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MONOGRAPH COLUMN

Tips and tricks for using cement augmentation of pedicle screws and vertebral body replacements—A literature review supported by two case reports

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Augmentation;
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Abstract
Background: The prevalence of osteoporosis is escalating alongside an aging global population, increasing the demand for spinal surgeries, including those necessitating cement augmentation for enhanced construct stability.
Objective: This article delves into the nuanced application of cement augmentation techniques for pedicle screws and vertebral body replacements (VBR), aimed at optimizing surgical outcomes in osteoporotic spines.
Method: Drawing from a comprehensive literature review according to important clinical and biomechanical studies and the authors' clinical experiences, we elucidate strategies to mitigate complications and improve surgical efficacy.
Results: Cement augmentation has shown promise in managing vertebral fractures and in securing pedicle screws within osteoporotic vertebrae, with the advent of polymethylmethacrylate (PMMA) bone cement marking a pivotal advancement in spinal surgery. We highlight intraoperative measures like the choice between pre-injecting cement and utilizing cannulated or fenestrated screws, emphasizing the importance of controlling cement viscosity to prevent leakage and embolism. Through two case reports, we demonstrate the practical application of endplate cementation following VBR.

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Conclusion: While the use of cement augmentation poses certain risks, its judicious application—supported by evidence-based guidelines and surgical expertise—can substantially enhance the stability of spinal constructs in osteoporotic patients. This allows a reduction in instrumentation length by enhancing biomechanical stability concerning pullout, bending, and rotational forces. Furthermore, the incidence of endplate sintering following VBF can be significantly reduced. Future research, particularly on antibiotic-loaded PMMA, may further expand its utility and optimize its safety profile.

PALABRAS CLAVE
Cemento óseo;
Cirugía de columna;
Tornillos pediculares;
Cuerpo vertebral

Consejos y trucos para el uso de cemento óseo en tornillos pediculares y en reemplazos de cuerpos vertebrales: una revisión de la literatura respaldada por dos informes de casos

Resumen
Antecedentes: La prevalencia de la osteoporosis está aumentando junto con el envejecimiento de la población mundial, lo que aumenta la demanda de cirugías de columna, incluidas aquellas que requieren el uso de cemento óseo para mejorar la estabilidad.
Objetivo: Este artículo profundiza la aplicación matizada de técnicas con cemento óseo en tornillos pediculares y reemplazos de cuerpos vertebrales (VBR), con el objetivo de optimizar los resultados quirúrgicos en columnas osteoporóticas.
Método: A partir de una revisión exhaustiva de la literatura según importantes estudios clínicos y biomecánicos, así como las experiencias clínicas de los autores, dilucidamos estrategias para mitigar las complicaciones y mejorar la eficacia quirúrgica.
Resultados: El uso de cemento óseo ha mostrado ser prometedor en el tratamiento de las fracturas vertebrales y en la fijación de tornillos pediculares dentro de las vértebras osteoporóticas. La llegada del cemento óseo de polimetilmetacrilato (PMMA) marca un avance fundamental en la cirugía de la columna. Se destacan medidas intraoperatorias como la elección entre preinyectar el cemento óseo y utilizar tornillos canulados o fenestrados, enfatizando la importancia de controlar la viscosidad del cemento para prevenir fugas y embolias. A través de dos informes de casos, demostramos la aplicación práctica de la cementación de la base del cuerpo vertebral después de VBR.
Conclusión: Si bien, el uso de cemento óseo plantea ciertos riesgos, su aplicación juiciosa es respaldada por directrices basadas en evidencia y experiencia quirúrgica, pudiendo mejorar sustancialmente la estabilidad de las estructuras espinales en pacientes osteoporóticos. Esto permite una reducción en la longitud de la instrumentación al mejorar la estabilidad biomecánica con respecto a las fuerzas de tracción, flexión y rotación. Además, se puede potenciar significativamente su uso en conjunto con fusiones espinales después de cementar la base del cuerpo vertebral (VBF). Las investigaciones futuras, en particular sobre el PMMA impregnado de antibióticos, pueden ampliar aún más su utilidad y optimizar su perfil de seguridad.

Introduction

Osteoporosis is the most prevalent bone disease worldwide and represents an increasing challenge in spinal surgery, contributing to the complexity of surgical interventions and affecting the patient outcomes.[1,2] As the global population ages, the incidence of osteoporosis is projected to further increase, and thus, its impact on spinal health and healthcare systems is becoming an increasingly pertinent issue.[1,3] This systematic skeletal disease is characterized by a decreased bone density and the degradation of bone microarchitecture, which significantly increases the fracture risk.[4] Furthermore, the decreased bone quality complicates the treatment of spinal fixation and fusion procedures, particularly in the context of pedicle screw fixation strength and the success of vertebral body replacement (VBR).[5] The inherent weakness of osteoporotic bone compromises the efficacy of conventional fixation techniques, necessitating innovative approaches to improve construct stability and ensure successful patient recovery.[6]

Cement augmentation techniques have shown promising results in the treatment of osteoporotic spines, facilitating the management of vertebral fractures through vertebroplasty or kyphoplasty and enhancing the stability of constructs, notably in the implantation of pedicle screws within osteoporotic vertebrae.[7,8] Therefore, these procedures gained increasingly popularity within the last three decades, leading to an increased number of cementation procedures in spinal surgery.[9] However, the utilization of cement augmentation remains a topic of ongoing debate among spinal surgeons due to associated severe complications. An increase in stiffness enhances the risk of adjacent segment fractures, and the treatment of potential deep wound infections becomes more challenging. The most common risk involves cement leakages, with incidences reported up to 90% in pedicle screw augmentation, which are mostly asymptomatic.[10,11] However, in rare cases, these leakages can lead to fatal pulmonary artery embolism or, when leaking into the spinal canal, injury of neural structures, potentially resulting in paralysis.[12,13] Consequently, the use of cement augmentation techniques must be approached with caution, ultimately to improve patient care in the context of the challenging increase of patients requiring spinal surgery while suffering from osteoporosis.

The aim of this study is to share a comprehensive compilation of tips and tricks for using cement augmentation of pedicle screws and VBR, garnered from our clinical experience as well as from biomechanical and clinical studies, highlighting the nuanced strategies that can reduce the complication rate and, thus, optimize the surgical outcome following cement augmentation procedures in osteoporotic spine patients.

Methods

We conducted a comprehensive review of relevant literature to aggregate and analyze existing biomechanical and clinical studies on the application of cement augmented vertebral fixation for patients who have osteoporosis. Our search aimed to encompass research articles published in English, German, or Spanish in peer-reviewed journals without any temporal restriction. Additionally, we reviewed guidelines and systematic reviews related to cement augmentation to extract further recommendations. These findings are presented for (1) cement augmentation of pedicle screws and (2) cement augmentation of VBR, augmented by the authors' own clinical experiences.

To effectively fill the gap between theoretical knowledge and practical application, we selected two case reports from our institutional database that illustrate the use of cement augmentation in VBR procedures. These cases were specifically chosen for their ability to illustrate the application, benefits, challenges, and outcomes of these techniques in distinct patient scenarios.

Cement augmentation of pedicle screws

Patient selection

Patients with osteoporosis are at an increased risk for screw loosening and axial pullout, with this risk being even higher in transition zones.[6] To improve construct stability, surgeons may choose long segment fixation, usage of larger screw diameters, or cement augmentation of the pedicle screws. However, given the multimorbidity of elderly patients, small pedicle diameters, especially in fractures of the thoracic or thoracolumbar spine, as well as the need for correction of deformity, cement augmentation can be effectively combined with minimally invasive techniques such as percutaneous short segment fixation (to minimize blood loss and soft tissue damage), dynamic stabilization using PEEK rods and decompression without anterior fusion, as well as small-diameter pedicle screws.[14,15] To account for potential severe adverse events, the decision to use bone cement should be made based on clear indication criteria (see Table 1). Therefore, cement augmentation is usually recommended in cases of severe osteoporosis with a T-score below −3 as measured by Dual-Energy X-ray Absorptiometry (DEXA).[16,17] Although DEXA measurement is commonly considered the gold standard in the diagnosis of osteoporosis, consideration for cement augmentation should also be given in cases where bone density is below 120 HU on CT scans.[4,18–21] From our experience, cementation of bones with a density below 80 HU offers a clinically relevant advantage and can be performed as a standard. For this reason, a CT scan of the fracture and adjacent levels is justified in most cases, even in younger patients, especially in postmenopausal women. This is particularly pertinent as preoperative DEXA measurements are rarely available. Fur-

Table 1 Cement augmentation of pedicle screws.

	''Tips and tricks''
Patient selection	When should cement augmentation be considered? - Intended short-segment fixation or fusion - Usage of small-diameter pedicle screws - Fracture reduction or deformation correction intended - Revision of cement-augmented pedicle screws Osteoporotic bone quality likely - DEXA measurement: T-score below −3 - CT measurement: HU below 120–80 - Surgeon's experience: low insertion torque
Intraoperative measures	Injection of high-viscosity bone cement: ''take your time'' Pulsed jet lavage prior to cementation Volume per screw: lumbar spine 1–2 ml, thoracic spine 1–1.5 ml Pulsed fluoroscopy while injecting Symmetric cement volumes PEEP > 15 cmH_2O while injecting (Limited cement augmentation in long segment constructs, confined to the two end vertebrae)

Overview. CT: computed tomography. DEXA: dual-energy X-ray absorptiometry. PEEP: positive end-expiratory pressure. HU: Hounsfield unit.

thermore, our experience has shown that it is also effective to use cement if low insertion torque is encountered during screw placement. For this reason, a decision should be made preoperatively for an appropriate screw type, especially if there is suspicion of reduced bone quality. If revision of cement-augmented pedicle screws is needed, the revision screws should be also implanted cement-augmented, as this improves the axial pull-out force of the revision screw compared to non-augmented screws. Although some studies have reported favorable outcomes following the use of cement augmentation in cases of infectious spinal diseases, due to current lack of scientific evidence, we generally consider the application of cement in the context of spinal infections contraindicated. Nonetheless, antibiotic-loaded polymethylmethacrylate (PMMA) presents an intriguing area for future research endeavors.[22]

Intraoperative measures

Cement augmentation of pedicle screws can be performed through two distinct methods: firstly, by pre-injecting bone cement before screw placement, and secondly, using cannulated or fenestrated screws. Biomechanical testing has demonstrated the superiority of cannulated screws, thereby establishing them as the standard approach.[23–25] The authors advocate for the use of cannulated – or fenestrated – screws in cases where compromised bone quality is anticipated or when reduction of a deformity is planned. This approach allows for a post-insertion decision on whether cement augmentation is necessary. Should cement augmentation of the screws not be required – for instance, due to satisfactory insertion torque and screw retention in the pedicle – cannulated screws present no disadvantage compared to standard non-cannulated screws.[26] This strategy helps to avoid unnecessary intraoperative screw revisions that could compromise primary stability. Furthermore, when performing a repositioning maneuver on the instrumented vertebrae, biomechanical testing has shown that cement augmentation of pedicle screws after the repositioning achieves greater construct stability compared to cement augmentation prior to the insertion.[27]

The most common adverse event during pedicle screw augmentation is cement leakage. In numerous studies the cement viscosity has been identified as crucial factor influencing the risk of cement leakage.[12,28–31] Injecting cement at low viscosity significantly increases the risk of uncontrolled cement leakage, ultimately increasing the risk of pulmonary embolism.[12] Therefore, cement augmentation should be performed after the viscosity increase. In clinical practice, the desired viscosity is attained at the earliest when the cement, upon being extruded through a syringe, does not spontaneously drip due to gravity but instead maintains a tubular formation.[32] To conclude, the cement should be injected at the latest time possible.[33] However, injection of high viscose cement necessitates higher injection forces, presenting challenges for manual injection systems and increasing the risk of (fat) embolism.[12,29] Recent in vitro and in vivo research indicates that pulsed jet lavage can mitigate these risks by reducing the required injection force. To do so a sodium solution is administered through one pedicle and then removed with low vacuum from the contralateral side (see Fig. 1).[33–35] This technique can be performed during the polymerization phase of the PMMA cement—namely, in the interval between screw placement and the onset of high cement viscosity—thereby not significantly extending the surgical duration. Additionally, this procedure aids in ensuring the accurate placement of pedicle screws before commencing cementation. At the time of cement injection, the surgeon should inform the anesthesiologist to increase the positive end-expiratory pressure (PEEP) to 15 cmH_2O, as this may reduce the incidence of local venous and pulmonary embolism.[36]

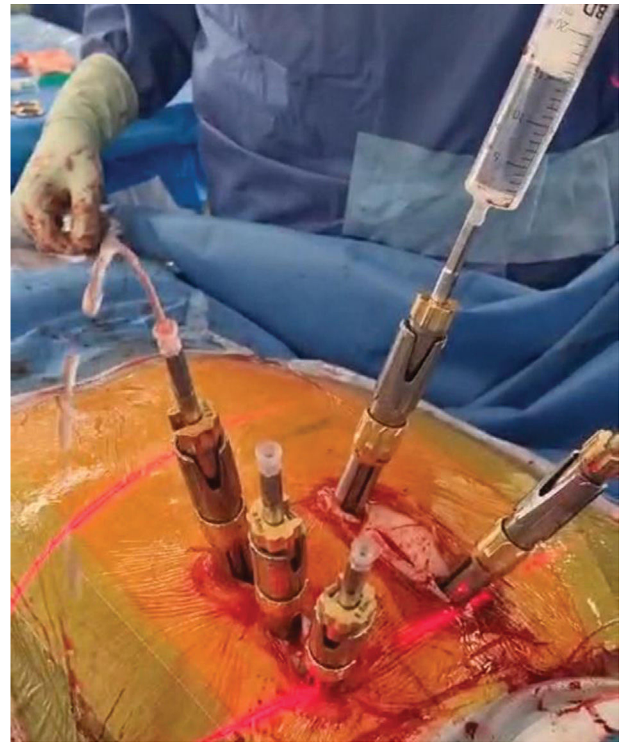

Figure 1 Exemplary illustration of pulsed jet lavage in a bisegmental percutaneous cement augmented dorsal fixation: 0.9% sodium chloride solution is flushed through the vertebral body using a 20 ml syringe and exits on the contralateral side. This results in a washout of the vertebra's intertrabecular bone marrow, reducing the required injection pressure. Additionally, the screw position is confirmed prior to cement augmentation.

To further reduce the risk of cement or fat embolism, the maximum volume of bone cement should not exceed 1–2 ml for one lumbar vertebra and 1–1.5 ml for a thoracic vertebra per pedicle screw. Higher volumes of injected cement do not correlate with an increased construct stability but with a higher the risk of pulmonary embolism.[11,37–39] Additionally, biomechanical testing suggests that symmetric cement application contributes to enhanced construct stability.[40] To achieve this, both pedicle screws should be cemented either simultaneously or alternately. Cement augmentation of pedicle screws must be consistently performed under lateral pulsed fluoroscopy to monitor the injection process. This enables early identification of potential cement leakage into the venous system, spinal canal, or disk space. In cases requiring long segment fixation, often seen in revision or tumor surgery, a limited cement augmentation confined

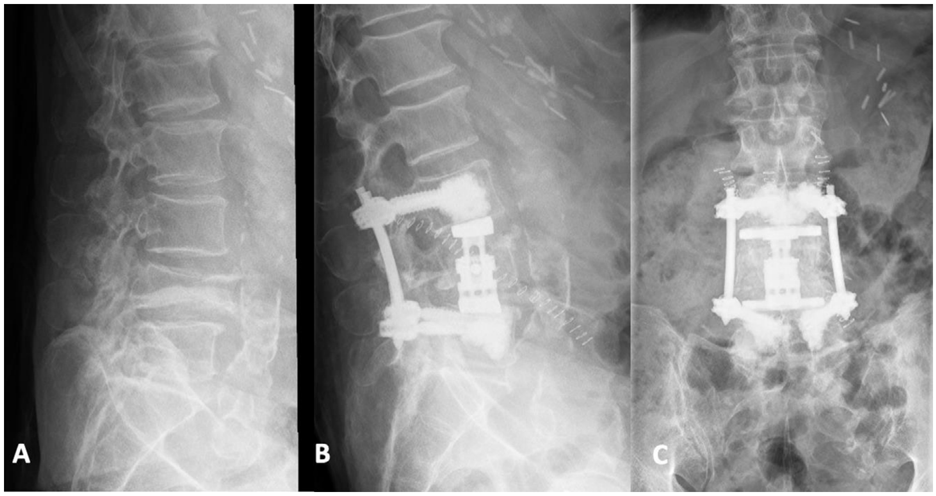

Figure 2 Vertebral body replacement L4. (A) Pathological L4 fracture due to metastatic bronchial carcinoma. (B) Lateral X-ray following short segment fixation with cement augmented pedicle screws and VBR with endplate cementation. (C) Anteroposterior view.

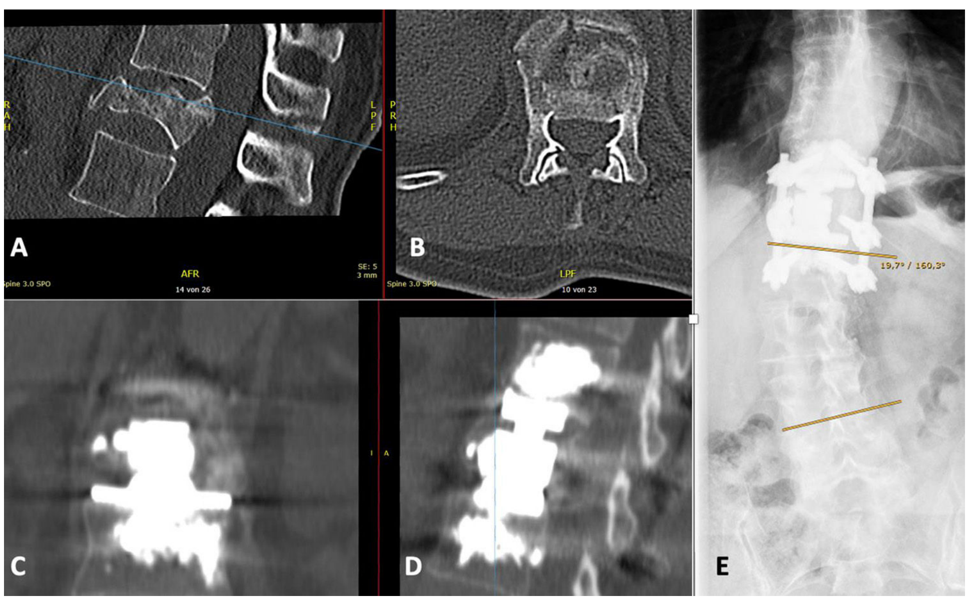

Figure 3 Traumatic Th12 fracture. (A/B) Preoperative CT scan. (C/D) Postoperative CT scan following short segment fixation with cement augmented pedicle screws and VBR with endplate cementation. (E) Stand up X-ray (coronal view) at last follow up. The lumbar scoliosis remained constant. The patient was fully functional and had no restraints in daily activities five years postoperatively.

to the two end vertebrae, may help reduce surgical duration and the risk of complications.[10,41]

Cement augmentation of vertebral body replacements

While the cement augmentation of dorsally implanted pedicle screws is widely practiced and has become a standard part of a spinal surgeon's repertoire, cement augmentation of VBR currently plays a minor role in the clinical practice of most surgeons. In 2010, Geiger et al. first described the feasibility of cement augmentation for VBR in a clinical study involving 20 patients, with clinical and radiological follow-up over two years.[42] The study group aimed to prevent or reduce the likelihood of collapse in VBR cases with reduced bone quality. For this technique, the patient is positioned in a lateral decubitus after dorsal fixation. To access vertebral body fractures above the second lumbar vertebra, a transpleural approach combined with a diaphragmatic split is often performed. For vertebral body fractures involving the second lumbar vertebra or below, a mini-open extraperitoneal approach is performed, and standard VBR is conducted. When preparing the VBR care must be taken to preserve the subchondral bone of the adjacent endplates. After successful implantation of the cage, a 10-

G vertebroplasty needle can be placed half a centimeter above the endplate of the lower and half a centimeter below the endplate of the upper vertebra through the already open approach, under the surgeon's direct vision. Cement augmentation is then carried out under pulsed lateral fluoroscopy guidance. Beyond this initial description, only a few studies have been published. However, biomechanical investigations suggest that cement augmentation significantly increases construct stability.[43,44] According to Ullrich et al. PMMA endplate augmentation should be performed when bone HU are below 180.[45]

As an example, we chose the described approach for an 81-year-old patient presenting to our clinic with a pathological L4 fracture due to metastatic bronchial carcinoma (Fig. 2). Following radiation therapy, there was a progressive compression and instability of the vertebral body as a result of radiation-induced vertebral necrosis. Due to accompanying symptomatic spinal canal stenosis with right-sided lumbar sciatica from neuroforaminal and lateral recess stenosis, a dorsal percutaneous spondylodesis from L3 to L5 with cement-augmented pedicle screws was performed, along with a dorsal hemilaminectomy of the fourth lumbar vertebra with facetectomy and decompression of the right L4 and L5 nerve roots. Subsequently, after repositioning the patient, VBR (Obelisk, Ulrich Medical) with cementation of the endplates was conducted under direct vision as previously described.[42] Ten days postoperatively, the patient was discharged for outpatient treatment. Follow-up examinations showed a satisfactory outcome.

Another case involved a 71-year-old female patient who presented after falling from a horse, sustaining a traumatic Th12 fracture (Fig. 3). X-rays revealed degenerative lumbar scoliosis (Cobb angle 19°). Despite a *T*-score of −1.9, we opted for cement-augmented short segment fixation for this mobile and active patient, and due to recurrent axial traumas from horseback riding, we decided on additional cementation of the endplates. The procedure was performed in two stages without complications. One year postoperatively, the patient reported being able to horseback ride unrestrictedly, and despite the short-segment fusion at the thoracolumbar junction the most recent five-year follow-up showed an uneventful and satisfactory clinical and radiological outcome.

Conclusion

Amidst the demographic shift toward an aging global population, not only is the necessity for spinal procedures expected to increase overall, but there is also an anticipated increase in the number of spinal interventions requiring cement augmentation due the rising incidence of osteoporotic spinal fractures. Although cement augmentation may initially seem daunting to young surgeons due to potentially severe complications, extended surgery duration, and more demanding techniques, the decision to use cement often proves beneficial in the long run. With careful patient selection and adherence to the experiences accumulated over recent decades, cement augmentation of pedicle screws is generally a feasible and safe procedure that significantly reduces the need for revision surgeries due to implant failure. Furthermore, cement augmentation of endplates provides an effective method for VBR, preventing the collapse of the rigid construct even in short segment dorsoventral approaches. Future research, such as on antibiotic loaded PMMA, may further expand its utility and safety profile, especially for high-risk patients such as those that need spinal fixation due to tumor or revision surgery.

Level of evidence

Level of evidence III.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Informed consent

Informed consent was obtained from all individual participants included in the study.

Conflicts of interest

The authors declare that they do not have conflicts of interest.

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