Cement augmentation in vertebral burst fractures

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As a result of axial compression, traumatic vertebral burst fractures disrupt the anterior column, leading to segmental instability and cord compression. In situations with diminished anterior column support, pedicle screw fixation alone may lead to delayed kyphosis, nonunion, and hardware failure. Vertebroplasty and kyphoplasty (balloon-assisted vertebroplasty) have been used in an effort to provide anterior column support in traumatic burst fractures. Cited advantages are providing immediate stability, improving pain, and reducing hardware malfunction. When used in isolation or in combination with posterior instrumentation, these techniques theoretically allow for improved fracture reduction and maintenance of spinal alignment while avoiding the complications and morbidity of anterior approaches. Complications associated with cement use (leakage, systemic effects) are similar to those seen in the treatment of osteoporotic compression fractures; however, extreme caution must be used in fractures with a disrupted posterior wall.

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Key Words • vertebroplasty • kyphoplasty • burst fracture • thoracic lumbar trauma • cement augmentation

Traumatic burst fractures account for approximately 15% of all spinal injuries.21 These fractures occur due to axial compression and varying degrees of flexion.25 The compressive forces result in anterior and posterior cortical disruption and frequently lead to segmental instability. Multiple classification systems of thoracolumbar injuries exist; some are descriptive, while others attempt to correlate fracture pattern and treatment strategy. Nevertheless, there is still no absolute consensus on which fractures should be treated operatively and what surgical techniques should be used.11,21,36,46,49,57,62,68

Over the past few decades, advancements in pedicle screw instrumentation have allowed surgeons to stabilize thoracolumbar fractures; however, in the setting of diminished anterior column support, isolated pedicle screw use may result in delayed kyphosis, nonunion, and instrumentation failures.14,55,70 Cement augmentation of the vertebral body by vertebroplasty (VP) and kyphoplasty (KP) was originally introduced for osteoporotic compression fractures, but surgeons have now applied these techniques as a method of enhancing anterior column support while avoiding the morbidity and complications associated with anterior approaches.46,47 In this paper, we discuss the utility of VP and KP in the setting of thoracolumbar burst fractures.

History of Cement Augmentation

Vertebroplasty was initially introduced in the mid-1980s in Europe where it was originally applied toward the treatment of vertebral hemangiomas.18,25 Its utility has been extended to the treatment of painful metastatic lesions and osteoporotic compression fractures.28,36,67 Vertebroplasty involves the injection of cement into the vertebral body using a large-bore needle under fluoroscopic guidance via a transpedicular approach.31 Injection of low-viscosity cement allows for a homogeneous distribution within the vertebral trabecular network, thus strengthening the weakened vertebral body.7

Vertebroplasty as well as KP, which is a modified VP technique that allows the restoration of vertebral body height through the use of an expandable balloon, has rapidly gained popularity in the treatment of osteoporotic vertebral fractures. Compared with VP, KP allows improved height restoration and kyphosis correction. Theoretically, there is also a decreased incidence of cement leakage with KP, since cement is injected into a larger cavity under a lower pressure.

In acute osteoporotic fractures, cement augmentation typically leads to rapid pain reduction and early improvement in quality of life in the majority of patients.22,41,65

Abbreviations used in this paper: ASIA = American Spinal Injury Association; CPC = calcium phosphate cement; KP = kyphoplasty; ODI = Oswestry Disability Index; PMMA = polymethylmethacrylate; VAS = visual analog scale; VP = vertebroplasty.

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Beyond pain control, vertebral augmentation leads to shorter hospital stays and better survival than those following nonoperative treatment.\textsuperscript{12} In recent years, cement augmentation has been increasingly used in traumatic burst fractures with promising short-term results.\textsuperscript{10,24}

Cements

The application of polymethylmethacrylate (PMMA) cement in the treatment of osteoporotic compression fractures has a long track record. This type of cement makes an acceptable bone void filler; it is inexpensive, inert, and provides immediate stability.\textsuperscript{52} Low-viscosity PMMA interdigitates within the spongy vertebral trabeculae and hardens through an exothermic reaction that theoretically can provide an analgesic effect by thermal ablation of intraosseous nerve endings.\textsuperscript{1} The limitations of PMMA include the risk of thermal necrosis of surrounding soft tissue during curing and the release of a toxic monomer, which can lead to systemic manifestations.\textsuperscript{6,20} Polymethylmethacrylate may interdigitate between fracture lines and prevent bone healing by acting as a nonresorbable spacer. In addition, PMMA stimulates inflammation and results in the formation of a fibrous layer between bone and cement.\textsuperscript{52}

While the use of PMMA for the treatment of osteoporotic fractures has resulted in excellent outcomes in older patients, the long-term effects of this cement in younger individuals have not been evaluated. Existing evidence on PMMA application in younger patients with traumatic burst fractures is inconclusive. Recently, Cortoss, a new methacrylate polymer, was introduced. This novel composite, whose mechanical properties resemble those of bone more closely than PMMA, has shown promising clinical outcomes in patients with osteoporotic compression fractures.\textsuperscript{4} Long-term reports supporting its use are lacking, however.

Osteoconductive bone void fillers, such as calcium phosphate cement (CPC) and hydroxyapatite biomaterials, have also been used in the treatment of traumatic burst fractures.\textsuperscript{52,63} Calcium phosphate cement undergoes endothermic rather than exothermic curing and thus exhibits less intense thermal effects on surrounding soft tissue. While undergoing degradation by creeping substitution, CPC supports new bone formation and integration at the bone-cement interface.\textsuperscript{5,39,52} Despite its favorable biocompatible properties, CPC in the presence of physiological fluids, such as blood, is susceptible to decay. Because of this disintegration, CPC microemboli can lead to cardiovascular deterioration and even death.\textsuperscript{57} In addition, CPC has been shown to undergo resorption, potentially leading to the loss of vertebral body reduction after KP.\textsuperscript{53} Therefore, we do not currently recommend CPC usage in clinical practice.

Complications Related to Cement Augmentation

During VP, low-viscosity bone cement is injected under pressure and can lead to cement leakage outside the vertebral body. In the majority of cases, cement leaks into the vertebral disc space or paravertebral soft tissues. Although rare, neurological deficits can occur when cement leaks into the spinal canal or vertebral foramina.\textsuperscript{17,29} Other reported complications include cement arterial and pulmonary emboli, epidural hematoma, arterial injury, anaphylaxis, pedicle fractures, and death.\textsuperscript{9,16,19,48} Serious adverse effects are uncommon.

Complications related to KP are less numerous in the literature, most likely because of the more viscous cement that is injected under lower pressure into the vertebral cavity created by the balloon. A recent meta-analysis showed that KP, as compared with VP, has a lower incidence of procedure-related complications and a lower rate of adjacent-level fractures. Cement leaks were found in 14% of cases in the KP group and 75% of cases in the VP group (p < 0.001). These leaks were symptomatic in 0.06% of

![Fig. 1. Kyphoplasty was performed in this patient who had suffered a high-energy fall. Coronal (upper) and axial (lower) views show cement leakage into the paravertebral tissues abutting a calcified aorta.](image-url)
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subjects in the KP group and 1.48% in the VP group. Another meta-analysis supported similar trends in cement leaks between KP and VP groups but failed to show any difference in the incidence of new adjacent vertebral fractures.

Indications for Cement Augmentation in Burst Fractures

Fractures with diminished anterior support due to fracture may result in a 70% decrease in flexural and torsional stiffness. Magerl et al. described anterior column integrity and instability in a very comprehensive classification (AO type fractures). A more recent AOSpine Thoracolumbar Spine Injury Classification scheme combined the work done by Magerl et al. with the Thoracolumbar Injury Classification system (TLICS) in attempt to guide surgical decision making based on fracture morphology as well as neurological status. In burst fractures, especially with disruption of the posterior ligamentous complex, surgery is often recommended to restore the stability of a vertebral segment.

To avoid the morbidity of anterior surgery, many surgeons attempt to treat burst fractures with a posterior-only approach. While many surgeons prefer constructs to include 2 levels above and below the injury, short-segment pedicle screw instrumentation has been used. Despite its advantages in including fewer vertebral segments in spinal fusion, short-segment pedicle screw instrumentation relies heavily on anterior column support. In the setting of deficient anterior support, posterior fixation alone may result in the loss of reduction, hardware failure, and increased kyphosis. McCormack et al. introduced the Load-Sharing Classification to predict when posterior spinal instrumentation would be at risk for failure due to incompetent anterior column support. This classification accounts for the degree of comminution and displacement of the fractured vertebral body fragments in addition to the local kyphosis. At scores greater than 6, Korovessis and colleagues recommend a longer posterior construct or a short-segment pedicle screw instrumentation supplemented with anterior column support. One method of augmenting the anterior column while avoiding the morbidity of the anterior approach is cement vertebral augmentation by VP or KP (Fig. 2).

Review of the Literature

Both VP and KP, alone or in combination with posterior spinal instrumentation, have been described for the treatment of burst fractures. “Stand-alone” cement augmentation is an option, although it is not frequently used. Cement augmentation with posterior spinal instrumentation may provide sufficient anterior column support to obviate the need for anterior column reconstruction and may also allow for shorter posterior fixation options.

Stand-Alone Cement Augmentation

Chen and Lee published one of the first reports on VP in which the procedure was performed in 6 patients with traumatic burst fractures in whom at least 3 months of conservative treatment had failed. The reduction in pain from baseline to the 72-hour and 3-month follow-ups demonstrated statistical significance (p < 0.05). Although PMMA leakage into the disc space and/or paravertebral space was noted in 4 vertebrae (66.7%), all patients were asymptomatic. Furthermore, Huwart et al. described 62 neurologically intact adults with AO type A2 fractures treated with CT-guided PMMA-based percutaneous VP. There was significant improvement in the visual analog scale (VAS) score and Oswestry Disability Index (ODI) at the 6-month follow-up (p < 0.0001). Even though CT guidance allowed for precise PMMA placement, 11% of the patients had intradiscal cement leaks. The authors did not assess kyphosis correction or maintenance of alignment at the final follow-up.

In contrast to VP, KP allows injection of cement under lower pressure, therefore theoretically reducing the risk of cement leakage. In a study of AO type A3.1–A3.3 fractures, including those with posterior wall protrusion, Hartmann et al. used KP without supplemental instrumentation. These authors found significant height restoration and kyphosis reduction postoperatively with immediate improvement in pain levels. The final follow-up,
at an average of 14.6 months after surgery, revealed about a 6° loss in kyphosis correction in most cases; however, no canal encroachment by the posterior wall appeared on follow-up imaging. Despite increased kyphosis, functional outcomes were not affected. Maestretti et al. reported on 33 AO type A1 and A3 fractures treated with CPC.43 Although an average 5° of kyphosis reduction was achieved using KP, a 3° loss of correction was found at the final follow-up. Interestingly, although clinically irrelevant, 20% of these fractures treated with CPC showed resorption.

When utilizing VP or KP in trauma settings, particular attention should be given to correct trocar positioning in the anterior third of the vertebral body while injecting bone void fillers. Injection should be performed under direct fluoroscopic visualization and stopped as soon as cement reaches the posterior wall. To limit complications related to cement leaks in burst fractures, we recommend KP over VP for the reasons previously mentioned.

Despite the aforementioned reports, long-term studies of VP or KP as a stand-alone modality in the treatment of burst fractures are lacking. It is unknown how anterior column cement augmentation without instrumentation affects patients with burst fractures over the span of multiple years. Even though the loss of kyphosis reduction after KP treatment did not lead to poor outcomes,29,43 large-scale long-term studies are necessary for KP or VP to become an acceptable option in the treatment of burst fractures without instrumentation.

Cement Augmentation With Posterior Spinal Instrumentation

Cement augmentation may offer anterior support to a traumatic burst fracture allowing for short-segment posterior fixation. Biomechanically, spine stiffness is decreased by burst fractures by as much as 47.5%, compared with the intact spine. Polymethylmethacrylate-based VP has been found to restore stiffness to 107.8% of the intact spine.42 As shown in a cadaveric study, transpedicular vertebral body augmentation reduces pedicle screw bending moments by 59% in flexion and by 38% in extension, thereby decreasing the stresses on posterior instrumentation.47 Furthermore, MRI analysis of burst fractures led Oner et al. to conclude that anterior column insufficiency can also result from herniation of the nucleus pulposus into the vertebral body through a fractured vertebral endplate.51 While depressed vertebral cortices can be reduced indirectly through ligamentotaxis via traction on the annular fibers, the central portion of the vertebral body remains depressed.23 Kyphoplasty offers a potential solution to this problem by directly reducing and buttressing the depressed endplate while providing stability to anterior column bone healing.24 In their cadaveric study of traumatic burst fractures, Oner et al. showed that balloon-assisted endplate reduction successfully elevated central endplate compression that was not reduced by distraction through pedicle instrumentation.52 Subsequently, this technique was extrapolated to the treatment of 20 patients who had sustained traumatic burst fractures with an intact posterior longitudinal ligament. After short-segment fixation and KP at the fractured level, the average Cobb angle was corrected from 11° of kyphosis to 1.6° of lordosis postoperatively. The average vertebral body height was improved from 66% to 81%; this correction was maintained at 80% after instrumentation removal at an average of 17 months postoperatively. Cement leakage into the disc, paravertebral space, or psoas muscle occurred in 4 patients, while a central canal leak was noted in 1 patient. All 5 patients remained asymptomatic in terms of cement extravasation.32

Multiple other studies have also shown success with cement augmentation and short pedicle fixation. Afzal et al. reported on a case series of 16 patients with Denis Type B and C lumbar burst fractures.2,21 With KP and concomitant short-segment instrumentation, the average degree of kyphosis correction was approximately 11°. Vertebral body height improved from 67% to 83% at an average final follow-up of 22 months. The authors noted 3 cases of cement leakage; in 2 of these, the cement leaked into the canal. The cement was evacuated immediately, and all 3 cases had an uneventful recovery. Verlaan et al. reported a comparable amount of kyphosis correction following KP and short-segment pedicle screw instrumentation and noted statistically significant central and anterior vertebral body height restoration (p < 0.0001).63 Fuentes et al. also documented good initial correction of vertebral height and kyphosis with negligible radiographic loss at 26 months after treatment in neurologically intact patients with AO type A3.1–A3.3 fractures.24 Rahamimov et al. presented similar findings in a retrospective case series on AO type A3 burst fractures treated with KP and short-segment pedicle screw instrumentation.59 These authors noted only a 3° loss of sagittal correction at the final follow-up with most complications related to cement leakage. There were no leaks into the spinal canal, and no significant clinical events were related to the cement leaks.

Blondel et al. described similar methodology and findings in a retrospective case series of neurologically intact patients with AO type A3.1–A3.3 burst fractures.10 Twenty patients initially underwent KP followed by short-segment osteosynthesis, while 7 patients were initially stabilized with posterior instrumentation followed by KP. Both groups demonstrated a similar amount of correction and maintenance of reduction at a final follow-up of 24 months. Zairi et al. also supported the utility of KP and short-segment pedicle screw instrumentation in patients with an intact neurological status.71 At the final follow-up of 15 months, treatment of AO type A1 through A3 as well B1 and B2 type fractures revealed significantly improved kyphosis and VAS scores. Treatment of AO type A2 fractures, which involve a vertebral body split, did not result in any cement leaks. Nevertheless, the authors acknowledged that cement augmentation of these fractures is associated with high risks of cement leakage into the adjacent disc space. Cho et al. evaluated patients with thoracolumbar burst fractures who had been stabilized using short-segment fixation with and without PMMA VP.53 The authors concluded that vertebral bodies augmented with cement lost significantly less correction, effected better improvement in pain levels, and had no failures of posterior instrumentation at the 2-year follow-
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up. Lastly, a prospective randomized trial in patients older than 65 years with AO type A3 fractures were randomized into KP (controls) and KP with short-segment pedicle screw instrumentation. Patients treated with KP and spinal instrumentation showed statistically improved VAS and ODI scores at the 2-year follow-up. In addition, the instrumented group exhibited better kyphosis reduction and maintenance of the corrected alignment.

Kyphoplasty has also been extended to the treatment of patients with neurological deficits. Korovessis et al. described 23 patients with AO type A3 fractures treated with CPC KP supplemented with long-segment fixation at the thoracolumbar junction and short-segment fixation from the L-2 through L-4 levels.52 Preoperative kyphosis and vertebral body height ratios improved. Additionally, 5 patients with incomplete neurological impairments showed at least 1 grade of improvement on the American Spinal Injury Association (ASIA) scale even though they did not undergo formal decompression via laminectomy or laminoforaminotomy. Toyone et al. reported on 16 burst fractures causing neurological deficit; the fractures were augmented with the transpedicular placement of hydroxyapatite blocks and pedicle screw fixation.60 The amount of kyphosis was reduced from 17° to −2° with improvement of canal compromise from 64% to 22% after the index procedure. All patients improved at least 1 ASIA grade. Hardware was removed at an average of 12 months after treatment, and the reduction loss was only 1°. The spinal canal encroachment continued to improve to 11% by the final follow-up.

While favorable reports on stand-alone cement augmentation techniques in traumatic burst fractures exist, short-term follow-up reports show superior results for KP combined with short-segment pedicle instrumentation over stand-alone KP in terms of sagittal alignment maintenance and clinical outcomes.29,30 With the recent increase in the application of percutaneous pedicle screw fixation methods, several authors have attempted this technique with anterior column cement augmentation. Although there is a tendency toward superior outcomes in treating AO type A fractures with cement augmentation and posterior instrumentation at 2 years, the long-term effects of spinal hardware on spine dynamics and alignment in the absence of fusion are unknown. One recent prospective randomized trial compared clinical and radiographic outcomes for AO type A3 thoracolumbar burst fractures treated with short-segment fixation with and without fusion. Results revealed that the nonfusion group demonstrated significantly better radiographic parameters, shorter operative times, and decreased blood loss. There was no difference in clinical outcomes between the 2 groups.96 While other reports also support favorable short-term outcomes of posterior instrumentation without fusion,50,51 long-term evaluations must be undertaken in order for posterior spinal instrumentation without fusion to become a universally accepted method in the treatment of thoracolumbar burst fractures. If a fusion was not performed at the time of the index procedure, most surgeons advocate instrumentation removal at about 6–9 months to facilitate motion at the previously instrumented levels and to prevent instrumentation failure. Presently, no reports advocate or oppose hardware removal in these situations; thus, removal of the spine hardware should be dictated by the clinical judgment of a treating surgeon.

Conclusions

Cement augmentation has a potentially valuable role in the treatment of traumatic burst fractures. Cited benefits are rapid pain relief and improved spinal biomechanics and stability. Both VP and KP have been shown to decrease the rate of instrumentation failure. In addition, cement augmentation improves anterior column support, allowing surgeons to instrument fewer levels in thoracolumbar trauma. Compared with VP, KP has a higher safety profile and allows improved restoration of post-traumatic kyphosis and endplate elevation. Therefore, we prefer KP when dealing with these fractures.

While some reports support the use of VP or KP as a stand-alone modality in burst fractures, the addition of posterior spinal instrumentation allows for the maintenance of spinal alignment and better clinical outcomes. As a result, given the current available evidence, we cannot recommend VP or KP as a stand-alone method.

Regardless, when using either VP or KP, utmost caution should be used to limit complications related to cement extravasation, especially in fractures with posterior wall disruption.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper. Dr. Fischgrund is a consultant for Stryker and Relievant and has direct stock ownership in Baxano Surgical. Dr. Park is a consultant for DePuy, Stryker, Baxano Surgical, and K2M and has direct stock ownership in Johnson & Johnson. Dr. Baker has received clinical or research support from Arthrex Inc., Stryker Orthopaedics, and Zimmer Holdings for the described study and is a consultant for Globus Medical.

Author contributions to the study and manuscript preparation include the following. Drafting the article: Zaryanov. Critically revising the article: all authors. Reviewed submitted version of manuscript: Zaryanov.

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