Short-segment cement-augmented fixation in open separation surgery of metastatic epidural spinal cord compression: initial experience

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OBJECTIVE High-grade metastatic epidural spinal cord compression from radioresistant tumor histologies is often treated with separation surgery and adjuvant stereotactic body radiation therapy. Historically, long-segment fixation is performed during separation surgery with posterior transpedicular fixation of a minimum of 2 spinal levels superior and inferior to the decompression. Previous experience with minimal access surgery techniques and percutaneous stabilization have highlighted reduced morbidity as an advantage to the use of shorter fixation constructs. Cement augmentation of pedicle screws is an attractive option for enhanced stabilization while performing shorter fixation. Herein, the authors describe their initial experience of open separation surgery using short-segment cement-augmented pedicle screw fixation for spinal reconstruction.

METHODS The authors performed a retrospective chart review of patients undergoing open (i.e., nonpercutaneous, minimal access surgery) separation surgery for high-grade epidural spinal cord compression using cement-augmented pedicle screws at single levels adjacent to the decompression level(s). Patient demographics, treatment data, operative complications, and short-term radiographic outcomes were evaluated.

RESULTS Overall, 44 patients met inclusion criteria with radiographic follow-up at a mean of 8.5 months. Involved levels included 19 thoracic, 5 thoracolumbar, and 20 lumbar. Cement augmentation through fenestrated pedicle screws was performed in 30 patients, and a vertebroplasty-type approach was used in the remaining 14 patients to augment screw purchase. One (2%) patient required an operative revision for a hardware complication. Three (7%) nonoperative radiographic hardware complications occurred, including 1 pathologic fracture at the index level causing progressive kyphosis and 2 incidences of haloing around a single screw. There were 2 wound complications that were managed conservatively without operative intervention. No cement-related complications occurred.

CONCLUSIONS Open posterolateral decompression utilizing short-segment cement-augmented pedicle screws is a viable alternative to long-segment instrumentation for reconstruction following separation surgery for metastatic spine tumors. Studies with longer follow-up are needed to determine the rates of delayed complications and the durability of these outcomes.

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KEYWORDS cement augmentation; epidural spinal cord compression; metastatic disease; posterolateral decompression; spinal fixation

METASTASES to the spinal column are common in malignant disease and can manifest with a combination of pain, mechanical instability, and neurological deficits.¹⁻³ The treatment of spinal metastases is palliative with the goal of alleviating pain, preserving or restoring neurological function, maintaining spinal stability, and achieving local tumor control while minimizing

patient morbidity. To this end, the management of spinal metastatic disease is dependent on the tumor histology, the extent of epidural spinal cord compression (ESCC), patient symptomatology, and bony integrity.⁴ Spine stereotactic body radiation therapy (SBRT) has demonstrated durable local control of tumors previously considered radioresistant when used as either definitive therapy or a

ABBREVIATIONS ASIA = American Spinal Injury Association; ECOG = Eastern Cooperative Oncology Group; ESCC = epidural spinal cord compression; MRC = Medical Research Council; SBRT = stereotactic body radiation therapy.

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FIG. 1. Images obtained in a 78-year-old man with a history of metastatic thyroid cancer who presented with asymptomatic grade 2 ESCC. **A and B:** Sagittal (A) and axial (B) postcontrast T1-weighted MR images demonstrating grade 2 ESCC. The patient underwent separation surgery with posterolateral decompression and placement of T7–9 cement-augmented pedicle screw fixation. **C:** Sagittal CT myelogram obtained in the immediate postoperative period demonstrating good decompression with reconstitution of the thecal sac. **D:** Lateral radiograph obtained immediately postoperatively demonstrating short-segment hardware placement with cement augmentation. **E:** Axial T2-weighted MR image obtained 9 months after hybrid therapy demonstrating regression of the epidural tumor with no compression of the thecal sac.

postoperative adjuvant.^{5,6} Subsequently, the goal of surgical intervention has shifted from aggressive resection to circumferential decompression and reconstitution of the thecal sac, or “separation surgery,”^{7,8} creating an optimal target for SBRT (i.e., “hybrid therapy”).⁹

In order to achieve the circumferential separation of tumor from neurological structures, complete removal of the posterior elements is required. Hence, even patients with no clear signs of spinal instability preoperatively will require posterior segmental fixation because, in the process of removing the posterior elements, spinal stability is compromised.^{4,10} Thus, posterior segmental fixation is a vital component of this treatment. Recent technological advances, including fenestrated and expandable pedicle screws, have demonstrated superior biomechanical properties and have suggested a reduction in the number of hardware failures when utilized.^{11,12} As a result of these advances, we have transitioned to the use of cement augmentation for percutaneous stabilization with low rates of symptomatic hardware failure requiring revision surgery.^{13,14} This experience has led us to explore the possi-

bility of minimizing the extent of posterior segmental fixation for open decompression with short-segment cement-augmented constructs (Fig. 1). Herein, we review our initial experience with these constructs.

Methods

Design

This was a retrospective, single-center observational study at a tertiary cancer center. The local institutional review board approved this study, and informed consent was obtained. Patient clinical and radiographic information was obtained preoperatively, at 3 weeks immediately postoperatively, at 3-month intervals until 1 year postoperatively, and then yearly until the conclusion of follow-up. Signs of symptomatic or asymptomatic radiographic hardware failure were the primary endpoint. At each clinical follow-up point, we also obtained American Spinal Injury Association (ASIA) impairment scale scores, Eastern Cooperative Oncology Group (ECOG) performance status scores, and Medical Research Council (MRC) muscle strength scores.

Patient Population

The records of patients who underwent open posterolateral decompression and resection of epidural metastases in the thoracic or lumbar spine with cement-augmented pedicle screw fixation at 1 level above and 1 level below the index level(s) (i.e., short segment) were screened. Inclusion criteria were imaging confirmation of metastatic epidural disease, with or without clinical symptoms of mechanical instability, in patients who underwent open separation surgery with short-segment cement-augmented pedicle screw constructs. Patients who had a segmental kyphosis or deformity from vertebral body fracture were included for consideration. Patients were excluded from consideration if fixation crossed the cervicothoracic junction or adequate fluoroscopic imaging could not be obtained for safe cement delivery. Additionally, patients who required stabilization over multilevel discontinuous disease were not considered for short-segment fixation. Patients who underwent percutaneous stabilization and/or minimal access tubular decompression, or those who did not require decompression, were excluded from this analysis.

Treatment

All patients included in this study underwent posterolateral decompression with cement-augmented posterior instrumented fixation. In this study, cement augmentation included either the use of fenestrated screws or direct vertebroplasty-type injection of cement through the tapped screw track. Over the course of the study, there was a transition from cement delivery via vertebroplasty-type approach to fenestrated screws as they became available.

All surgeries were performed by one of 3 surgeons (M.H.B., I.L., or O.B.). A detailed method of performing separation surgery has been described elsewhere¹⁵ and was performed in the cases included in this series, with the only variation being the shorter constructs and the cement-augmentation techniques.

In brief, surgery consists of a linear midline incision and subperiosteal dissection of paraspinal muscles and ligament to expose the transverse processes at each level. Short-segment pedicle screw fixation is placed using neuronavigation and cement augmentation using fluoroscopy. Segmental kyphosis and fracture deformities are fixed in situ without corrective maneuvers. The bony decompression is tailored to the specific exposure necessary for safe tumor resection. The laminae, medial pedicle(s), and facet joint(s) are resected with a 3-mm matchstick burr. Posterolateral tumor resection is initiated from normal dural planes with nerve root sparing. A posterior partial corpectomy is performed, followed by resection of the posterior longitudinal ligament to affect a margin on the anterior dura mater, thus creating a circumferential decompression. Cement augmentation is used to fill large vertebral body defects.

Data Analysis

This was a retrospective, observational study utilizing descriptive analysis of patient clinical and radiographic outcomes.

Results

Preoperative Demographics

Overall, 44 patients who underwent separation surgery for metastatic epidural disease with short-segment cement-augmented constructs and had > 1 month of radiographic follow-up were included in this retrospective review. The mean age at the time of surgery was 63 years, and 22 (50%) patients were female.

Thirty-three (75%) patients presented with preoperative high-grade ESCC grade 2 or 3. The Spine Instability Neoplastic Score (SINS) ranged from 2 to 18, and patients were classified as follows: 9 (20%) stable, 29 (66%) potentially unstable, and 6 (14%) unstable. The most common tumor histologies treated were non-small cell lung (n = 10, 23%), prostate (n = 6, 13%), colorectal (n = 5, 11%), and breast (n = 4, 9%) carcinoma. Preoperatively, most patients had ASIA grade E (n = 34, 77%), had an MRC score of 5 (n = 34, 77%), and an ECOG score of 1 (n = 26, 59%) or 2 (n = 12, 27%) (Table 1).

Operative Details

Of the operations in 44 patients who underwent open short-segment cement-augmented fixation, 19 (43%) were performed in the thoracic spine, 20 (45%) were in the lumbar spine, and 5 (11%) crossed the thoracolumbar junction (Table 2). No patients had previous surgery at the index level. Most patients underwent a 2-level posterolateral resection of the epidural tumor (n = 36, 81%), with 5 patients (11%) receiving vertebral body cement augmentation at the index level. Fenestrated screws were used in 30 patients (68%), and vertebroplasty via the cannulated pedicle tracks was performed in the remaining 14 patients, immediately followed by pedicle screw placement into the vertebral body. The mean estimated blood loss was 330 mL, with a mean operative duration of 161 minutes. The average hospital length of stay was 4.7 days.

For patients receiving postoperative radiation therapy, the average time to treatment was 20 days, with a median time of 18 days. All patients received SBRT with doses ranging from 24 Gy in a single fraction to 40 Gy in 5 fractions.

Radiographic Outcomes

The mean duration of radiographic follow-up was 8.5 months. Overall, 1 (2%) patient required an operative intervention for revision of the pedicle-screw construct. This patient initially underwent a T1–3 posterolateral decompression with cement-augmented fixation (Fig. 2). Three months after the initial surgery, the patient demonstrated symptomatic fractures of the bilateral T3 pedicle screws with progressive kyphosis for which he was taken back to the operating room for a T1–5 extension of instrumented fixation with cement augmentation (Fig. 2).

There were 3 (7%) additional cases of asymptomatic radiographic findings at a mean of 3 months: 2 (4%) patients had screw haloing at the top of the construct (both patients underwent L1–3 fixation), and 1 (2%) patient had progressive kyphosis at the index level (L1) due to progression of a pathologic fracture. There were no cases of cement-related complications (extravasation into the spinal canal

TABLE 1. Patient demographics

Variable	Value
Total patients	44 (100)
Age, yrs	
Range	37–83
Mean	63.7
Median	63.2
Sex	
Female	22 (50)
Male	22 (50)
Preop ESCC grade	
0	2 (5)
1A	3 (7)
1B	3 (7)
1C	3 (7)
2	9 (20)
3	24 (55)
Preop SINS	
Range	2–18
Mean	10
Median	10
0–6 (stable)	9 (20)
7–12 (potentially unstable)	29 (66)
13–18 (unstable)	6 (14)
Preop ASIA grade	
E	34 (77)
D	5 (11)
C	5 (11)
B	0 (0)
A	0 (0)
Preop ECOG score	
0	4 (9)
1	26 (59)
2	12 (27)
3	2 (5)
Preop MRC score	
0	1 (2)
1	0 (0)
2	3 (7)
3	1 (2)
4	5 (11)
5	34 (77)
Previous surgery at index site	44 (100)

SINS = Spine Instability Neoplastic Score.

Values represent the number of patients (%) unless stated otherwise.

or pulmonary embolism) that required surgery or change in management.

Clinical Outcomes

The mean duration of clinical follow-up was 10.7 months. There were 18 deaths (41%) during follow-up.

TABLE 2. Operative, clinical, and radiographic details

Variable	Value
Fixation location	
Thoracic	19 (43)
Thoracolumbar junction	5 (11)
Lumbar	20 (45)
Kyphoplasty at index level	
Yes	5 (11)
No	39 (89)
Fenestrated screws	
Yes	30 (68)
No	14 (32)
Laminectomy levels	
1	1 (2)
2	36 (81)
3	7 (16)
Mean estimated blood loss, mL	330
Mean OR time, mins	161
Mean length of stay, days	4.7
≥3 mos clinical follow-up	43
Mean length of clinical follow-up, days	320
≥3 mos radiographic follow-up	37 (84)
Mean radiographic follow-up, days	257
Hardware failure requiring return to OR for revision	1 (2)
Screw loosening (asymptomatic)	2 (4)
Progressive kyphosis (asymptomatic)	1 (2)
Wound complications	2 (4)
Wound complications requiring return to OR	0 (0)
Cement-related complication (PE, cord compression)	0 (0)

OR = operating room; PE = pulmonary embolism.

Values represent the number of patients (%) unless stated otherwise.

Concerning functional outcomes, 1-month postoperative ECOG, ASIA, and MRC scores were available for 32 (73%) patients. Most patients had no change (16 patients, 50%) or improvement (13 patients, 40%) in their ECOG score. The condition of 3 (9%) patients worsened due to a progression of systemic disease. All patients had stable or improved 1-month ASIA and MRC grades.

In addition to hardware complications, 1 patient developed local cellulitis and 1 patient had a superficial wound dehiscence. Both wound complications were managed conservatively and did not require surgical intervention.

Discussion

In this preliminary experience, we performed 44 short-segment cement-augmented posterolateral decompressions for metastatic epidural spinal cord compression, with only 1 case (2%) of hardware failure that required surgery and 3 asymptomatic radiographic hardware-related issues at a median radiographic follow-up of 8.5 months. All patients had stable or improved ASIA and MRC scores at the 1-month follow-up. Three patients had a decline in ECOG

FIG. 2. Images obtained in a 61-year-old man with a history of non–small cell lung adenocarcinoma who presented with metastatic spread to his T2 vertebra with a lytic compression fracture and radicular pain. The patient underwent a T2 posterolateral decompression with placement of T1–3 cement-augmented pedicle screws. **A and B:** Anteroposterior (A) and lateral (B) radiographs obtained immediately postoperatively demonstrating cement-augmented pedicle screw placement at T1 and T3. **C and D:** At the 3-month follow-up, bilateral T3 screws were found to have fractured and kyphosis had worsened as seen on lateral (C) and anteroposterior (D) radiographs. The patient was subsequently taken back to the operating room for revision surgery. **E and F:** Postoperative lateral (E) and anteroposterior (F) radiographs obtained after revision demonstrating extension of the construct from T1 to T5 with retained distal portion of the cemented pedicle screw at T3. Nine months after revision surgery, the patient remained stable and his pain was well controlled.

performance score due to aggressive systemic disease progression.

Cancer patients are known to have poor bone quality due to a combination of osteolytic metastases, chemotherapy, radiation therapy, osteoporosis, and other comorbidities. An additional observation is that tumor progression frequently occurs at spine segments directly adjacent to the index level. In order to overcome these issues, instrumentation strategies for separation surgery have traditionally used long-segment constructs at a minimum of 2 levels above and below the tumor-involved segments.^{16,17} As an adjunct to posterior fixation, tumor resection of > 50% of the vertebral body are additionally reconstructed with open cement augmentation at the index level. A review of 318 patients undergoing separation surgery using long-instrumented reconstructions with selective vertebral body cement augmentation demonstrated a 2.8% rate of symptomatic hardware failure requiring revision at a median follow-up of 13.3 months.¹⁸

In order to overcome the problem of poor bone quality, a number of strategies are being explored to increase the pullout strength and to minimize the need for longer-segment fixation, including expandable screws¹⁹ and cement augmentation of pedicle screws.^{12,13,20–22} These strategies have been explored in cases of trauma, osteoporosis, and percutaneous stabilization for pathologic fractures. Both biomechanical and clinical studies prompted us to explore the use of short-segment cement-augmented pedicle screws for reconstruction in open separation surgery.

Regarding the 4 patients who had radiographic evidence of fixation hardware failure, all involved constructs were at junctional spine segments. Both patients with radiographic evidence of screw loosening underwent L1–3 fixation and subsequently developed haloing around one of the L1 screws and an associated fracture. The patient with radiographic progression of kyphosis underwent T12–L2 fixation and had worsening L1 vertebral body fracture. As mentioned previously, the patient with clinically relevant

hardware failure initially underwent T1–3 fixation and had progressive kyphosis with bilateral T3 screw fractures requiring extension of fixation to T5. The location of these failures at or near junction levels is consistent with findings from the non-cement-augmented treatment of thoracolumbar burst fractures with short-segment constructs where early hardware failures at junctional segments were found.^{23,24} Regarding the use of short-segment cement-augmented constructs near junctional levels, cadaveric data has suggested that nonaugmented multilevel fixation is biomechanically superior to short segments with cement augmentation, but this superiority is largely outside the realm of physiological loading.¹² Additionally, Shin et al. demonstrated that, with the use of bracing and mobility restrictions, these junctional failure rates can be improved.²⁵ Taken together, these findings may suggest that junctional interventions may warrant the use of additional levels of fixation or prophylactic bracing with mobility restrictions, yet more robust patient outcomes data are needed.

The ability to obtain wide circumferential decompression without having to instrument multiple levels above and below the index level decreases operative time, blood loss, and patient morbidity. The use of cement augmentation has been shown to result in a nearly twofold increase in pullout strength compared with nonaugmented screws.^{26–28} Within the arena of cement augmentation, there are three different design choices for screws: solid screws with cement augmentation via vertebroplasty, partially fenestrated screws with distal openings for cement extrusion, and fully fenestrated screws. While limited cadaveric data have suggested that partially fenestrated screws with cement augmentation have higher pullout strengths than solid screws augmented with the vertebroplasty technique, there appears to be no significant difference between fully and partially fenestrated screws.¹¹ Additionally, that same study found no significant difference in removal torque forces between the three groups.

Although much of the literature discusses posterior pullout strength, posterior pullout is not the most common clinical mechanism for failure. Axial load testing more closely resembles physiological fatigue conditions, and, while cement-augmented screws are more resistant to failure than nonaugmented screws, multilevel nonaugmented constructs are significantly more resistant to failure.¹² However, it is worth noting that while the fatigue force of short-segment cement-augmented constructs is less than that of multilevel nonaugmented constructs, the short-segment cement-augmented constructs are able to withstand most fatigue forces within physiological ranges.

Whereas biomechanical studies may have suggested that the use of fenestrated screws is superior to vertebroplasty with subsequent screw placement,¹¹ we did not find this to be the case in our initial series. Of our 4 radiographic complications, fenestrated screws were used in 3 patients and cement vertebroplasty with subsequent solid screw placement was used in the remaining patient. While more patients are needed to determine if there are any differences in outcomes between short-segment cement augmentation with fenestrated versus solid screws, our initial experience seems to suggest that either may be used with good outcomes.

While we have previously published on the use of short-

segment percutaneous pedicle screw fixation with cement augmentation for tumor-induced spinal instability with associated vertebral body fractures,¹⁴ to our knowledge, the use of short-segment cement-augmented constructs in patients requiring open posterolateral decompression for separation surgery has not been described. The ability to utilize short cement-augmented constructs to maintain spinal stability while performing separation is appealing for cancer patients because of the ability to limit blood loss, operative time, and potential patient morbidity compared with longer-segment constructs in a category of patients with multiple comorbidities and variable degrees of frailty. Furthermore, this strategy may be beneficial for surgeons who do not perform minimally invasive spine surgery. Additionally, our mean length of stay of 4.7 days was similar to that of our earlier cohort of patients undergoing percutaneous pedicle screw fixation with percutaneous cement augmentation,¹³ which is another indicator of increased toleration by cancer patients of these less invasive, short-construct surgeries. Maximizing spinal stability while minimizing operative morbidity is especially critical when considered in context of the limited survival rate of our patients after intervention, which was 10.7 months in this series.

Study Limitations

Whereas this series represents a limited initial experience, several additional limitations should be noted. There are inherent flaws from the retrospective nature of analysis. Moreover, this is a small series of 44 patients with a combination of cement augmentation via either a fenestrated or vertebroplasty-type technique. A larger group would allow for better analysis of the impact of junctional location, as well as fenestrated versus solid screws on hardware failure. Furthermore, the short duration of our follow-up limits our ability to know if we would see more hardware failures at a delayed point or if the asymptomatic radiographic complications that we observed would progress to become symptomatic.

Conclusions

Based on our initial findings, for patients with metastatic spinal disease with limited life expectancy, short-segment cement-augmented pedicle screws used as a reconstructive strategy for open separation surgery provides durable stabilization compared with long constructs that have been traditionally used. All cases of radiographic and clinical hardware failure involved fixation constructs at junctional levels. Studies with longer follow-up, incorporation of patient-reported outcomes, and specific attention to the utilization of this technique at or near the junctional spine are warranted.

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Conception and design: Barzilai. Acquisition of data: Newman, Amin, Villavieja. Analysis and interpretation of data: Barzilai, Newman, Amin, Bilsky. Drafting the article: Barzilai, Newman, Amin, Bilsky. Critically revising the article: Barzilai, Amin, Laufer, Bilsky. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Barzilai. Study supervision: Barzilai.

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