicle screw placement in the injured vertebra can be used as a fulcrum, six-pedicle screws can leverage to the reconstruction of vertebral fracture, and inserting intermediate pedicle screws can change the two-plane fixation to a three-plane fixation, and avoid quadrilateral and suspension effect. At the same time, it can increase the stiffness of the structure and disperse the stress, greatly improving the biomechanical stability of the screw-rod system (5, 24). Some scholars believe that the longer the pedicle screw is, the better the fixation effect and the stability of the vertebral body reduction can be achieved, and the screw is not easy to loosen after surgery (25). Matsukawa et al. suggest that longer screws increase the degree of bone contact, and the use of deeper screw insertion and larger diameter screws is justified for better stability (26). Oe et al. pointed out that to some extent, the longer the pedicle screw, the greater the biomechanical stability, and the stability decreases after a certain length (27). However, it has been suggested that intermediate short-pedicle screw fixation can provide a similar level of stability to intermediate long-pedicle screw fixation, with no significant difference in the stress associated with bending, extension, and left–right axial rotation (28). In the current study, there was no consensus on the size and type of intermediate pedicle screws to be selected (29). Guven et al. used shorter intermediate pedicle screws to compare with no intermediate pedicle screws (30), while Farrokhi et al. used long intermediate pedicle screws which are the same length as those inserted in upper and lower vertebra of the same injured vertebra (31). This study showed that the sagittal balance parameters of PI, PT, SS, LL, and SL were the same between the intermediate long screw and the short screw before and after surgery, and there were no significant differences in maintaining the overall sagittal balance of the spine, except for the difference in the local spinal sagittal balance parameters FL. This suggests that the intermediate pedicle screw serves only as a fulcrum and does not provide greater mechanical stability by choosing longer intermediate pedicle screws, nor does it provide greater stability for the overall screw-rod system. The FL of the intermediate short screws group was smaller than that of the intermediate long screws group during the two follow-ups, and there was a significant difference. We think inserting long-pedicle screws will hinder the restoration of the injured vertebral body because the long-pedicle screws are bound to insert into the vertebral body fracture line. In the process of postoperative rehabilitation, the deep fracture line of pedicle screws will continue to hinder the screws at the bottom of the bone back to the location of the injury before. In the long term, the injured vertebra is difficult to restore vertebral body height, which can cause certain kyphosis and dysfunction. We need to take these factors into account.

Pain, disability, and reduced quality of life are common complications after spinal orthodontic fixation surgery. Sagittal imbalance of the spine is bound to cause pain and dysfunction during postoperative recovery. In this study, Functional outcomes for postoperative pain relief and functional improvement showed significant differences in all groups compared to preoperative status. Compared with two 6-pedicle screws groups, the 4-pedicle screws group showed no significant differences of VAS and ODI after surgery. This suggests that six-pedicle screws and four-pedicle screws had no significant effect on postoperative pain or dysfunction, which is also identical to the results of many studies (9, 10). The postoperative VAS and ODI in the intermediate short-pedicle screws group were significantly lower than those in the other two groups. We considered that the longer screws caused a larger cavity in the vertebra after surgery. Studies have shown that large cavities in fractured vertebrae slow the healing of bone tissue and speed up the correction of defects (32). Postoperative pain and dysfunction are inevitable due to slow bone healing and correction loss. Although a second operation is performed to remove the pedicle screws 1 year after surgery, the cavity caused by the long-pedicle screws is difficult to heal and may lead to further fractures. We recommend that longer pedicle screws are not necessary for the placement of two additional pedicle screws in the injured vertebra.

The limitations of this study must be stated. We only enrolled 97 patients in this study and should have included a larger sample size of patients for more meaningful statistical data. Second, prospective randomized controlled studies may be required for future studies. Some preoperative and

postoperative lumbar radiographs do not include the bilateral femoral head, so we can only estimate the central position of the femoral head by observing the shape of the acetabulum, which can lead to measurement errors in pelvic parameters.

Conclusion

Both four-pedicle screw fixation and six-pedicle screw fixation were safe and effective in treating lumbar fractures. Compared with four-pedicle screw fixation and 6-pedicle screw fixation with long intermediate pedicle screws, six-pedicle screw fixation with short intermediate pedicle screws showed better radiographic and functional outcomes from a long-term postoperative point of view. Therefore, we recommend six-pedicle screws fixation with short intermediate pedicle screws for the long-term recovery of sagittal balance and function.

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 authors.

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

LD: conceptualization, methodology, investigation, software, and writing—original draft. JZ: methodology, data curation, investigation, and writing—original draft. QZ: Conceptualization, Methodology, and Writing—original draft. YZ: methodology, data curation, and investigation. XiH: conceptualization, methodology, and data curation. XiaH: methodology, investigation, and software. HL: conceptualization, methodology, data curation, validation, writing—review and editing, and funding acquisition. ZQ: conceptualization, methodology, data curation, validation, and writing—review and editing. All authors contributed to the article and approved the submitted version.

Funding

Funding for this study was acquired from the Youth Science and technology project of rejuvenating health through science and education in Suzhou (grant no. KJXW2019010).

Acknowledgments

The authors thank the support from the First Affiliated Hospital of Soochow University.

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

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsurg.2022.905946/full#supplementary-material.

References

1. Mohanty SP, Bhat SN, Ishwara-Keerthi C. The effect of posterior instrumentation of the spine on canal dimensions and neurological recovery in thoracolumbar and lumbar burst fractures. *Musculoskelet Surg.* (2011) 95:101–6. doi: 10.1007/s12306-011-0111-1

2. Liao JC, Chen WJ. Short-segment instrumentation with fractured vertebrae augmentation by screws and bone substitute for thoracolumbar unstable burst fractures. *BioMed Res Int.* (2019) 2019:4780426. doi: 10.1155/2019/4780426

3. Müller U, Berlemann U, Sledge J, Schwarzenbach O. Treatment of thoracolumbar burst fractures without neurologic deficit by indirect reduction and posterior instrumentation: bisegmental stabilization with monosegmental fusion. *Eur Spine J.* (1999) 8:284–9. doi: 10.1007/s005860050175

4. Scholl BM, Theiss SM, Kirkpatrick JS. Short segment fixation of thoracolumbar burst fractures. *Orthopedics.* (2006) 29:703–8. doi: 10.3928/01477447-20060801-14

5. Dick JC, Jones MP, Zdeblick TA, Kunz DN, Horton WC. A biomechanical comparison evaluating the use of intermediate screws and cross-linkage in lumbar pedicle fixation. *J Spinal Disord*. (1994) 7:402–7.

6. Madkouri R, Brauge D, Vidon-Buthion A, Fahed E, Mourier K-L, Beaurain J, et al. Improvement in sagittal balance after decompression surgery without fusion in patients with degenerative lumbar stenosis: clinical and radiographic results at 1 year. *World Neurosurg*. (2018) 114:e417–24. doi: 10.1016/j.wneu.2018.03.002

7. Bayerl SH, Pöhlmann F, Finger T, Franke J, Woitzik J, Vajkoczy P. The sagittal spinal profile type: a principal precondition for surgical decision making in patients with lumbar spinal stenosis. *J Neurosurg Spine*. (2017) 27:552–9. doi: 10.3171/2017.3.SPINE161269

8. Zhou Q, Zhang JX, Zheng YF, Teng Y, Yang H-L, Liu H, et al. Effects of different pedicle screw insertion depths on sagittal balance of lumbar degenerative spondylolisthesis, a retrospective comparative study. *BMC Musculoskelet Disord*. (2021) 22:850. doi: 10.1186/s12891-021-04736-1

9. Liu H, Chen W, Zhang J, Jiang X, Yang H, Qu R, et al. Effects of pedicle screw number and insertion depth on radiographic and functional outcomes in lumbar vertebral fracture. *J Orthop Surg Res*. (2020) 15:572. doi: 10.1186/s13018-020-02111-9

10. Shao X, Peng P, Yang P, Xu T, Liu Z, Hua X, et al. A retrospective comparative study of clinical efficacy of percutaneous short segment pedicle screw fixation with or without screwing of the fractured vertebra with O-arm navigation. *BMC Musculoskelet Disord*. (2022) 23:108. doi: 10.1186/s12891-022-05069-3

11. Price DD, McGrath PA, Rafii A, Buckingham B. The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. *Pain*. (1983) 17:45–56. doi: 10.1016/0304-3959(83)90126-4

12. Fairbank JC, Pynsent PB. The Oswestry disability index. *Spine*. (2000) 25:2940–52, discussion 2952. doi: 10.1097/00007632-200011150-00017

13. Chang W, Zhang D, Liu W, Lian X, Jiao Z, Chen W. Posterior paraspinal muscle versus post-middle approach for the treatment of thoracolumbar burst fractures: a randomized controlled trial. *Medicine*. (2018) 97:e11193. doi: 10.1097/MD.0000000000011193

14. Wood KB, Li W, Lebl DR, Ploumis A. Management of thoracolumbar spine fractures. *Spine J*. (2014) 14:145–64. doi: 10.1016/j.spinee.2012.10.041

15. Modi HN, Chung KJ, Seo IW, Yoon HS, Hwang JH, Kim HK, et al. Two levels above and one level below pedicle screw fixation for the treatment of unstable thoracolumbar fracture with partial or intact neurology. *J Orthop Surg Res*. (2009) 4:28. doi: 10.1186/1749-799X-4-28

16. Altay M, Ozkurt B, Aktekin CN, Ozturk AM, Dogan O, Tabak AY. Treatment of unstable thoracolumbar junction burst fractures with short- or long-segment posterior fixation in Magerl type a fractures. *Eur Spine J*. (2007) 16:1145–55. doi: 10.1007/s00586-007-0310-5

17. Aly TA. Short segment versus long segment pedicle screws fixation in management of thoracolumbar burst fractures: meta-analysis. *Asian Spine J*. (2017) 11:150–60. doi: 10.4184/asj.2017.11.1.150

18. Choudhury AM, Alam MS, Saha MK, Jonayed SA, Rasel MH, Akter K. Short segment pedicle screw fixation including fracture vertebrae for the management of unstable thoracolumbar burst fracture. *Mymensingh Med J*. (2021) 30:485–92.

19. Le Huec JC, Faundez A, Dominguez D, Hoffmeyer P, Aunoble S. Evidence showing the relationship between sagittal balance and clinical outcomes in surgical treatment of degenerative spinal diseases: a literature review. *Int Orthop*. (2015) 39:87–95. doi: 10.1007/s00264-014-2516-6

20. Tong MJ, Tang Q, Wang CG, Xiang G-H, Chen Q, Xu H-Z, et al. Efficacy of using intermediate screws in short-segment fixation for thoracolumbar fractures: a meta-analysis of randomized controlled trials. *World Neurosurg*. (2018) 110:e271–80. doi: 10.1016/j.wneu.2017.10.157

21. Anekstein Y, Brosh T, Mirovsky Y. Intermediate screws in short segment pedicular fixation for thoracic and lumbar fractures: a biomechanical study. *J Spinal Disord Tech*. (2007) 20:72–7. doi: 10.1097/01.bsd.0000211240.98963.f6

22. Li H, Wei X, Feng Z. Letter to the editor concerning "pedicle screw fixation of thoracolumbar fractures: conventional short segment versus short segment with intermediate screws at the fracture level-a systematic review and meta-analysis" by C. Kapoen, et al. [Eur Spine J; 2020; 29(10):2491–2504]. *Eur Spine J*. (2021) 30:2726–7. doi: 10.1007/s00586-021-06935-9

23. El Behairy HF, Abdelaziz AM, Saleh AK, Hashem Elsherief FA, Abdellatif Abuomira IE, Elkawary AI, et al. Short-segment fixation of thoracolumbar fractures with incorporated screws at the level of fracture. *Orthop Surg*. (2020) 12:170–6. doi: 10.1111/os.12590

24. Norton RP, Milne EL, Kaimrajh DN, Eismont FJ, Latta LL, Williams SK. Biomechanical analysis of four- versus six-screw constructs for short-segment pedicle screw and rod instrumentation of unstable thoracolumbar fractures. *Spine J*. (2014) 14:1734–9. doi: 10.1016/j.spinee.2014.01.035

25. Karami KJ, Buckenmeyer LE, Kiapour AM, Kelkar PS, Goel VK, Demetropoulos CK, et al. Biomechanical evaluation of the pedicle screw insertion depth effect on screw stability under cyclic loading and subsequent pullout. *J Spinal Disord Tech*. (2015) 28:E133–9. doi: 10.1097/BSD.0000000000000178

26. Matsukawa K, Yato Y, Imabayashi H. Impact of screw diameter and length on pedicle screw fixation strength in osteoporotic vertebrae: a finite element analysis. *Asian Spine J*. (2021) 15:566–74. doi: 10.31616/asj.2020.0353

27. Oe S, Narita K, Hasegawa K, Natarajan RN, Yamato Y, Hasegawa T, et al. Longer screws can reduce the stress on the upper instrumented vertebra with long spinal fusion surgery: a finite element analysis study. *Global Spine J*. (2021):21925682211018467. doi: 10.1177/21925682211018467

28. Su Y, Wang X, Ren D, Liu Y, Liu S, Wang P. A finite element study on posterior short segment fixation combined with unilateral fixation using pedicle screws for stable thoracolumbar fracture. *Medicine*. (2018) 97:e12046. doi: 10.1097/MD.0000000000012046

29. Kapoen C, Liu Y, Bloemers FW, Deunk J. Pedicle screw fixation of thoracolumbar fractures: conventional short segment versus short segment with intermediate screws at the fracture level—a systematic review and meta-analysis. *Eur Spine J*. (2020) 29:2491–504. doi: 10.1007/s00586-020-06479-4

30. Guven O, Kocaoglu B, Bezer M, Aydin N, Nalbantoglu U. The use of screw at the fracture level in the treatment of thoracolumbar burst fractures. *J Spinal Disord Tech*. (2009) 22:417–21. doi: 10.1097/BSD.0b013e3181870385

31. Farrokhi MR, Razmkon A, Maghami Z, Nikoo Z. Inclusion of the fracture level in short segment fixation of thoracolumbar fractures. *Eur Spine J*. (2010) 19:1651–6. doi: 10.1007/s00586-010-1449-z

32. Knop C, Fabian HF, Bastian L, Blauth M. Late results of thoracolumbar fractures after posterior instrumentation and transpedicular bone grafting. *Spine*. (2001) 26:88–99. doi: 10.1097/00007632-200101010-00016

Frontiers in Surgery

Explores and improves surgical practice and clinical patient management

A multidisciplinary journal which explores surgical practices - from fundamental principles to advances in microsurgery and minimally invasive techniques. It fosters innovation and improves the clinical management of patients.

Discover the latest Research Topics

See more →

Frontiers

Avenue du Tribunal-Fédéral 34
1005 Lausanne, Switzerland
frontiersin.org

Contact us

+41 (0)21 510 17 00
frontiersin.org/about/contact