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Revisiting Cement Augmentation in Osteoporotic Vertebral Fractures: A Narrative Review

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Study Design: This narrative review synthesizes recent literature on cement augmentation techniques for osteoporotic vertebral fractures, together with current anti-osteoporotic pharmacologic therapies.
Objectives: To evaluate recent advancements in bone cement augmentation, with a focus on material innovations, procedural refinements, and adjunctive therapies that improve vertebral stability and clinical outcomes.
Summary of Literature Review: Polymethylmethacrylate (PMMA) remains the standard augmentation material because of its high compressive strength and predictable polymerization characteristics. However, its stiffness mismatch with osteoporotic bone may increase stress at adjacent vertebral levels. Advances in cement viscosity optimization and low-pressure injection techniques have reduced cement leakage while maintaining mechanical stability. Comparative studies indicate that both percutaneous vertebroplasty (PVP) and percutaneous kyphoplasty (PKP) provide effective pain relief, with PKP demonstrating superior vertebral height restoration and kyphotic angle correction. Implant-assisted systems, such as SpineJack, further enhance vertebral body expansion and sagittal alignment while reducing cement volume and leakage. Despite these technical improvements, secondary vertebral fractures remain frequent, underscoring the importance of adjunctive pharmacologic therapies, including anabolic agents such as teriparatide and romosozumab, to promote bone regeneration.
Materials and Methods: A comprehensive literature review of English-language studies involving human subjects was conducted, including clinical trials, experimental studies, reviews, and meta-analyses.
Results: Both PVP and PKP were associated with significant short-term pain relief, with PKP showing greater vertebral height restoration and kyphotic correction. Implant-assisted augmentation systems, including SpineJack, demonstrated improved vertebral alignment and lower rates of cement leakage. Nonetheless, the incidence of adjacent vertebral fractures remained substantial, highlighting the need for concomitant osteoporosis treatment.
Conclusions: Cement augmentation remains essential in OVCF management. An integrated approach that combines biomechanical optimization with systemic anabolic osteoporosis therapy may offer the greatest potential for achieving both structural stability and biological bone restoration.

Key words: Osteoporotic vertebral compression fractures (OVCFs), Bone cement augmentation, Percutaneous vertebroplasty (PVP), Balloon kyphoplasty (PKP), Polymethylmethacrylate (PMMA), Anabolic therapy

Introduction

Osteoporotic vertebral compression fractures (OVCFs) are the most common kind of fracture associated with osteoporosis. OVCFs comprise around 27% of all osteoporotic fractures and linked to high economic burden.[1,2] It is prevalent among the older population, and as life expectancy and the number of people with osteoporosis rise, OVCFs are becoming more common across the world. In the younger population, OVCFs occur less frequently and often associated with minimal trauma and pre-existing metabolic or other medical conditions

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(e.g. Cushing's syndrome) or chronic use of glucocorticoids.[3,4]

In addition to discomfort and deformity, OVCFs have serious effects physically and mentally. Prolonged recumbency can produce acute vertebral collapse, which can lead to pressure sores, venous thromboembolism, and pulmonary compromise, as well as limitation of movement.[5] Progressive kyphosis leads to persistent discomfort, reduced lung capacity, loss of sagittal balance, and a decline in quality of life over time. OVCFs are independently associated with a 15–21% elevation in mortality within one-year post-injury and can increase the likelihood of recurrent fractures by as much as four times.[1,5] OVCFs can affect activities of daily living (ADLs), which further declines the quality of life (QOL) of the affected individual.

OVCFs are often managed conservatively, comprising of analgesic medication, anti-osteoporotic medication, exercise (e.g. physiotherapy), and a spinal orthosis or short-term bed rest.[1] However, complicated cases that cannot be managed conservatively can be challenging. Vertebral cement augmentation has been a key part of managing OVCFs for the past 30 years when more conservative methods don't work. It provides mechanical stability and quick pain alleviation. The field has shifted from percutaneous vertebroplasty to balloon kyphoplasty and, more recently, to third-generation expandable devices like the SpineJack®, in order to improve the restoration of spine height and prevent cement from leaking.[1] The objective of cement augmentation has been broadened beyond vertebral body stability to embrace entire osteoporotic spine repair at the same treatment, employing cement-augmented pedicle screw fixation and preventive reinforcing of surrounding levels.[1,5] Despite the numerous studies focusing on vertebral cement augmentation as treatment for OFs, the significant heterogeneity present in each studies make the findings conflicting.

1. Three Generations of Vertebral Cement Augmentation

Three generations of vertebral cement augmentation techniques for osteoporotic vertebral compression fractures (OVCFs) have been developed over the years. Theoretically, each is said to have enhanced efficacy and safety over the previous one but also entail higher cost and newer technology.[6]

Several classification systems for osteoporotic vertebral compression fractures (OVCFs) have been proposed over the past decades based on imaging characteristics e.g. Eastell et al., McCloskey et. al, Sugita et. al, Genant et. al and DGOU classifications. However, only a limited number have achieved international recognition and continue to be debated among specialists.[7] Additionally, classification from time of fracture is not standardized e.g. acute, subacute or chronic and the type of cement augmentation technique recommended for these different classifications is lacking.

In 2012, Nieuwenhuijse et al.[8] classified painful OVCFs as Acute and subacute (2 months to 6 months or chronic (more than 6 months).

Percutaneous vertebroplasty (PVP), the first percutaneous cement augmentation technique done mainly for pain management, originated in the late 1980s.[6] To mend the trabecular bone and quickly relieve pain, polymethylmethacrylate (PMMA) is injected into the injured vertebra while being observed via a fluoroscope.[9] Percutaneous vertebroplasty is still linked to rather high rates of cement leakage, even if new technologies like phased or high-viscosity injections have made it safer. However, symptomatic leakage remains low. Although it doesn't restore spinal height, it does help with pain and mobility.[10] A study highlighted the effectiveness of PVP in managing painful OVCFs, showing that its benefits are not influenced by the time elapsed since the fracture, provided it falls between 2 and 12 months. The researchers concluded that patients with painful OVCFs older than two months can still safely undergo percutaneous vertebroplasty, making it a viable treatment option within 2 to 12 months after symptom onset.[8] A meta-analyses indicates that percutaneous vertebroplasty provides greater improvements in pain, functional ability, and quality of life than conservative treatment. However, when compared with placebo, these benefits become less evident.[11]

Percutaneous balloon kyphoplasty (PBK) known to be the second generation of vertebral cement augmentation, was created to resolve some of the limitations of percutaneous vertebroplasty. It lowers the risk of leaking and is indicated to restore spinal height. The method creates an intravertebral cavity using inflating balloons, which elevates the endplates before injecting low-pressure cement,[11,12] shown in Fig. 1. Meta-analyses indicate that percutaneous balloon kyphoplasty enhances short-term pain relief and functionality compared to conservative therapy, while comparative studies demonstrate its superior correction of kyphotic deformity and reduced leakage rates relative to percutaneous vertebroplasty.[13] The indications for percutaneous balloon kyphoplasty are largely similar

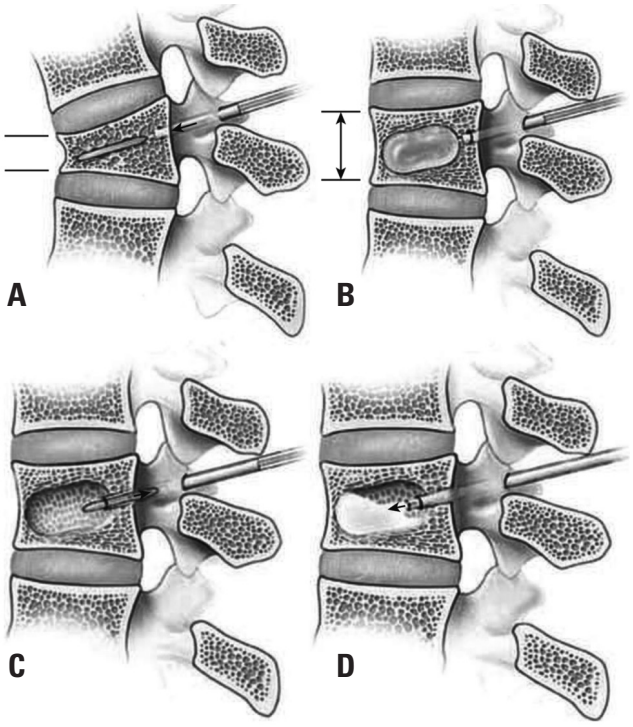

Fig. 1. (A) During kyphoplasty, the fractured vertebral body is percutaneously cannulated with an inflatable bone tamp. **(B)** The tamp is inflated, which elevates the vertebral body endplates and restores vertebral body height. **(C)** The tamp is withdrawn, leaving a cavity to be filled with bone void filler. **(D)** Bone void filler is placed into the vertebral body under low pressure.
Herkowitz, H. N., Garfin, S. R., Eismont, F. J., Bell, G. R., & Balderston, R. A. (2011). Rothman-Simeone the spine (6th ed.). Elsevier Health Sciences (pp. 1599).

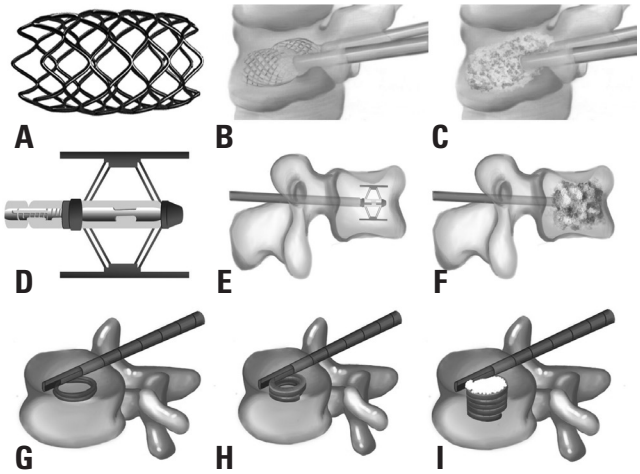

Fig. 2. Vertebral body stenting, Spine Jack, and Kiva system. **(A)** Vertebral body stenting appearance. **(B)** Vertebral restoration using vertebral body stenting. **(C)** Bone cements injected after vertebral body stenting expansion. **(D)** Expanded Spine Jack. **(E)** Spine Jack expanded inside the vertebra via a transpedicular approach. **(F)** Bone cements augmenting the restored vertebra after the Spine Jack is placed inside the vertebra. **(G)** Guided coil of the Kiva system inserted via transpedicular cannula. **(H)** PEEK implant of the Kiva system along the guide wire forming a hollow cylinder inside the vertebra. **(I)** Injected polymethylmethacrylate cement, surrounded by the Kiva system.
Luo Y, Yang DM, Yang HM, Wu D, Xie FY. Innovative minimally invasive implants for osteoporosis vertebral compression fractures. Front Med (Lausanne). 2023;10:1161174. Published 2023 Mar 20. DOI: 10.3389/fmed.2023.1161174

to those of percutaneous vertebroplasty. However, its ideal application is in acute traumatic vertebral fractures (less than 7–10 days old), especially compression-type fractures with a kyphotic angle exceeding 15 degrees.[14]

The third generation of vertebral cement augmentation highlights the use of advanced systems, which are said to be more effective and outperform the previous methods in correcting localized kyphosis and minimizing adverse events.[15] SpineJack® and Jack vertebral dilator kyphoplasty are third-generation therapies that use expandable intravertebral implants to mechanically restore the height of the vertebral body before cement is injected as shown in Fig. 2. These tools cut down on the quantity of cement used, allows managing the endplate reduction, and make it easier to fix sagittal alignment.[16,17] These systems provide pain relief comparable to kyphoplasty and vertebroplasty but offer better vertebral height restoration and local kyphotic angle correction.[18] Similar to PBK, the Percutaneous Vertebral Augmentation guidelines recommend that percutaneous intravertebral implant procedures (PIP), such as the SpineJack® system, be reserved for younger patients with acute (less than 7 days old) traumatic vertebral fractures accompanied by a significant local kyphotic angle greater than 15 degrees.[19] These devices may offer biomechanical benefits and long-term anatomical rectification, making them suitable solutions for certain patients, despite their increased cost and technical complexity.

Conversely, beyond providing immediate pain relief, the primary advantage of the SpineJack® system lies in its capacity to correct kyphotic deformity, even in cases of chronic osteoporotic vertebral compression fractures (OVCFs).[20]

The main advantage of VCA is to alleviate the acute symptoms and avoid prolonged immobilization. In a study by Hazzard et al.[21] kyphoplasty and vertebroplasty have comparable long-term costs, reoperation and complication to non-surgical treatment. They concluded that VCA is superior in terms of pain relief considering that vertebral augmentation

and conservative management of osteoporotic vertebral compression fractures (OVCFs) show similar outcomes in terms of cost, reoperation rates, and complications. Techniques for acute versus chronic OVCFs are still variable making it difficult to standardize based on this classification.

2. Medical treatment and Cement Augmentation

To improve results for osteoporotic vertebral fractures (OVCFs), current studies explore the association between vertebral cement augmentation and pharmaceutical osteoporosis treatment. In 2024, Jeon et al.[22] performed a meta-analysis examining the utilization of anabolic therapies in combination with cement augmentation operations like as kyphoplasty or vertebroplasty. The results showed that anabolic medications, such as romosozumab and teriparatide, are significantly more effective than bisphosphonates in reducing the occurrence of new osteoporotic vertebral fractures (RR 0.57, $p<0.001$). Nonetheless, their influence on fracture healing overall remains negligible.

Another study in 2023 by Nair et al.[23] observed that teriparatide led to better functional recovery and less kyphotic progression (4.97° vs. 8.09°) than bisphosphonate therapy alone in the treatment of osteoporotic vertebral compression fractures. Furthermore, union rates are higher in teriparatide at 6 months. The study emphasized that anabolic regimens have biomechanical effects that are either equivalent to or enhance those of cement augmentation.

On the other hand, using bisphosphonates, a common pharmacologic used concurrently with vertebral cement augmentation, for a long time may make remodeling take longer and make the cement-bone contact more brittle. Recent studies recommend starting anabolic treatment and shifting to antiresorptive for long-term maintenance after structural stability is attained.[24,25]

In 2025 study by Mun et al[26] concluded that vertebroplasty offers faster pain relief within the first month, whereas romosozumab achieves better Numeric rating scale (NRS) pain scores after one year. There are no significant differences between the two in radiographic or clinical outcomes, such as Cobb angle or compression ratio. Additionally, romosozumab leads to greater lumbar BMD gains and effectively reduces major osteoporotic fracture risk, benefiting both postmenopausal and senile osteoporosis management.

Polymethylmethacrylate (PMMA) injection provides mechanical stability, which is improved by pharmacological augmentation of bone remodeling, especially in reducing adjacent-level fractures, a common consequence of vertebral cementation. Early post-augmentation anabolic treatment improves the healing of microarchitectural bone and helps the augmented area regain its ability to share loads.

Current data supports an integrated therapy model in which cement augmentation offers immediate mechanical stability while pharmacological therapies treat the underlying pathophysiology of bone fragility. Integrating pharmacologic medications with cement augmentation is a dual-modality strategy to osteoporotic vertebral fractures. Anabolic medicines, as seen in previous studies, showed greater improvements in bone mineral density improving functional outcomes. Also, it decreases risk of recurrence of future fractures, pain, and progressive deformity by mechanically restoring strength while biologically enhancing bone quality.

3. Pedicle screw Cement Augmentation

In severe osteoporosis, pedicle screws are frequently compromised by reduced bone mineral density. In cement augmentation of pedicle screws (CAPS), the integrity and stability of the pedicle screws are enhanced.

In 2023, Boucas et al.[27] stated that there are four main methods on how to perform CAPS. Transpedicular vertebroplasty augmentation is when the cement is injected into the vertebral body through the pedicle before the screw is put in place. In kyphoplasty-assisted augmentation, balloon inflation is used to restore the height of the vertebrae before cementation and pedicle screw placement. Third method is when the cement is directly applied onto the pedicle screw before insertion. Lastly, using fenestrated screws where the cement is injected through the implant, provides a homogeneous "cement cloud" that improves the interface between the bone and the implant while reducing extravasation. Existing studies usually focus on a singular method, thus the lack of studies comparing the four methods make it challenging to conclude which one is the best to use. Nevertheless, the comparison of the four techniques to the control group all demonstrated statistically significant increases in pullout strength.

A direct correlation between the maximal extraction strength and the cement filling volume has been observed in different

studies. Yet, it should be balanced against the risk of cement leakage.[29–31] Screw insertion into "doughy" or semi-viscous cement improves bonding in comparison to late insertion after full polymerization or early injection into fluid cement.[27] Hsieh et al.[28] discovered that increasing PMMA from 2 ml to 4 ml heightens pull-out strength by 47% in osteopenic bone, 34% in normal bone, and 10% in osteoporotic bone. To achieve a compromise between pull-out strength and safety, Sung et al.[32] standardized 3 mL injections in their experimental design, demonstrating that this volume is biomechanically ideal for the application of fenestrated screws. Additionally, a controlled injection pressure of 1.6 and 2.0 kg and adjusting cement viscosity is important to prevent leakage. On the other hand, excessive cementing can make leakage worse, especially in very osteoporotic bone, since it makes the trabecular porosity higher. Current clinical consensus indicates that precise quantities of cement approximately 1 mL to 3 mL for thoracolumbar applications are necessary to ensure adequate fixation while minimizing problems.[33] However, it should be emphasized that the exact quantity of cement may vary depending on the specific procedure and the individual patient factors, but the benchmark volumes may serve as a guide for optimal outcomes.

In addition, the duration of cement polymerization significantly affects the interfacial integrity of the screw and cement. A previous study stated that inserting screws into "doughy" or semi-viscous cement works better than inserting them late, after full polymerization, or early, when the cement is still fluid.[27] Schmoelz et al.[34] elaborated that insertion of screw in a "doughy" cement and firmly bonded to it, failed mainly at the cement-bone interface, causing the screw-cement construct to move within the trabecular bone. On the other hand, insertion of screw in a "hard" resulted to loosening at screw cement interface. Delayed insertion creates microfractures in hardened cement, which weakens the fixing strength. Cho et al.[35] noted that substituting calcium phosphate (CP) cement for PMMA results in maximal augmentation power at 4 minutes post-mixing, followed by a quick fall after 6 minutes. These results show that in order to improve the bone-cement and screw-cement interfaces, synchronizing cement viscosity and insertion time should be observed.

Polymethylmethacrylate (PMMA) is the usual cement material pedicle screw augmentation because it polymerizes quickly, is easy to work with, and is strong enough to hold up under stress. Its exothermic response and lack of osteoconductive property, on the other hand, has made others interested in bioactive substitutes. Boucas et al.[27] shared that calcium phosphate (CP) and calcium sulfate (CS) are good options for long-term bone remodeling since they can help bones grow and heal. However, even though these materials have certain benefits, they don't hold together as well at first as PMMA does, and they only become stable after osseointegration. Renner et al. and Choma et al.[36,37] found that PMMA injection resulted in significantly greater pullout strength in both revision and augmentation procedures compared to CP cement injection. Although, calcium phosphate cement may not reliably predict long-term effectiveness, as the calcium-based cement interacts with and is gradually replaced by bone. CP led to a more even spread of the cement. Silicone-based elastomeric materials have also shown superior resilience to cyclic loading in cadaveric models, which makes them good for applications that don't need a lot of heat. Distribution among different cement materials vary. Due to the relatively recent popularity of alternative material use as compared to PMMA, data comparing the materials used for CAPS is lacking. In general, the biomechanical data support to the utilization of cement augmentation to enhance the strength of the implanted construct.[27]

As important as the cement material to be used, various screw designs are also available. The most common screw types in clinical use are cannulated screw (Cann); distal one-hole screws (D1); distal two-hole screws (D2); middle two-hole screws (M2); and traditional screws (Trad). Sung et al.[32] revealed that the M2 screws exhibited the greatest distance between the cement center and screw point, which suggests a heightened risk of cement discharge into the spinal canal. The Trad screws exhibited the greatest migration distance, which suggests a higher level of risk. The D1 screws exhibited the highest pull-out strength, followed by D2 especially in severe osteoporosis as shown in Fig. 3. Their study concluded that D1 screws were the best option for optimizing biomechanical function and reducing cement leakage in osteoporotic bone patients undergoing spinal surgery.

4. Prophylactic Adjacent level cement augmentation in deformity surgery

Prophylactic vertebral cement augmentation usually uses

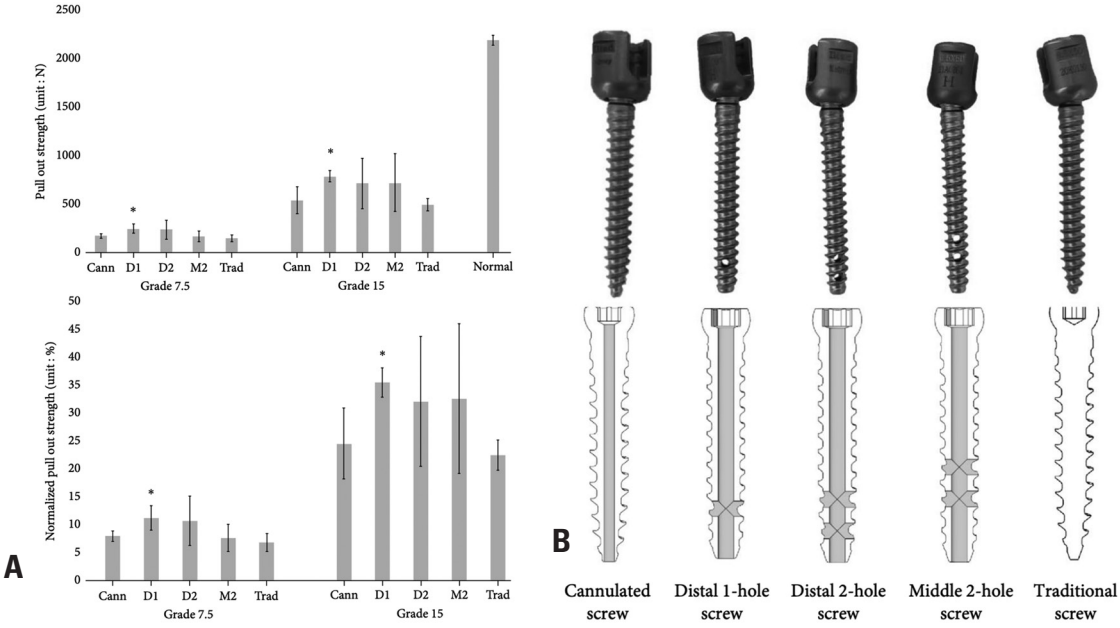

Fig. 3. (A) Comparison of Pull-out strength and normalized pull-out strength. **(B)** Different types of screws for augmentation.
Sung S, Kwon JW, Park TH, Lee SB, Moon SH, Lee BH. Biomechanical comparison and three-dimensional analysis of cement distribution patterns for different pedicle screw designs. Biomed Res Int. 2022;2022(1):8293524.

vertebroplasty and done at the levels adjacent to long-segment fusions. This has emerged as a preventive strategy against proximal junctional kyphosis (PJK) and proximal junctional failure (PJF), which are mechanical complications that frequently arise following extensive deformity correction in patients with osteoporosis. Although there is no universally accepted definition of proximal junctional kyphosis (PJK), it is commonly described as a Cobb angle of ≥10°–20° between the upper instrumented vertebra (UIV) and the two vertebrae above it.[38] Lee and Park[38] states that PJK happens in 6–41% of long-fusion cases, usually within the first 3–18 months after surgery, due to the poor bone quality of upper instrumented vertebra (UIV) and adjacent segments, stress build up, and the rupture of posterior ligament complex. It has been suggested that prophylactic cement reinforcing might enhance local stiffness and postpone junctional collapse to counteract these pathomechanical alterations. Even so, some studies also suggest that prophylactic vertebral cement augmentation increase the risk of adjacent-level fractures by modifying the distribution of physiological stress. Single-level augmentation at the UIV preserves mobility and load distribution; however, multi-level preventive vertebroplasty induces stress asymmetry, potentially hastening degeneration at neighboring levels, as evidenced by a finite element analysis by Shin et al.[39] Fig. 4.

Another meta-analysis conducted by Li et al.[40] involving 1,160 patients found that cement augmentation at the UIV and UIV+1 decreased the risk of PJF by 36% and revision surgery rates by 71%, although there was no statistically significant difference in the overall incidence of PJK. Findings also showed that there were a few occurrences of cement leaking into the spinal canal and cement embolism in the lungs. The study emphasized that prophylactic vertebral cement augmentation is highly beneficial for patients with severe osteoporotic conditions or when fusion ceases at the thoracolumbar junction (e.g., T9–L1), where biomechanical stress is maximal. Han et al.[41] on the other hand, indicated that prophylactic vertebral cement augmentation should be cautiously used in other cases as it may increase the risk of interposed vertebral collapse.

Furthermore, the distribution of bone cement may hasten degeneration in adjacent intervertebral discs, particularly when the cement meets both the superior and inferior endplates, leading to a higher risk of adjacent disc degeneration.[42]

Shin et al.[39] emphasized that careful patient selection is important in performing prophylactic vertebral cement augmentation. The clinical relevance of these findings is in the optimization of the use of prophylactic vertebroplasty and

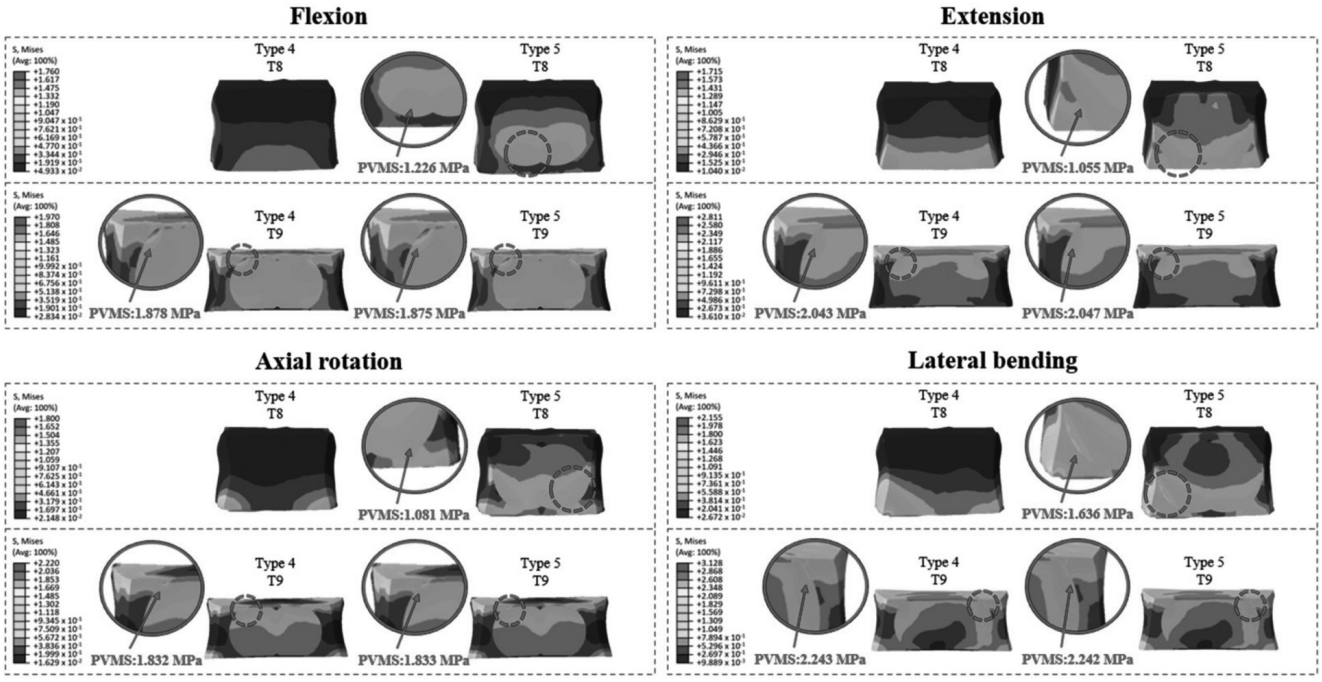

Fig. 4. Areas with elevated stress levels are highlighted and magnified to show the specific distribution and magnitude. The cement augmented T8-T9 are specifically highlighted in this figure.
Shin JW, Kim DH, Kang KM, Park TH, Oh YR, Lee SJ, Lee BH. Biomechanical effects of cement augmentation and prophylactic vertebroplasty on adjacent segment stability in multilevel spinal fusion: a finite element analysis. Bioengineering. 2025;12(10):1071.

cement augmentation to balance structural reinforcement and reduce the risk of injury. It is recommended that additional research should be conducted in osteoporotic populations.

Conclusions

Bone cement augmentation continues to play a vital role in managing painful OVCFs. According to the review of available literature, there are still no standard technique and materials used for vertebral cement augmentation. Advances in implant design and cement delivery are refining its safety and efficacy. Treatment protocols and pathway mainly depend on the individual needs and capacity of the patient and the healthcare team, in addition to many other factors that should be considered in choosing the right option. Integrating biomechanical optimization with systemic anabolic therapy represents a promising direction toward comprehensive structural and biological restoration.

Additional high-quality studies are further needed to fully explore and improve vertebral cement augmentation guidelines.

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골다공증성 척추 골절에서 골시멘트 보강술의 재조명: 서술적 문헌고찰

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연구 계획: 본 종설은 골다공증성 척추 골절의 치료에 사용되는 시멘트 보강술의 최신 기법과 항골다공증 약물 치료에 대해 종설한다.
목적: 골시멘트의 재료적 혁신, 시술 기법의 개선 및 척추 안정성과 임상적 결과를 향상시키는 보조 치료법의 발전을 평가한다.
선언 연구문헌의 요약: 폴리메틸메타크릴레이트(PMMA)는 높은 압축 강도와 예측 가능한 중합 반응으로 인해 여전히 표준 보강 재료로 사용된다. 그러나 골다공증성 뼈와의 강성 불일치는 인접 분절의 응력 증가를 초래할 수 있다. 최근에는 점도 조절 및 저압 주입 기술의 발전으로 시멘트 누출 위험이 감소하면서도 기계적 안정성이 유지되고 있다. 경피적 척추성형술(PVP)과 풍선척추성형술(PKP)은 모두 단기간 통증 완화에 효과적이며, PKP는 척추체 높이 회복과 후만 변형 교정에서 우수한 결과를 보였다. SpineJack®과 같은 임플란트 보조 시스템은 적은 시멘트 양으로도 척추체 확장과 정렬 유지에 효과적이다. 그러나 이차 골절이 여전히 빈번하여 테리파라타이드나 로모소주맙과 같은 약물 치료의 병행이 중요하다.
연구 방법: 영문으로 발표된 인간 대상 연구를 대상으로, 임상 및 실험 연구, 종설, 메타분석을 포함한 포괄적 문헌 고찰을 수행하였다.
결과: 경피적 척추성형술(PVP)과 풍선척추성형술(PKP) 모두 단기간의 통증 완화에 유의한 효과를 보였으며, PKP는 척추체 높이 회복과 후만 변형 교정에서 더 우수한 결과를 나타냈다. SpineJack®과 같은 임플란트 보조 시스템은 척추 정렬을 개선하고 시멘트 누출을 감소시켰다. 그러나 인접 분절 골절은 여전히 빈번하게 발생하여, 보조적인 골다공증 약물 치료를 함께하는 것이 효과적이다.
결론: 골시멘트 보강술은 여전히 골다공증성 척추 골절 치료의 핵심이다. 생체역학적 최적화와 전신적 골형성 치료의 병합은 구조적 및 생물학적 회복을 동시에 달성할 수 있는 접근법으로 평가된다.

색인 단어: 골다공증성 척추 압박 골절(OVCF), 골시멘트 보강술, 경피적 척추성형술(PVP), 풍선 척추성형술(PKP), 폴리메틸메타크릴레이트(PMMA), 골형성제제
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