Brain and Spine 5 (2025) 104227

Contents lists available at ScienceDirect

Brain and Spine

journal homepage: www.journals.elsevier.com/brain-and-spine

Cementation strategies in the osteoporotic, metastatic, or ankylosing thoracolumbar spine in older adults: Cement-associated complications and implant failure

Ulrich J.A. Spiegl [1,2], Philipp Gomon [2], Georg Osterhoff, Christoph-E. Heyde, Philipp Pieroh [*]

Department of Orthopedics, Trauma and Plastic Surgery, University of Leipzig, Liebigstrasse 20, 04103, Leipzig, Germany

ARTICLE INFO

Handling Editor: Prof F Kandziora

Keywords:
Osteoporosis
Vertebral fracture
Cementation
Screw augmentation
Pedicel screw fixation

ABSTRACT

Background: Although cement augmentation of pedicle screws increases stability, complications, such as pulmonary embolism, must be considered. One possible approach to minimize complication risk is not augmenting all pedicle screws. It remains unclear whether full augmentation is necessary or if restricted cement augmentation is sufficient regarding cement-associated complications, implant failure, or adjacent fractures.

Research question: Is there a difference in cement-associated complications, implant failure rate, and revision rates in non-cemented, fully augmented, and restricted cement-augmented long-segment posterior stabilization of the thoracolumbar spine?

Methods: In a single-center retrospective observational study, patients aged ≥60 years who underwent pedicle screw fixation of ≥3 segments in the thoracic/lumbar spine treating an osteoporotic fracture, metastatic lesion, or ankylosing spondylitis fracture were enrolled and categorized into no, full, and restricted cementation groups. Demographics, cement-associated complications, revision surgeries, implant failures, adjacent fractures, and other complications were also recorded.

Results: Cement leakage rate was significantly higher in the full than in the restricted cementation group ($p < 0.05$), with no sign of pulmonary embolism in either group. Patients with osteoporotic fractures experienced implant failure and adjacent fractures significantly more frequently than those with other pathologies ($p < 0.05$). In the full cementation group, the rate of screw cut-out with fractures of the last instrumented vertebra and adjacent fractures was the highest ($p < 0.05$).

Discussion and conclusion: Restricted cementation does not result in a higher rate of complications, particularly cement-associated complications, screw cut-out, or implant failure, and appears more favorable than full cementation.

1. Introduction

Several biomechanical studies have demonstrated substantial and relevant improvement in pedicle screw retention in the osteoporotic thoracolumbar spine through cement augmentation (Hoppe et al., 2014; Bostelmann et al., 2017; Riesner et al., 2021). Cement augmentation of pedicle screws considerably decreases clinical loss of reduction and implant failure after isolated posterior stabilization (Spiegl et al., 2016; Feng et al., 2022). However, the potential complications associated with pedicle screw cement should be considered. Symptomatic pulmonary embolization rates of 0–26% have been described; moreover, a 1.8% 30-day mortality rate was demonstrated in one study (Janssen et al., 2017; Morimoto et al., 2023).

Therefore, cement augmentation should be carefully considered. Decreasing the total amount of cement by reducing the number of augmented screws might combine the advantages of cement augmentation and reduce the risk of cement-associated complications.

Restricted cement augmentation (solely augmenting the most cranial and caudal pairs of pedicle screws) demonstrated comparable stability to full cementation in two biomechanical studies (Spiegl et al., 2020, 2021).

However, whether the biomechanically proven construct stability

* Corresponding author.
E-mail address: Philipp.Pieroh@medizin.uni-leipzig.de (P. Pieroh).

[1] Present address: Clinic for Trauma Surgery and Orthopaedics, Munich Harlaching, Sanatoriumspl. 2, 81545 München, Germany.
[2] These authors contributed equally to this work.

https://doi.org/10.1016/j.bas.2025.104227
Received 13 January 2025; Received in revised form 22 February 2025; Accepted 26 February 2025
Available online 28 February 2025

with restricted cementation can be consistently observed in clinical practice remains unclear. Therefore, this study aimed to compare cement-associated complications, implant failure rates, and revision rates in non-cemented, fully augmented, and restricted cement-augmented long-segment posterior stabilization of the thoracolumbar spine. We hypothesized that no increase in cement-associated complications or implant failure rates would be detectable after restricted cementation.

2. Methods

2.1. Participants

The ethics committee of the University of Leipzig (069/24-ek, 26-03-2024) approved this study. Owing to the retrospective study design, no informed consent was required by the ethics committee. This study was conducted in accordance with the Declaration of Helsinki and all relevant laws and institutional guidelines.

2.2. Study design

This was a single-center retrospective observational cohort study performed in a level-1 trauma center between October 1, 2014, and June 15, 2022. Patients aged ≥60 years who underwent pedicle screw fixation of ≥3 segments in the thoracic or lumbar spine and were not treated for degenerative spine pathologies were consecutively enrolled. Patients aged <60 years were only included if they had known osteoporosis (confirmed by patient history, dual energy X-ray absorptiometry [DXA], or medication) or inadequate or no trauma. Spinal pathologies included osteoporotic fracture (OF), ankylosing spondylitis (AS) fracture (including diffuse idiopathic skeletal hyperostosis [DISH]), and metastatic spine lesions. Osteoporosis in patients with DISH, AS fractures, and metastatic spine lesions was not discussed separately. Patients treated for inflammatory spinal diseases (such as spondylitis and spondylodiscitis), treated additionally with intersomatic fusion (intervertebral cage or anterior cage), with primary spinal tumors, or who were pregnant were excluded. Patients were categorized into the following groups: no cementation, full cementation (including patients with subtotal augmentation), and restricted cementation (only the most cranial and caudal pedicle screw pair was augmented) (Fig. 1). Patient selection is shown in Fig. 2.

In the full cementation group, two patients aged <60 years were included: one had known osteoporosis and experienced an atraumatic fracture, and the other had known osteoporosis confirmed by pathological DXA. In the restricted cementation group, four patients aged <60 years were included. One had osteoporosis confirmed by pathological DXA, one had osteoporosis due to mastocytosis proven by histology, one had lytic metastasis, and one had osteoporosis due to glucocorticoid treatment for rheumatoid arthritis.

2.3. Outcome measures

The following demographic parameters were compared: sex, age, Charlson Comorbidity Index (CCI), American Society of Anesthesiologists (ASA) classification, length of hospital stay, mortality, Frankel grading, affected vertebral region, single- or multi-affected vertebrae, and treated pathology, number of instrumented segments. If transdiscal disruption was observed, both affected vertebrae were counted, and the patients were allocated to the multi-affected vertebra subgroup. To analyze cement-associated complications, the number of cemented screw pairs, cement leakage frequency, cement leakage type, diagnostics for deep vein thrombosis, and computed tomography findings with proven pulmonary embolism were assessed. The following types of cement leakage were defined: paravertebral, vascular, and intraspinal (Fig. 3).

Data on complications and revision surgeries were derived from in-hospital and outpatient data. The rates of revision due to infections, wound healing disorders, implant failure, adjacent fractures next to the instrumentation, and nonadjacent spinal fractures were analyzed. Implant failure was defined as follows: screw cut-out with fracture of the most cranial or caudal instrumented vertebra, screw cut-out with fracture of the most cranial or caudal instrumented vertebra and an adjacent fracture next to the last instrumented vertebra, and rod failure. In addition, the following complications were evaluated: neurological deficits, sensory or motor loss, incontinence, decubitus, urinary tract infection, pneumonia, acute renal failure, cardiological problems, asystolia, respiratory failure, and neurological disorders.

2.4. Statistical analysis

Data were collected in a predefined Research Electronic Data Capture form and analyzed using GraphPad Prism software 10 (GraphPad Software, La Jolla, USA) (Harris et al., 2009). Gaussian distribution was assessed using the Shapiro–Wilk test. Gaussian and non-Gaussian

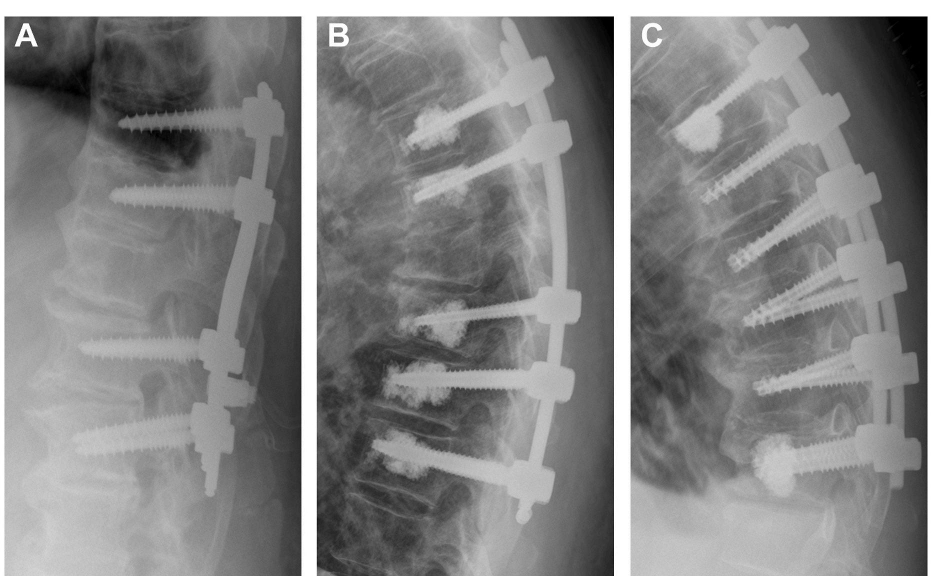

Fig. 1. Groups compared. **A** No cementation, **B** Full cementation, and **C** Restricted cementation of the posterior fixation.

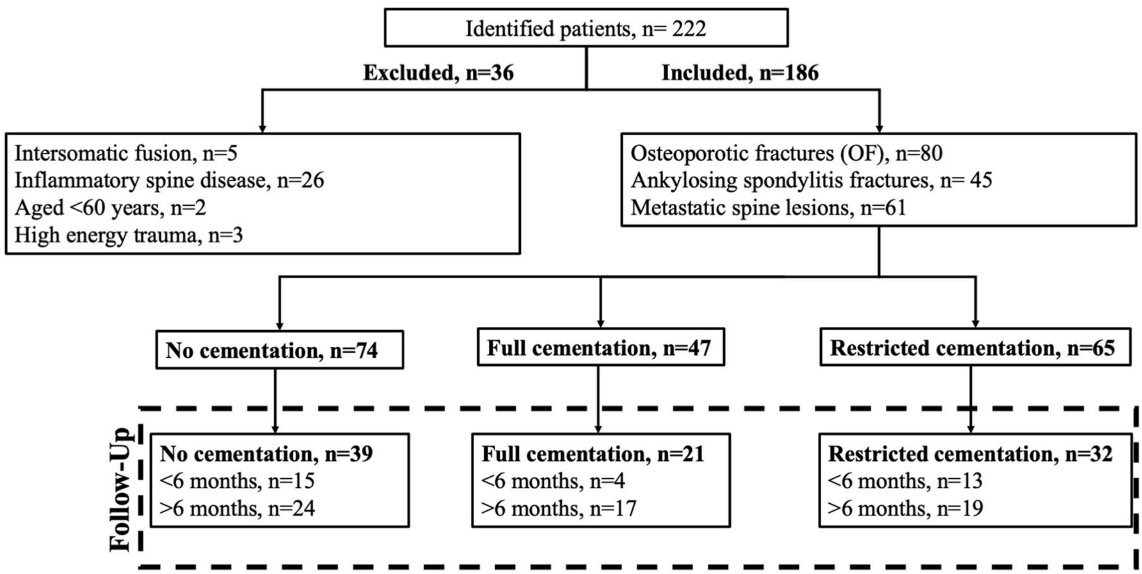

Fig. 2. Patient selection flow-chart including distribution according to the treated pathology, respective group, and available follow-up in the outpatient clinic.

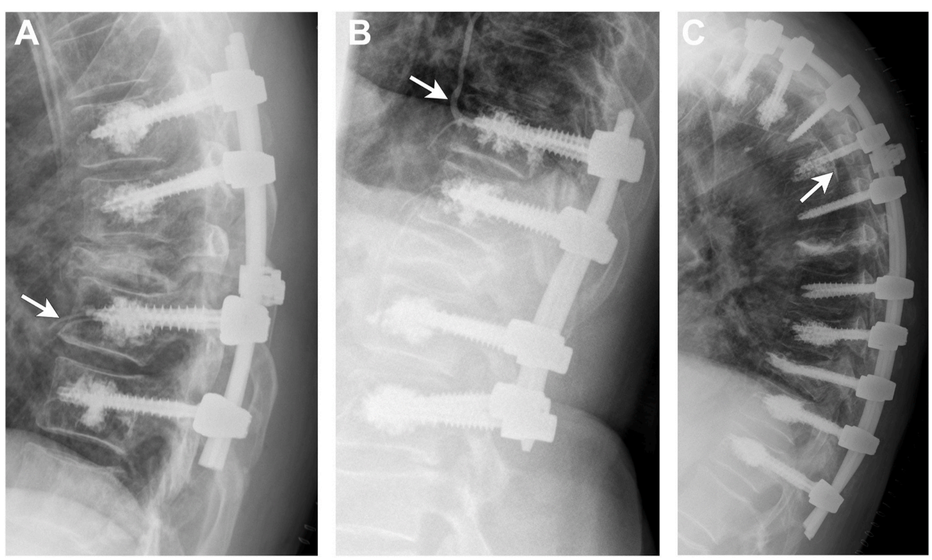

Fig. 3. Cement-associated complications. **A** Paravertebral, **B** Vascular, and **C** Intraspinal cement leakages.

distributed data are presented as the mean ± standard deviation and median [interquartile range $(IQR)_{25\%}$; $IQR_{75\%}$], respectively. Ordinal data were compared using Fisher's exact test. Gaussian-distributed data were analyzed using one-way analysis of variance followed by Bonferroni correction for multiple comparisons. Non-Gaussian distributed data were compared using the Kruskal–Wallis test followed by Dunn correction. Statistical significance was defined as $p < 0.05$.

3. Results

3.1. Demographics and indication for cement augmentation

The no cementation group significantly comprised more men than both cemented groups did ($p < 0.001$; Table 1). Compared with the full cementation group, patients in the no cementation group were significantly older, with higher CCIs ($p < 0.05$; Table 1). Regarding the ASA, no significant differences were observed in length of hospital stay, mortality, and preoperative Frankel grading ($p > 0.05$).

No significant differences were observed between the groups in the treated spinal region ($p > 0.05$; Table 2), with the thoracic spine being the most frequently affected region. There were 65 and 121 patients with single and multi-affected vertebrae, respectively (Table 2 and Table a1). Further, the no-cementation group comprised significantly more multi-affected vertebrae than the other groups ($p = 0.0145$).

Fig. 4 shows the affected vertebrae in each group. Osteoporotic fractures were significantly more frequently treated with cement augmentation, whereas DISH, AS, and metastatic lesions were more frequently treated without cement augmentation ($p < 0.05$; Table 2). The no cementation group had significantly more instrumented levels than the cementation groups did ($p < 0.05$; Table 2).

3.2. Cement-associated complications

Cement leakage rate was significantly higher in the full than in the restricted cementation group ($p < 0.05$; Table 3). No significant differences were observed regarding single- or multi-level ($p = 0.4757$) or the type (paravertebral, vascular, or intraspinal) of cement leakage ($p > 0.99$) between full and restricted cementation. Furthermore, no sign of

Table 1
Patient demographics. Sex, categorization in the Charlson comorbidity index (CCI) and to ASA<3 or ASA≥3, mortality, and Frankel grading are presented as number of respective patients (n). Age is presented as the mean ± standard deviation. CCI and length of hospital stay are presented as the median [interquartile range $(IQR)_{25\%}$; $IQR_{75\%}$]. m, male; f, female; d, days; y, yes; n, no ASA, American Society of Anesthesiologists.

	Non-cementation (n = 74)	Full cementation (n = 47)	Restricted cementation (n = 65)	p-value
Sex (m:f)	51:23	21:27	22:44	*< 0.001*
Age	77.3 ± 6.7	76.6 ± 8	73.5 ± 8.7	*0.0118*
CCI	8 [5; 9]	6 [4; 8]	7 [4.5; 9]	*0.0078*
no (0 points)	0	0	0	
mild (1–2 points)	0	0	7	
moderate (3–4 points)	14	18	9	
severe (≥5 poitns)	60	29	49	
ASA <3:≥3	14:60	12:35	15:50	0.5691
Length of hospital stay [d]	18 [15; 27]	19 [14; 22.5]	18.5 [13.25; 24.75]	p > 0.05
Mortality y:n	3:71	2:45	5:60	0.7069
Frankel grading				0.2679
A	1	0	1	
B	1	0	3	
C	3	1	3	
D	8	2	1	
E	61	44	57	

Table 2
Distribution of the treated spine pathologies according to corresponding group. Osteoporotic fractures are classified based on the OF classification (Schnake et al., 2018). All data except the number of instrumented segments are presented as the number of respective patients (n). Number of instrumented segments is presented as the median [interquartile range $(IQR)_{25\%}$; $IQR_{75\%}$]. T, thoracic; L, lumbar; TL, thoracolumbar; y, yes; n, no; DISH, diffuse idiopathic skeletal hyperostosis; AS, ankylosing spondylitis; OF, osteoporotic fracture.

	No cementation (n = 74)	Full cementation (n = 47)	Restricted cementation (n = 65)	p-Value
Affected Region (T:L:TL)	69:1:4	42:3:2	59:3:3	0.6592
Muti-affected vertebra y:n	35:39	14:33	16:49	*0.0145*
Osteoporotic fracture	**6**	**36**	**38**	*< 0.001*
OF2	1	3	1	
OF3	4	16	19	
OF4	1	16	17	
OF5	–	1	1	
AS	34	4	7	*< 0.001*
Metastatic lesion	**34**	**7**	**20**	*< 0.001*
Pathological fracture	3	4	2	
Unstable	31	3	18	
Number of instrumented segments	5 [4; 6]	4 [4; 5]	4 [4; 5]	

pulmonary embolism was observed in both cementation groups. One patient in the restricted cementation group had intraspinal cement leakage and a pedicle screw near the aorta but refused revision surgery. Another in the fully cemented group experienced intraspinal cement leakage. Notably, two patients with tumors in the no cementation group experienced deep vein thrombosis and pulmonary embolism.

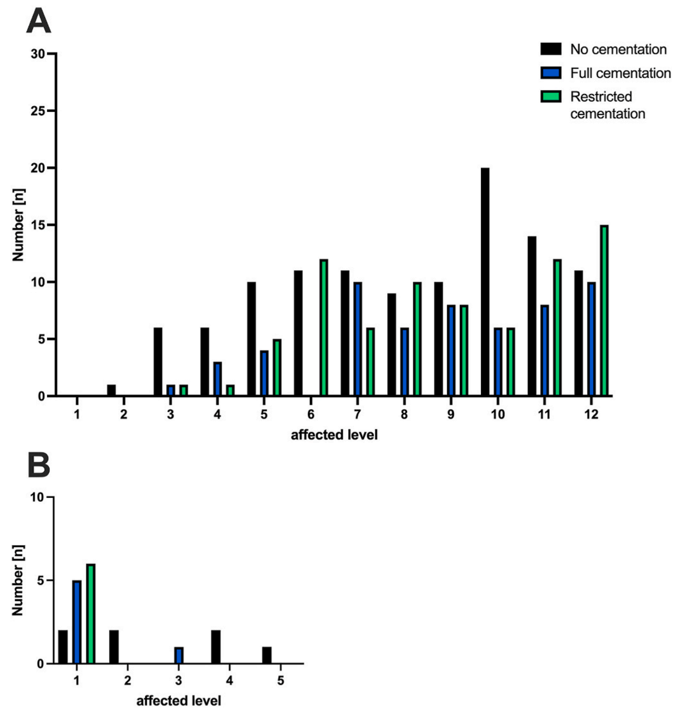

Fig. 4. Distribution of affected vertebra according to the corresponding treatment group for the thoracic (A) and lumbar (B) spine.

Table 3
Distribution of cement-associated complications. The number of cement-augmented screws is presented as the median [interquartile range $(IQR)_{25\%}$; $IQR_{75\%}$]; the remaining data are presented as the number of respective patients (n). y, yes; n, no.

	Full cementation (n = 47)	Restricted cementation (n = 65)	p-value
Cemented screw pairs	4 [4; 5]	2	*0.0001*
Cement leakage y:n	21:26	17:48	*0.046*
Single-:multi-level	15:6	14:3	
Paravertebral cement leakage	9	8	
Vascular cement leakage	12	9	

3.3. Revision due to infection or wound healing disorders and other in-hospital complications

In the no cementation group, four patients with metastatic spine lesions required revision surgery owing to wound healing disorders. One patient required screw exchange because of loosening. One patient with a metastatic lesion and one with an AS fracture required revision surgery but refused it. Another with an AS fracture required revision surgery owing to a hematoma, leading to neurological deficits. Five patients with AS fractures and two with metastatic lesions were re-admitted, requiring revision surgery owing to wound healing disorders.

In the full cementation group, three patients with OF required revision surgery because of wound healing disorders. Among them, one required additional surgery because of an intraspinal hematoma. In the restricted cementation group, two patients with OF, one each with an AS fracture and metastatic lesion required revision owing to wound healing disorders. In both cementation groups, one patient was readmitted, requiring revision surgery owing to wound healing disorders. Overall, revision surgery due to infection or wound healing disorders was indicated in 13/74 (17.6%), 4/47 (8.5%), and 5/65 (7.7%) in the no, full, and restricted cementation groups, with no statistically significant differences (p = 0.1696). The remaining complications are summarized in Table a2.

3.4. Implant failure and adjacent fractures

During the in-hospital stay, one patient each in the no cementation and restricted cementation groups experienced a screw cut-out with fracture of the caudally instrumented vertebra, leading to a revision surgery extending the instrumented vertebrae and full cementation. In the full cementation group, one patient experienced rod breakage; in the revision surgery, a two-level Ponte osteotomy and rod customization was performed.

Implant failure and adjacent fracture were observed in 28 patients after discharge (Table 4). Two patients had metastatic lesions: one had an AS fracture, and the remaining 25 had OFs. Patients with OF experienced implant failure and adjacent fractures significantly more often than those with other pathologies ($p < 0.0001$).

In the comparison of failure modes and adjacent fractures, the most common failure modes were screw cut-out and fracture of the most cranial or caudal vertebrae (p = 0.0133). In the full cementation group, three patients had screw cut-outs, a fracture of the most cranial or caudal vertebra, and an adjacent fracture next to this vertebra (p = 0.0106). All patients with screw cut-outs and fractures were treated with extension of the posterior fixation of at least two vertebrae and full cementation. In the full and restricted cementation groups, one patient suffered from screw cut-out and a fracture of the last instrumented vertebra but refused surgery.

In the no cementation group, one patient with an AS fracture had an adjacent fracture and was treated with no cementation extension of posterior fixation.

In the full cementation group, one patient had adjacent fractures, treated with five-level kyphoplasty caudal to the instrumentation. Another patient with an adjacent fracture was treated non-operatively. Two patients with adjacent fractures were treated with full cemented extension of their posterior fixation. In the restricted cementation group, one adjacent fracture occurred and was treated with kyphoplasty. Adjacent fractures occurred significantly more frequently in the full cementation group than in the other groups (p = 0.0440).

Non-adjacent fractures occurred in both the no cementation and restricted cementation groups and in two patients in the full cementation group. All the patients were treated without surgery. One rod breakage combined with nonunion occurred in the restricted cementation group, treated with full-cemented extension of the posterior fixation and cage implantation.

Table 4
Distribution of implant failure and (non-) adjacent fractures.

	No cementation (n = 39)	Full cementation (n = 21)	Restricted cementation (n = 32)	p-value
Screw cut-out with fracture of the most caudal or cranial vertebra	6	5	2	0.1654
Screw cut-out with fracture of the most caudal or cranial vertebra + adjacent vertebra	0	3	0	0.0106
Rod failure	–	1	1	0.3292
Adjacent	1	4	1	0.0440
Non-adjacent	1	2	1	0.4402

4. Discussion

The main findings of this study demonstrate that restricted cementation provides construct stability comparable to full cementation of all pedicle screws while offering advantages such as lower rates of cement leakage and adjacent segment pathologies. In addition, a higher revision rate was observed after procedures without cementation, although no increase in screw loosening or implant failure was observed.

At first glance, the high revision rates after no cementation, despite similar implant failure rates, seem surprising. However, upon closer inspection, this can be largely explained by the differences in indications and the more frequent use of open procedures in these cases. Sufficient long-term stabilization is necessary in patients with DISH or AS; however, postoperative sintering of fractures is uncommon (Schaefer et al., 2024). Moreover, these fractures generally have a good tendency to consolidate within 3 months. In addition, open access was chosen for tumor-related fractures because decompression was frequently performed. The open procedure, as well as the extension of the procedure with decompression, leads to an extension of the operating time and is therefore associated with high infection rates and postoperative bleeding (Kreinest et al., 2017; Bresolin et al., 2024). Nevertheless, the cemented approach has been shown to have advantages in metastatic fracture treatment, including reduced surgical revisions and low implant failure rates (Feng et al., 2022). The low kyphotic malalignment rate in the later stages also explains the low rate of subsequent adjacent segment pathology.

The low cement leakage rate in the restricted cementation group was expected owing to the reduced number of cemented screws and the associated limited amount of cement, which confirms our previous hypothesis. Notably, the amount of cement per screw remained constant. Between 0.8 and 1.2 mL of cement was used per pedicle screw, consistent with recommendations in the literature (Morimoto et al., 2023). Cementation was stopped immediately intraoperative evidence of cement leakage was observed. Therefore, in these cases, small cement amounts were used for the individual screws. Contrary to literature reports, no patient showed clinical abnormalities due to cement leakage (Janssen et al., 2017), probably because cementation was performed extremely carefully and slowly, with fluoroscopic controls every 0.3 ml. In addition, sufficient time was allowed for sufficient cement viscosity, and positive end-expiratory pressure increased before cementation (El et al., 2013). Finally, as described above, screw cementation was stopped at the slightest indication of cement leakage under fluoroscopy.

OF treatment often leads to kyphotic sintering and sagittal imbalance with subsequent higher stress on the cranial and caudal screws (Ruiz Santiago et al., 2023; Yuan et al., 2023). The results of this study confirm the biomechanical data showing comparable construct stability without evidence of increased screw loosening or implant failure rates after restricted cementation (Spiegl et al., 2020, 2021). However, higher rates of adjacent segment pathologies were observed after full cementation. The amount of cement, which can influence the rate of adjacent segment disease, had no influence owing to similar cementation techniques used, as described above. Further, similar implantation and reduction maneuvers were performed. Therefore, performing reduction by positioning the patient in the supine position alone appears sufficient. In addition, the fracture types and levels did not differ significantly between the full and restricted cementation groups, probably because the full cementation group had a somewhat older patient population. In addition, restricted cementation has been increasingly used in recent years; therefore, the higher rate of concomitant anti-osteoporotic therapy in these years may have had a positive effect.

Overall, a high revision rate was observed, which is quite realistic given the old and multimorbid patient population and the longer follow-up in most patients. More studies with longer follow-up periods are desirable in the future to obtain a realistic assessment of the complication rates and types of complications in these complex patients.

This study has some limitations. First, it was a single-center retrospective study with all the associated limitations. In addition, the no cement-augmentation group was not fully comparable with the other two groups, owing to differences in indications and the more common open approach. Nevertheless, we believe it is important to include this group and highlight screw loosening and implant failure cases, even in biomechanically more favorable situations. Spinal CT scans were not routinely performed; therefore, minor cement leakage might be undetected. Chest CT scans were only conducted in cases of clinically suspected embolism, thus silent embolism could have been overlooked.

Moreover, the follow-up periods varied. However, a distinction was made between short follow-up (<6 months) and long follow-up periods. Finally, clinical follow-up data were not analyzed.

In addition, detailed information regarding bone density measurements, including T-scores and osteoporosis treatment history, is lacking. These factors are crucial for determining spinal surgery outcomes and implant stability. This information was unavailable for all patients and thus excluded. Another limitation is the lack of information regarding the decision to determine the number of screws to be augmented owing to the retrospective nature of the study. Based on these results, we recommend restricted cementation augmentation. In addition, we did not analyze global spinal alignment and local kyphosis angles pre- and postoperatively, which might have affected the material complications.

However, as this study mainly aimed to investigate restricted and full cementation in relation to construct stability, complications and surgical revisions were analyzed, and clinical data were excluded.

5. Conclusion

Long-distance dorsal stabilization of the geriatric spine using restricted cementation did not result in high complication rates, particularly screw loosening or implant failure. In addition, the restricted procedure reduced cement leakage rate. Overall, complication rates remain high, even in no cementation procedures, in older adults and often multimorbid patient populations. These findings highlight the comparable stability of restricted cement augmentation with full cementation, making it a viable treatment option. Future multi-center studies with longer follow-up periods are desirable for obtaining more comprehensive and generalizable results.

Author contribution

Conception and design of the study: UJAS, PG, and PP. Acquisition of data, or analysis, and interpretation of data: UJAS, PG, PP, GO, and CEH. Drafting the article or revising it critically for important intellectual content: UJAS, PG, PP, GO, and CEH. All the authors have read and approved the final version of the manuscript.

Declaration of generative AI in scientific writing

The authors disclose the use of AI and AI-assisted technologies in the writing process.

Funding

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

Conflict of interest

The authors report no conflicting interests.

Acknowledgements

We would like to thank Editage (www.editage.com) for English language editing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bas.2025.104227.

References

Bostelmann, R., Keiler, A., Steiger, H.J., Scholz, A., Cornelius, J.F., Schmoelz, W., 2017. Effect of augmentation techniques on the failure of pedicle screws under craniocaudal cyclic loading. Eur. Spine J. 26, 181–188. https://doi.org/10.1007/s00586-015-3904-3.

Bresolin, N., Sartori, L., Drago, G., Pastorello, G., Gallinaro, P., Del Verme, J., Zanata, R., Giordan, E., 2024. Systematic review and meta-analysis on optimal timing of surgery for acute symptomatic metastatic spinal cord compression. Medicina (Kaunas) 60, 631. https://doi.org/10.3390/medicina60040631.

El Saman, A., Kelm, A., Meier, S., Sander, A.L., Eichler, K., Marzi, I., Laurer, H., 2013. Intraoperative PEEP-ventilation during PMMA-injection for augmented pedicle screws: improvement of leakage rate in spinal surgery. Eur. J. Trauma Emerg. Surg. 39, 461–468. https://doi.org/10.1007/s00068-013-0319-x.

Feng, Q., Zhang, Z., Wang, D., Feng, J., 2022. Comparing the efficacy and safety of cement-augmented fenestrated pedicle screws and conventional pedicle screw in surgery for spinal metastases: a retrospective comparative cohort study. Transl. Cancer Res. 11, 4397–4408. https://doi.org/10.21037/tcr-22-2631.

Harris, P.A., Taylor, R., Thielke, R., Payne, J., Gonzalez, N., Conde, J.G., 2009. Research electronic data capture (REDCap)–a metadata-driven methodology and workflow process for providing translational research informatics support. J. Biomed. Inf. 42, 377–381. https://doi.org/10.1016/j.jbi.2008.08.010.

Hoppe, S., Loosli, Y., Baumgartner, D., Heini, P., Benneker, L., 2014. Influence of screw augmentation in posterior dynamic and rigid stabilization systems in osteoporotic lumbar vertebrae: a biomechanical cadaveric study. Spine 39, E384–E389. https://doi.org/10.1097/BRS.0000000000000198.

Janssen, I., Ryang, Y.M., Gempt, J., Bette, S., Gerhardt, J., Kirschke, J.S., Meyer, B., 2017. Risk of cement leakage and pulmonary embolism by bone cement-augmented pedicle screw fixation of the thoracolumbar spine. Spine J. 17, 837–844. https://doi.org/10.1016/j.spinee.2017.01.009.

Kreinest, M., Rillig, J., Grützner, P.A., Küffer, M., Tinelli, M., Matschke, S., 2017. Analysis of complications and perioperative data after open or percutaneous dorsal instrumentation following traumatic spinal fracture of the thoracic and lumbar spine: a retrospective cohort study including 491 patients. Eur. Spine J. 26, 1535–1540. https://doi.org/10.1007/s00586-016-4911-8.

Morimoto, T., Kobayashi, T., Hirata, H., Tsukamoto, M., Yoshihara, T., Toda, Y., Mawatari, M., 2023. Cardiopulmonary cement embolism following cement-augmented pedicle screw fixation: a narrative review. Medicina (Kaunas) 59, 407. https://doi.org/10.3390/medicina59020407.

Riesner, H.J., Blattert, T.R., Krezdorn, R., Schädler, S., Wilke, H.J., 2021. Can cavity-based pedicle screw augmentation decrease screw loosening? A biomechanical in vitro study. Eur. Spine J. 30, 2283–2291. https://doi.org/10.1007/s00586-020-06676-1.

Ruiz Santiago, F., Láinez Ramos-Bossini, A.J., Moraleda-Cabrera, B., 2023. Factors influencing vertebral collapse in osteoporotic vertebral fractures: a case-control study of symptomatic patients attended in the emergency department. Arch. Osteoporosis 19, 6. https://doi.org/10.1007/s11657-023-01365-0.

Schaefer, R.O., Rutsch, N., Schnake, K.J., Aly, M.M., Camino-Willhuber, G., Spiegl, M. Holas U., Muijs, S., Albers, C.E., Bigdon, S.F., 2024. Rigid spine injuries - a comprehensive review on diagnostic and therapeutic challenges. Brain Spine 4, 102811. https://doi.org/10.1016/j.bas.2024.102811.

Schnake, K.J., Blattert, T.R., Hahn, P., Franck, A., Hartmann, F., Ullrich, B., Verheyden, A., Mörk, S., Zimmermann, V., Gonschorek, O., Müller, M., Katscher, S., Saman, A.E., Pajenda, G., Morrison, R., Schinkel, C., Piltz, S., Partenheimer, A., Müller, C.W., Gercek, E., Scherer, M., Bouzraki, N., Kandziora, F., 2018. Classification of osteoporotic thoracolumbar spine fractures: recommendations of the spine section of the German society for Orthopaedics and trauma (DGOU). Glob. Spine J. 8, 46S–49S. https://doi.org/10.1177/2192568217717972.

Spiegl, U.J.A., Jarvers, J.S., Heyde, C.E., Glasmacher, S., von der, Höh N., Josten, C., 2016. Zeitverzögerte Indikationsstellung zur additiv ventralen Versorgung thorakolumbaler Berstungsfrakturen Welcher Korrekturverlust ist zu erwarten. Unfallchirurg 119, 664–672. https://doi.org/10.1007/s00113-015-0056-1.

Spiegl, U.J., Weidling, M., Schleifenbaum, S., Reinhardt, M., Heyde, C.E., 2020. Comparison of long segmental dorsal stabilization with complete versus restricted pedicle screw cement augmentation in unstable osteoporotic midthoracic vertebral body fractures: a biomechanical study. World Neurosurg 143, e541–e549. https://doi.org/10.1016/j.wneu.2020.08.002.

Spiegl, U.J., Weidling, M., Nitsch, V., Heilmann, R., Heilemann, M., Wendler T, T., Schleifenbaum, S., Reinhardt, M., Heyde, C.E., 2021. Restricted cement augmentation in unstable geriatric midthoracic fractures treated by long-segmental posterior stabilization leads to a comparable construct stability. Sci. Rep. 11, 23816. https://doi.org/10.1038/s41598-021-03336-2.

Yuan, L., Zhang, X., Zeng, Y., Chen, Z., Li, W., 2023. Incidence, risk, and outcome of pedicle screw loosening in degenerative lumbar scoliosis patients undergoing long-segment fusion. Glob. Spine J. 13, 1064–1071. https://doi.org/10.1177/21925682211017477.