Interbody distraction and vertebral body reconstruction with polymethylmethacrylate for the treatment of pathological fractures

Scott L. Zuckerman, MPH, MD, Ganesh Rao, MD, Laurence D. Rhines, MD, Ian E. McCutcheon, MD, Richard G. Everson, MD, and Claudio E. Tatsui, MD

Department of Neurological Surgery, Vanderbilt University School of Medicine, Nashville, Tennessee; and Department of Neurological Surgery, The University of Texas MD Anderson Cancer Center, Houston, Texas

OBJECTIVE Treatment of epidural spinal cord compression (ESCC) caused by tumor includes surgical decompression and stabilization followed by postoperative radiation. In the case of severe axial loading impairment, anterior column reconstruction is indicated. The authors describe the use of interbody distraction to restore vertebral body height and correct kyphotic angulation prior to reconstruction with polymethylmethacrylate (PMMA), and report the long-term durability of such reconstruction.

METHODS A single institution, prospective series of patients with ESCC undergoing single-stage decompression, anterior column reconstruction, and posterior instrumentation from 2013 to 2016 was retrospectively analyzed. Several demographic, perioperative, and radiographic measurements were collected. Descriptive statistics were compiled, in addition to postoperative changes in anterior height, posterior height, and kyphosis. Paired Student t-tests were performed for each variable. Overall survival was calculated using the techniques described by Kaplan and Meier.

RESULTS Twenty-one patients underwent single-stage posterior decompression with interbody distraction and anterior column reconstruction using PMMA. The median age and Karnofsky Performance Scale score were 61 years and 70, respectively. Primary tumors included renal cell (n = 8), lung (n = 4), multiple myeloma (n = 2), prostate (n = 2), and other (n = 5). Eighteen patients underwent a single-level vertebral body reconstruction and 3 underwent multilevel transpedicular corpectomies. The median survival duration was 13.3 months. In the immediate postoperative setting, statistically significant improvement was noted in anterior body height (p = 0.0017, 95% confidence interval [CI] -4.15 to -1.11) and posterior body height (p = 0.0116, 95% CI -3.14 to -0.45) in all patients, and improved kyphosis was observed in those with oblique endplates (p = 0.0002, 95% CI 11.16–20.27). In the median follow-up duration of 13.9 months, the authors observed 3 cases of asymptomatic PMMA subsidence. One patient required reoperation in the form of extension of fusion.

CONCLUSIONS In situ interbody distraction allows safe and durable reconstruction with PMMA, restores vertebral height, and corrects kyphotic deformities associated with severe pathological fractures caused by tumor. This is accomplished with minimal manipulation of the thecal sac and avoiding an extensive 360° surgical approach in patients who cannot tolerate extensive surgery.
epidural spinal cord compression (ESCC). An increase in the number of elderly patients along with improved systemic cancer therapies has resulted in a rise in the incidence, prevalence, and number of patients with metastatic disease.5,7,34

The current standard of care for patients with high-grade ESCC by the Spine Oncology Study Group is surgical decompression followed by conventional radiotherapy or spinal stereotactic radiosurgery (SRS).3,25 Recently, Laufer et al.18 have described the concept of separation surgery, which includes a single-stage posterior spinal stabilization, removal of epidural tumor, and reconstitution of the thecal sac prior to delivery of spinal SRS. Local control is achieved by delivering adequate doses of radiation but limiting the dose to the spinal cord.18,21

In cases of severe fracture and/or kyphotic deformity with significant axial loading failure, reconstruction of the anterior column may be required for palliative benefit. In addition to decompression and pain control, surgical goals include restoring neutral spinal alignment. Two-staged 360° reconstruction may be undesirable because of an increased risk of complications, especially in patients with a fragile state due to prolonged cancer treatments.6,27 Options for posterior-only anterior column reconstruction include polymethylmethacrylate (PMMA) injection and titanium or polyetheretherketone (PEEK) cage placement.30 Both PMMA and cage placement have shown similar postoperative outcomes, as measured by blood loss, pain, and survival.6 However, cage placement often requires nerve root sacrifice, which cannot be performed in the lumbar spine. Moreover, risks of both endplate subsidence and high cost may be increased with a titanium or PEEK cage.15

In the current case series of patients with spinal tumors causing ESCC, we describe the use of in situ interbody distraction to both restore vertebral body height and correct kyphotic angulation prior to reconstruction with PMMA during a single-stage transpedicular approach. We report the long-term postoperative changes in vertebral body height and kyphosis with an emphasis on durability of this treatment strategy.

Methods
Study Design
A retrospective, single-institution case series was undertaken from 2013 to 2016. Study approval was obtained by the university IRB. Inclusion criteria were any patients undergoing surgery in the setting of ESCC caused by tumor requiring anterior column reconstruction. Indications for anterior column reconstruction included severe mechanical back pain, pathological fractures with > 50% loss of height, and > 50% resection of the vertebral body. Any patients with ESCC due to nontumor reasons and those not requiring anterior column reconstruction were excluded. The current study adhered to the guidelines put forth by the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) effort.31

Data Collection
Preoperative demographic and disease-specific data points were obtained, which included sex, age, Karnofsky Performance Scale (KPS) score, histology, and Frankel scale score. Intraoperative variables collected included corpectomy level, instrumentation used, fracture alignment, and construct length. Postoperatively, overall survival (OS) and complication data were collected through routine patient visits and imaging studies. OS was defined as the time from operation to death, measured in months.

Three measurements were taken to assess the spinal construct: anterior height, posterior height, and segmental kyphosis. These measurements were taken at 3 different time points: preoperatively, immediately postoperatively, and last follow-up. All parameters were measured on the sagittal CT scan reconstruction. Anterior and posterior height were defined as the distance between the inferior endplate above the corpectomy site to the superior endplate below the corpectomy site, measured at the anterior and posterior vertebral body limits, respectively. Segmental kyphosis was defined as Cobb angle measured between the superior endplate of the level above the fracture to the inferior endplate of the unaffected vertebra below the fracture. All measurements were completed on a picture archiving and communication system.

The primary outcome measure was the assessment of the immediate restoration of vertebral body height and, when applicable, correction of the kyphotic deformity. Neurological status was assessed during patient follow-up.

Operative Technique
All surgeries were performed using a single-stage posterior midline approach. A standard subperiosteal dissection was performed with adequate exposure at all levels of planned pedicle screw fixation. Pedicle screws were usually placed 2 levels above and below the affected level. In tumors located in the transition zones or requiring 2 or more levels of anterior reconstruction, additional levels of pedicle stabilization were used. In cases of severe osteopenia, it is our practice to perform pedicle screw cement augmentation with 3–5 ml of cement prior to placement of the pedicle screw, as described in previous series.22 Cement augmentation along the pedicle screw tract has been shown to increase screw pullout strength4 and decrease rates of pseudarthroses in osteoporotic patients.26

Our typical surgical technique involves dorsal element resection, ligation of thoracic spinal nerves proximal to the dorsal root ganglion, resection of the posterior longitudinal ligament, disectomies above and below the affected vertebral body, and then corpectomy.7 The interbody distractor (Fig. 1) is inserted to the anterior-most aspect of the vertebrectomy defect in front of the instant axis of rotation (Fig. IC), which can be confirmed with fluoroscopy as needed. Prior to distraction, a rod is contoured and placed on the contralateral side, with 1 screw fully locked and 1 loosely tightened. Distraction is then performed with similar force used during placement of an expandable cage, taking care to avoid overdistraction and fracture of the endplates. Once adequate height and kyphosis reduction have been restored, the temporary rod is locked in place. Improvement in reduction is judged based on the tension of the thecal sac, screw head movement around the rod, and fluoroscopic images.

In cases of single-level reconstruction, the distrac-
tion creates a pre-tensioned state, which will place the cement block in compression once the temporary rod is released. In addition, restoring the parallel alignment of the endplates allows better distribution of the axial load in the anterior and middle column, decreasing the chance of cement displacement. With the corpectomy site distracted and locked in with 1 rod, PMMA is poured into the defect using a 60-ml syringe. We use a Penfield no. 3 dissector to mold the liquid PMMA, contouring it to match the corpectomy defect until the cement hardens. We emphasize that only two-thirds of the vertebrectomy defect is to be filled with PMMA, because significant cement expansion occurs during the process of polymerization. Failure to follow this rule will result in expansion of the cement block causing compression of the dura and the need for a relatively difficult drilling off the PMMA block to decompress the thecal sac. For vertebrectomy defects of 2 or more contiguous levels, a small screw is placed at the superior and inferior endplate prior to the cement injection to act as a buttress after the PMMA polymerizes around it. Alternatively, a Steinman pin can be inserted into the endplates adjacent to the defect with the same purpose.

Once the cement has hardened, rods are placed bilaterally. Compression is then applied on each side across the previously placed pedicle screws, and the rods are locked in place consecutively under compression. Once the second rod has been compressed and locked, attention is turned to decortication. Cancellous chips and demineralized bone matrix are placed at the sites of possible fusion. Vancomycin powder is spread along the muscle, and multiple subfascial drains are placed. Lastly, hemostasis is achieved, followed by a meticulous closure of the fascia, subcutaneous tissue, and skin in anticipation of radiation. Surgical steps are demonstrated graphically (Fig. 2) and through a representative case (Video 1).

**VIDEO 1.** Clip showing a representative case and video of interbody distraction. Copyright Claudio E. Tatsui. Published with permission. Click here to view.

**Statistical Analysis**

Descriptive statistical analysis was performed. Means, standard deviations, and ranges were calculated for continuous variables. Percentages were calculated for binary and categorical variables. When assessing OS, a survival analysis was completed according to the method described by Kaplan and Meier. A normal distribution was tested with the Shapiro-Wilk test for the variables of interest, which included changes in anterior height, posterior height, and kyphosis. Each measurement at all 3 time points was found to be normally distributed, with p values > 0.05. Thus, a Student paired t-test was performed for each variable of interest to assess parametric, paired, continuous data. Two separate comparisons were performed: 1) preoperative values compared with immediately post-

**FIG. 1.** A: Interbody distractor. B: Anteroposterior view of interbody distractor inserted into vertebrectomy site. C: Sagittal view of interbody distractor inserted into vertebrectomy site. D: Sagittal view of distracted interbody distractor with reduced kyphosis and improved vertebral body height.
operative values, and 2) immediately postoperative to last follow-up. Significance was considered as any p value < 0.05 and 95% confidence interval (CI) not including zero.

Marginal significance was noted for any p value < 0.10.

All statistical analysis was performed in Stata (version 14, StataCorp LP).

**Results**

**Patient Demographic Characteristics**

A total of 21 patients underwent single-stage posterior decompression, in situ interbody distraction, and anterior column reconstruction using PMMA. The median age was 61 years (range 56–68 years) and 67% of patients were male. The median preoperative KPS score was 70, and all but 2 patients were neurologically intact (who had a Frankel score of D). Primary tumors included renal cell (n = 8), lung (n = 4), multiple myeloma (n = 2), prostate (n = 2), and others (n = 5). Demographic characteristics are summarized in Table 1.

**Operative Variables**

Fifteen patients had a single vertebral body reconstruction (11 thoracic, 4 lumbar) and 6 underwent multilevel corpectomies (2 at T2/3, 4 at T11/12). Posterior constructs varied from 1 to 4 levels above the corpectomy site. Most fracture patterns included parallel endplates above and below the fracture site, although 7 (33%) were oblique with significant segmental kyphosis. Three cases (14%) of cement reconstruction of multiple vertebral bodies required placement of an endplate screw to buttress the PMMA block due to poor bone quality and a desire to solidify the anterior column reconstruction. A representative case of significant preoperative kyphosis with oblique perilesion-
al endplates treated with in situ reduction is demonstrated in Fig. 3. The median follow-up duration was 13.9 months (range 0.1–37.1 months). The median OS was 13.3 months (range 1.4–38.7 months; Fig. 4). Perioperative variables are summarized in Table 2.

Vertebral Body Height and Kyphosis

In the immediate postoperative setting, significant improvement was seen in anterior body height ($p = 0.0017$, 95% CI $-4.15$ to $-1.11$; Table 3) by a mean of 2.63 cm (95% CI 1.12–4.15 cm). Similarly, posterior body height significantly improved ($p = 0.0116$, 95% CI $-3.14$ to $-0.45$) by a mean of 1.80 cm (95% CI 0.45–3.14 cm). A trend toward significance with respect to the reduction of kyphosis was seen ($p = 0.0863$, 95% CI $-0.67$ to $9.24$) with a mean reduction of 4.29° (95% CI $-0.67$° to 9.24°). Of the 7 patients with oblique endplate orientation, there was a statistically significant improvement in kyphosis immediately postoperatively ($p = 0.0002$, 95% CI 11.16°–20.27°). In patients with parallel endplates, with minimal kyphosis already, no significant change in kyphosis was observed, as expected.

In the second analysis comparing last follow-up to immediately postoperative, a significant decline in anterior height was noted ($p = 0.0107$, 95% CI 0.73–4.84). For posterior height and kyphosis, although both values changed over time—posterior height slightly improved whereas kyphosis worsened—they did not reach levels of statistical significance (Table 3). Figure 5 shows the absolute values of vertebral body height and kyphosis in oblique endplates measured by the Cobb angle.

Imaging and Clinical Follow-Up

In the postoperative period, a total of 8 patients had changes in imaging and 1 patient required clinical follow-up (Table 4). Nonoperative subsidence of the cement block was noted in 3 patients, and compression osteoporotic fractures adjacent to the construct occurred in 6 patients (1 patient with subsidence also had a compression fracture). Only 1 patient developed refractory pain due to the new fractures and required revision vertebrectomy (Fig. 6). Neurologically, all intact patients had preservation of neurological function until the last follow-up evaluation, and the 2 patients with Frankel Grade D improved to Frankel Grade E.

Discussion

In patients with ESCC and failure of axial loading ca-
Interbody distraction for treatment of pathologic fractures

In situ interbody distraction followed by cement reconstruction to restore vertebral body height, realign the endplates, and improve segmental kyphosis.

Patients with metastatic spinal disease often have many comorbidities and are frequently malnourished and deconditioned. Additionally, after surgical treatment, they undergo radiation. These factors may jeopardize spinal stability after resection and reconstruction. Because arthrodesis is rarely achieved in spine tumor cases, the reconstruction with vertebral body replacement and posterior segmental instrumentation is under significant stress, as this instrumentation is critical to maintaining spinal stability. Additionally, the occurrence of loosened bone/screw interface, adjacent-level osteoporosis, radiation/chemotherapy-induced muscle atrophy, and endplate subsidence may threaten reconstructions after spine tumor surgery. Thus, spinal reconstruction in patients with pathological fractures must be biomechanically viable.

Amankuluor and colleagues² reported symptomatic hardware failure, defined as reoperation, in a very low percentage (2.8%) of patients undergoing separation surgery with posterior segmental instrumentation. Anterior column instrumentation was used in a small subset of their patient population (17.4%). Furthermore, in the largest series of separation surgery patients to date, vertebral body replacement was performed with PMMA or a cage when more than 50% of the vertebral body was resected.¹⁸,⁳³ In single-stage posterior approaches, the surgeon has a limited capacity to reduce kyphosis when the distraction is attempted using pedicle screws placed adjacent to the fracture, which can result in stress fractures and loosening of the pedicle screws due to poor bone quality often seen in a cancer population. To overcome these limitations, some authors have used expandable cages to perform the reconstruction, distraction, and reduction of pathological fractures,²⁷,³⁰ which can be performed either as a combined anterior/posterior or posterolateral approach, requiring more extensive surgical approaches and meticulous endplate preparation to accommodate the cage.

We describe a simple technique in which an interbody}

### TABLE 3. Anterior height, posterior height, and kyphosis

<table>
<thead>
<tr>
<th>Variables</th>
<th>Preop</th>
<th>Immediately Postop</th>
<th>p Value (95% CI)</th>
<th>Last Follow-Up</th>
<th>p Value (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertebral body height (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean anterior height ± SD</td>
<td>26.3 ± 10.2</td>
<td>29.0 ± 9.8</td>
<td>0.0017* (−4.15 to −1.11)</td>
<td>27.2 ± 10.1</td>
<td>0.0107* (0.73–4.84)</td>
</tr>
<tr>
<td>Mean posterior height ± SD</td>
<td>28.3 ± 9.3</td>
<td>30.1 ± 8.5</td>
<td>0.0116* (−3.14 to −0.45)</td>
<td>30.7 ± 9.6</td>
<td>0.9437 (−1.19 to 1.28)</td>
</tr>
<tr>
<td>Kyphosis (°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± SD parallel endplates†</td>
<td></td>
<td>10.9 ± 7.5</td>
<td>12.4 ± 11.5</td>
<td>0.5210 (−6.11 to 3.25)</td>
<td>15.4 ± 12.1</td>
</tr>
<tr>
<td>Mean ± SD oblique endplates‡</td>
<td></td>
<td>25.0 ± 9.7</td>
<td>9.3 ± 3.1</td>
<td>0.0002* (11.16–20.27)</td>
<td>19.7 ± 12.4</td>
</tr>
<tr>
<td>Median follow-up in days (IQR)</td>
<td></td>
<td>0</td>
<td>1 (1–3)</td>
<td>418 (1–1113)</td>
<td></td>
</tr>
</tbody>
</table>

* Statistically significant.
† Fourteen patients available immediately postoperatively, 13 for last follow-up (1 patient lost to follow-up).
‡ Seven patients available immediately postoperatively, 6 for last follow-up (1 patient lost to follow-up).

![FIG. 5. Bar graph of preoperative and postoperative changes in vertebral body anterior and posterior height in all patients, and kyphosis changes in those with oblique endplates.](image-url)
distractor is applied directly over the endplates adjacent to the corpectomy defect after a transpedicular approach. Compared with the initial 1996 description of the transpedicular approach, when hooks and Luque rectangles were used, the use of both segmental pedicle screw fixation and expandable cages has vastly improved the surgeon’s ability to reduce deformity and maintain correction. It is our belief that this technique provides equivalent reduction to an expandable cage, because the distraction force is distributed between the anterior and middle columns, in front of the instantaneous axis of rotation. Distraction is maintained by placement of a temporary rod while the cement is applied. Once the PMMA polymerization is complete, temporary fixation is released, allowing the expanded vertebral body space to collapse over the block of cement, obtaining a similar compression effect with excellent press fit interface similar to the effect observed with an expandable cage. Initial vertebral body height in all patients and kyphosis in oblique endplates was significantly improved in our study. As reported in other series of traumatic burst fractures, progressive loss of the initial correction of vertebral body height was also noted in our patients, which explained the changes in segmental kyphosis over time; however, similar to these reports, this observation was not associated with symptoms and did not correlate with significant need for reoperation. We believe that the presence of the intact spinal hardware and the adequate load sharing in the reconstructed vertebral body allowed the axial load to be handled; therefore, the small loss of correction was not predictive of poor functional outcome. Only 1 patient (4.8%) in our series required reoperation due to refractory pain, subsidence, and loss of the initial kyphosis correction.

However, the utilization of expandable titanium cages for a reconstruction of spinal fractures is an alternative option with acceptable results. Eleraky et al. evaluated 32 patients undergoing corpectomies due to ESCC

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsidence</td>
<td>Yes</td>
</tr>
<tr>
<td>Distances (mm)</td>
<td>3.6, 3.9, 5.6</td>
</tr>
<tr>
<td>Fracture</td>
<td>6 (29)</td>
</tr>
<tr>
<td>Superior aspect of construct</td>
<td>2 (10)</td>
</tr>
<tr>
<td>Inferior aspect of construct</td>
<td>3 (14)</td>
</tr>
<tr>
<td>Outside of construct</td>
<td>1 (5)</td>
</tr>
<tr>
<td>Reoperation</td>
<td>1 (5)</td>
</tr>
</tbody>
</table>

Values are number of patients (%) unless otherwise indicated.

**FIG. 6.** A: Immediate postoperative CT scan of T11–12 vertebrectomy, PMMA reconstruction with endplate screws, and T8–L2 posterior spinal fusion. Note a significant portion of the nondiseased anterior body left in place. B: CT scan prior to revision vertebrectomy showing worsening kyphosis from 21° to 24° and retropulsion of PMMA block causing canal compromise. C: Postoperative CT scan after revision vertebrectomy. Note the completion of the vertebrectomy to include the anterior column. The interbody distraction allowed improvement in the anterior and posterior vertebral body height and reduction of the segmental kyphosis from 24° to 11°.
with expandable cage placement versus PMMA injection, and a marginal trend of reduced kyphosis was observed in the expandable cage group (10.04° vs 5.45°, p = 0.16), although interbody distraction was not performed in the PMMA group. However, PMMA offers the possibility of a partial body defect reconstruction when removal of the entire body is not required, whereas titanium or PEEK cage placement requires more extensive bone removal of the vertebral body.23 While only transpedicular access is needed for PMMA placement, a costotransversectomy or lateral extracavitary approach is needed for cage placement, requiring additional muscle dissection.8,23,32 Even in mini-open corpectomies, rib head removal is needed for cage placement.17 Furthermore, in the case of osteoporotic or tumor-invaded adjacent bone, rates of subsidence may be higher with a titanium cage than with PMMA due to smaller endplate contact.10 It has been our experience that cement reconstructions require less manipulation of the dura, spinal cord, and nerve roots (particularly in the lumbar spine) than with expandable cages. Because lumbar nerve roots are generally preserved, expandable cage placement is much more complicated when compared with the placement of PMMA.23 PMMA has been reported to induce some complications, including exothermic heat injury of neural structures and cement extravasation,11,20 but these were not seen in tumor populations and were associated with kyphoplasty operations.

Our report is subject to the weaknesses of a small series. In addition, a lack of comparison with other vertebral body reconstruction techniques prevents us from claiming true superiority of the described technique. Moreover, due to the palliative nature of each surgery, follow-up was relatively short. The short follow-up duration does not allow for a complete evaluation of each construct, and over time it is possible that additional patients may require revision surgery. In terms of vertebral body measurements, all values were obtained on CT scans for a better evaluation of each endplate. Although the endplates were well visualized, these were not taken in a standing, weight-bearing position. In spinal deformity surgery, standing 36-inch films are required to adequately assess spinal alignment. The same standard should be applied to tumor surgery; however, radiographs were unfortunately not part of our routine clinical practice. Due to the urgent or emergent nature of each operation, 36-inch standing radiographs are often not obtained preoperatively, which precluded postoperative comparison. Rather, to evaluate subsequent disease burden, postoperative MRI and CT scans were obtained on a routine basis and evaluated by medical and radiation oncologists. Despite a non–weight-bearing position, all measurements were taken on supine CT scans to accurately and consistently assess changes over time.

Conclusions

In patients with spinal tumors causing ESCC and severe axial loading capacity failure, reconstruction of the vertebral body is indicated. Restoration of vertebral body height with interbody in-situ distraction creates a pretensioned condition that allows an improved cement reconstruction. The resulting restoration of height and reduction in segmental kyphosis allows improved load sharing with the posterior segmental instrumentation and places the cement bloc in compression against the adjacent endplates. In our experience, this reconstruction was effective and allowed immediate spinal stability that translated to a durable maintenance of neurological function and performance status in our patient population.

References


Disclosures
Dr. Rhines reports being a consultant to Stryker and Medtronic.

Author Contributions
Conception and design: Tatsui. Acquisition of data: Tatsui. Analysis and interpretation of data: Tatsui, Zuckerman. Drafting the article: Zuckerman. Critically revising the article: all authors. Reviewed submitted version of manuscript: Tatsui, Zuckerman. Statistical analysis: Zuckerman. Administrative/technical/material support: Tatsui, Rao, Rhines, McCutcheon. Study supervision: Tatsui, Rao, Rhines, McCutcheon.

Supplemental Information
Videos

Correspondence
Claudio E. Tatsui, Department of Neurological Surgery, The University of Texas MD Anderson Cancer Center, 1515 Holcombe Blvd., Unit 442, Houston, TX 77030. email: cetatsui@mdanderson.org.