Kyphoplasty-augmented short-segment pedicle screw fixation of traumatic lumbar burst fractures: initial clinical experience and literature review

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Object. Surgical intervention for thoracolumbar burst fractures is indicated for patients with neurological deficits and/or evidence of severe spinal instability. The goals of surgery are decompression, deformity correction, and stabilization. Nevertheless, the optimal surgical strategy to achieve these goals remains a subject of debate. Short-segment pedicle screw fixation is associated with a 20 to 50% incidence of pedicle screw failure and progressive spinal deformity. Initial biomechanical and clinical studies have shown that reinforcement of short-segment pedicle screw fixation with vertebroplasty improves spinal stability and decreases instrument failure rates. In this study, the authors describe their initial clinical experience with kyphoplasty used to augment short-segment pedicle screw fixation of traumatic lumbar burst fractures.

Methods. Five patients with traumatic burst fractures of the lumbar spine were included in this retrospective review of patients treated for this disorder at the University of California, San Diego and the University of California, San Francisco between 2002 and 2004. All patients underwent transpedicular kyphoplasty and short-segment pedicle screw fixation. The mean follow-up period was 10.6 months (range 6–18 months). All patients underwent short-segment pedicle screw fixation reinforced with polymethyl methacrylate kyphoplasty. The preoperative, postoperative, and follow-up plain x-ray films were evaluated. Radiographic analysis included measurements of kyphotic angulation, anterior vertebral body height, and evidence of bone fusion. Clinical evaluation was performed postoperatively and at follow-up review.

Conclusions. Based on the authors' initial experience, kyphoplasty supplementation may improve the long-term integrity of short-segment pedicle screw constructs and allow for improved rates of fusion and better clinical outcomes in patients with traumatic lumbar burst fractures.

KEY WORDS • burst fracture • lumbar spine • kyphoplasty • pedicle screw fixation

The optimal treatment of burst fractures of the thoracolumbar spine remains a matter of debate. Traditionally, nonsurgical management with immobilization and external bracing has been recommended for patients with burst fractures located between T-11 and L-4 without accompanying neurological deficit or significant instability.^{11,27,45} Progressive deformity, neurological dysfunction, and pain are common in cases treated without surgical stabilization, however, and some authors have criticized treatment that does not include surgical decompression and stabilization.¹⁸ Although Class 1 data are lacking, surgical treatment of thoracolumbar burst fractures has been recommended for patients with neurological deficit or severe instability (that is, posterior element fractures, kyphotic deformity $\geq 20^\circ$, and $> 50\%$ loss of VB height with facet joint subluxation).^{2,16,23,24,29,36}

Abbreviations used in this paper: PMMA = polymethyl methacrylate; VB = vertebral body.

Short-segment pedicle screw fixation is a common and relatively simple method for treating thoracolumbar burst fractures, and potentially allows for spinal stabilization while preserving as many motion segments as possible.^{8,25,27,37,43,44} Nevertheless, instrument failure rates and progressive sagittal deformity have been reported in as many as 50% of patients treated with short-segment pedicle screw fixation alone.^{32,38} Patients with failed constructs in whom progressive kyphosis subsequently develops have poorer functional outcomes, higher analgesic medication requirements for back pain, and may ultimately require a second procedure for instrumentation removal.^{7,10,31}

Cement vertebroplasty has been shown to increase the strength, load-bearing capacity, and stiffness of fractured vertebrae.^{5,9,17} We believe that the addition of a balloon tamp (kyphoplasty) to the traditional vertebroplasty procedure may provide additional vertebral height restoration and stability. In this study, we review our initial clinical experience with kyphoplasty in which we used PMMA

cement to supplement short-segment pedicle screw fixation for traumatic lumbar burst fractures. We also describe the current biomechanical rationale for and clinical experience with vertebroplasty and kyphoplasty to augment short-segment posterior pedicle screw-rod constructs for thoracolumbar burst fractures.

CLINICAL MATERIAL AND METHODS

Patient Population

We retrospectively evaluated the results in five patients with traumatic burst fractures of the lumbar spine that were treated at our institutions with transpedicular kyphoplasty and short-segment pedicle screw fixation. The patients' mean age at the time of surgery was 53 years (range 42–68 years). Indications for surgical intervention were the presence of neurological deficit, severe spinal instability (loss of anterior VB height > 50%, canal compromise > 50%, or kyphotic deformity > 20°), or intractable back pain. The patients' demographic data are shown in Table 1. Four patients suffered burst fractures as a result of falls, whereas one had been in a motor vehicle accident. All patients had a single-level Type A1³ vertebral fracture (vertebral collapse with retropulsion of the posterior vertebral wall), according to the classification proposed by Magerl, et al.³⁵ The mean follow-up period was 10.6 months (range 6–18 months).

Surgical Methods

All patients underwent surgical intervention via a posterior approach. Bilateral pedicle screws were inserted at one level above and below the fractured VB. Under fluoroscopic guidance, a kyphoplasty trochar was introduced along the pedicle of the fractured VB and was placed just beyond the posterior vertebral wall. A kyphoplasty balloon was then advanced into the VB and slowly inflated to 150 psi. This allowed for both fracture reduction and vertebral height restoration. The balloon was then deflated and removed and the cavity was filled with 3 to 10 cm³ of barium-impregnated PMMA cement. Any extruded PMMA was promptly removed with pituitary rongeurs.

A laminectomy was then performed at the fractured level for spinal canal decompression. The ventral thecal sac was decompressed using pituitary rongeurs and down-pushing curettes were used to remove extruded bone fragments. Rods were then fashioned and secured to the pedicle screws bilaterally. Finally, a distraction force was applied to the pedicle screws bilaterally across the frac-

tured VB to achieve spinal reduction, and the screw-rod construct was tightened.

Radiographic Evaluation

The preoperative, postoperative, and follow-up plain x-ray films were evaluated. Radiographic analysis included measurements of kyphotic angulation, anterior VB height, and evidence of bone fusion. Local kyphosis was measured using the Cobb method, as described in Kunter, et al.³³ Anterior VB height was measured directly, and the percentage change in height was calculated by dividing the actual anterior VB height by the estimated normal height (defined as the mean of the anterior VB height of the uninjured adjacent vertebrae above and below). Evidence of bone fusion included the presence of trabecular bone bridging the interspace between the cement and adjacent VB, with no areas of increased lucency.

Clinical Evaluation

The clinical evaluation was performed postoperatively and at follow-up review. It included a thorough neurological examination and a questionnaire on the patients' perceived pain level based on the visual analog scale.

RESULTS

All patients had suffered fractures of the lumbar spine. Table 2 provides a summary of the radiographic results in this study. The mean preoperative kyphotic deformity was $36 \pm 3.74^\circ$ (all values are the mean $\pm$ standard deviation) and was corrected to $5 \pm 6.12^\circ$ ($p < 0.01$). The mean loss of correction of local kyphosis at follow-up review was $4 \pm 4.18^\circ$ ($p > 0.05$). The mean preoperative anterior height of the fractured VB was $54 \pm 4.12\%$. Postoperatively, this improved to $86 \pm 8.22\%$, a 32% increase in height ($p < 0.01$). Anterior VB height was not significantly changed at follow-up review. The preoperative, postoperative, and follow-up changes in kyphosis and vertebral height are summarized in Fig. 1. All patients had radiographic evidence of fusion, improved neurological deficits, and improved pain scores. There was no hardware failure or leakage of PMMA cement in any patient. The preoperative, intraoperative, and postoperative radiographic images obtained in a patient treated with PMMA vertebroplasty are shown in Fig. 2.

DISCUSSION

As shown in Table 3, the following three major ap-

TABLE 1
Demographic data in five patients
treated for traumatic burst fractures*

Case No.	Age (yrs), Sex	Fx Level	Presenting Symptoms	FU (mos)
1	44, F	L-4	back pain	6
2	42, M	L-2	back pain, neuro deficit	7
3	68, M	L-2	back pain	9
4	58, M	L-1	back pain	18
5	45, F	L-3	back pain, neuro deficit	13

* FU = follow up; fx = fracture; neuro = neurological.

TABLE 2
Radiographic results in five patients with burst fractures

Case No.	Kyphosis (°)				Anterior VB Height (%)			
	Preop	Postop	FU	% Correction Loss	Preop	Postop	FU	Loss
1	30	5	10	5	60	90	80	10
2	40	15	15	0	50	75	75	0
3	40	0	10	10	50	80	75	5
4	35	5	5	0	55	90	80	10
5	35	0	5	5	55	95	90	5
mean	36	5	9	4	54	86	80	6

Fig. 1. Graph showing kyphotic deformity and anterior VB height measurements in the preoperative, postoperative, and follow-up periods. Both kyphotic deformity and anterior vertebral height were significantly improved postoperatively and the improvement was maintained at follow-up evaluation. FU = follow up; NS = not significant ($p > 0.05$).

proaches have been used in the surgical treatment of thoracolumbar burst fractures. 1) Anterior approaches have proven effective in allowing for extensive decompression and successful fusion with minimal loss of sagittal alignment,^{4,26,29} but the time needed and morbidity rates associated with an anterior spinal exposure are both higher than with posterior approaches.²⁹ 2) Posterior approaches with short-segment pedicle screw fixation allow for adequate realignment and stabilization, but are associated with high rates of instrument failure because the anterior and middle columns are not reconstructed.^{3,38} Moreover, intervertebral disc material is redistributed into the fractured VB after height restoration, causing a subsequent collapse of adjacent disc spaces and leading to instrument fatigue and progressive kyphosis.^{42,51} Extension of the posterior pedicle screw-rod construct to include two or more segments above and below the fractured level can reduce instrument failure rates, but it also sacrifices additional motion segments and ultimately reduces the range of motion.¹³ 3) Combined anterior-posterior approaches allow for three-column reconstruction and stabilization,²¹ but also require more time and have higher rates of surgery-related morbidity.

An ideal technique would combine the stability offered by three-column reconstruction with the morbidity level associated with a single short-segment posterior approach only. Accordingly, transpedicular bone grafts have been used to provide additional anterior column support after short-segment posterior transpedicular screw fixation, but with mixed results.^{1,15,41,47} In a recent prospective, randomized study, Alanay, et al.,² found no difference in the failure rates of short-segment pedicle screw constructs supplemented with transpedicular intracorporeal bone graft compared with constructs without graft support. Moreover, transpedicular graft material can cause spinal canal compression if not placed properly.⁴⁶ The injection of cement into the anterior column (vertebroplasty) with or without an inflatable bone tamp (kyphoplasty) is another procedure that provides additional anterior support via a posterior approach for pedicle screw fixation. Vertebro-

plasty and kyphoplasty have been found to be effective in the treatment of osteoporotic compression fractures,^{14,19,28} and there is growing evidence that these methods may also be useful in improving instrumentation failure rates and deformity correction after posterior fixation in patients with thoracolumbar burst fractures.

Biomechanical Effects of Vertebroplasty and Kyphoplasty

The restoration of VB strength and stiffness is thought to be an important part of the mechanism by which vertebroplasty and kyphoplasty may relieve pain associated with fractured vertebrae.^{9,50} The use of PMMA cement has been shown to restore vertebral strength and stiffness in relation to the volume of cement injected, although complete filling of the VB is not necessary.⁵⁰ It is hypothesized that this increase in VB strength and stiffness may also result in a shift of loading forces onto the anterior column, thus decreasing the tensile forces on posterior instrumentation.⁴⁰

The use of inflatable bone tamps in kyphoplasty may provide additional restoration of VB height. In several studies, investigators have reported that kyphoplasty improves both anterior and midline vertebral height from 91 to 99% of estimated prefracture values.^{22,48,50} In research in which cadaveric spines were used, Belkoff, et al.,⁶ reported that kyphoplasty resulted in a 97% correction of deformity, compared with 30% with vertebroplasty. Verlaan, et al.,⁵¹ found that inflatable bone tamps facilitated endplate reduction and cement injection in a cadaveric study. Thus, by creating a void into which cement can be injected at low pressure, kyphoplasty may facilitate both vertebral height restoration and decrease the risk of cement leakage.⁵¹ In our series, we encountered no leakage of PMMA into the spinal canal.

Results of Vertebroplasty-Augmented Posterior Pedicle Screw Fixation

Progressive deformity, vertebral height loss, and implant failure occur with certainty after short-segment pedi-

Fig. 2. Radiographs obtained in a patient with an L-4 burst fracture. A: Preoperative sagittal computerized tomographic reconstruction demonstrating a burst fracture of the L-4 VB. B: Intraoperative fluoroscopic image demonstrating injection of PMMA cement into the L-4 body during kyphoplasty. C and D: Postoperative anteroposterior (C) and lateral (D) plain x-ray films demonstrating pedicle screw-rod fixation at one level above and below the fractured vertebrae and PMMA cement within the L-4 body.

cle screw fixation of thoracolumbar burst fractures. As much as 50 to 90% of kyphosis correction has been reported lost at follow-up evaluation.^{12,34} McNamara, et al.,³⁹ reported a mean loss of 8.6° of kyphosis correction, whereas Cho, et al.,¹³ found that 6.2° of kyphosis correction was lost in patients treated with short-segment fixation alone. Loss of VB height ranges from 11 to 14%,^{13,31} whereas 20 to 50% of patients experience implant failure.^{7,32,38} Chronic

and severe pain necessitate a second operation for removal of failed implants in as many as 10% of patients.^{12,40}

To our knowledge, the actual clinical experience with vertebroplasty and short-segment fixation is extremely limited. In a recent study in which they compared short-segment pedicle screw fixation with or without PMMA vertebroplasty for thoracolumbar burst fractures, Cho, et al.,¹³ found that the amount of kyphosis correction lost at follow-up review was 6.20° in the group without vertebroplasty compared with 0.33° in the group with reinforced fixation ($p = 0.0001$). There were no instrument failures in the vertebroplasty group, whereas 22% failed in the group without reinforcement. Fusion rates were not reported. The results of this study indicate that vertebroplasty can maintain kyphosis correction and anterior vertebral height, and can decrease instrument failure rates after short-segment posterior fixation for thoracolumbar burst fractures.¹³

We hypothesized that the use of a bone tamp to provide a distractive force within the VB during kyphoplasty may result in additional kyphosis correction and anterior VB height restoration. We were able to achieve a 31° correction of kyphosis after surgery and restore 32% of the anterior vertebral height. Cho, et al.,¹³ reported a mean of 6.4° of kyphosis correction and 12.9% anterior VB height res-

TABLE 3

Summary of surgical options for thoracolumbar burst fractures

Approach	Advantages	Disadvantages
anterior	extensive decompression successful fusion restoration of anterior VB height limited exposure low morbidity	high morbidity level no posterior column fixation
posterior	3-column fixation w/ pedicle screws	no anterior or middle column reconstruction significant instrument failure rates
combined	3-column fixation & reconstruction	significant morbidity w/ combined exposure

toration after vertebroplasty and short-segment fixation. Although our patients had a greater preoperative anterior vertebral height (54% compared with 45%), they also had a larger preoperative kyphotic deformity (36° compared with 20°) than the patients reported on by Cho, et al.¹³ We found no significant loss of kyphosis correction or anterior vertebral height at follow-up review. Moreover, all patients demonstrated radiographic evidence of fusion.

Future Directions

Large, randomized prospective studies are needed to evaluate fully the efficacy of vertebroplasty and kyphoplasty for augmentation of short-segment pedicle screw constructs in the treatment of thoracolumbar burst fractures. Additionally, cements other than PMMA should be incorporated into these studies. Injury to spinal tissues is one concern when using PMMA; this material can have toxic effects as a monomer, and may also cause thermal injury during its exothermic polymerization reaction.^{9,20,30} Thus, more biocompatible and, ideally, osteoconductive (calcium-phosphate) cements are being studied. In a biomechanical study of compression fractures in cadavers, Tomita, et al.⁴⁹ found that there was no difference in percentage of VB height restoration or strength restoration after PMMA kyphoplasty compared with a calcium-phosphate cement kyphoplasty.

CONCLUSIONS

Vertebroplasty decreases instrument failure rates after short-segment pedicle fixation for thoracolumbar burst fractures. Based on our initial experience with only a small number of patients, use of inflatable bone tamps with kyphoplasty may provide additional kyphosis correction, vertebral height restoration, and long-term integrity of short-segment pedicle screw constructs. This may ultimately result in improved rates of fusion and better clinical outcomes for patients with traumatic lumbar burst fractures. Large, prospective studies are needed to evaluate fully the efficacy of vertebroplasty and kyphoplasty in augmenting short-segment pedicle screw fixation for thoracolumbar burst fractures.

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