Original Article

Microscopically-assisted Uninstrumented Surgical Tumor Decompression as an alternative to open surgery for symptomatic metastatic epidural spinal cord compression

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Background: The current standard of care recommends spinal tumor decompression surgery prior to radiation. However, the differences in open *vs.* minimally invasive surgery (MIS), extent of vertebroplasty, and role of instrumentation remains unclear across the literature. This study aims to assess whether our proposed Microscopically-Assisted Uninstrumented Spinal Tumor Decompression (MUST-D) technique using vertebral augmentation (VA) offers a surgical advantage over standard open instrumented fusion in the treatment of symptomatic metastatic epidural spinal cord compression (MESCC).

Methods: This single-institution retrospective cohort study evaluated patients who underwent either standard open decompression with instrumented fusion (Control) or MIS with vertebrectomy and cement augmentation (MUST-D) for MESCC decompression from November 2006 to June 2016. Demographic, surgical, and follow-up data were extracted from medical records. The inclusion criteria were radiographic evidence of MESCC, pathology-confirmed spinal metastasis, and symptoms of vertebral instability or neural compression. Outcomes included length of operation, anesthesia duration, estimated blood loss (EBL), hospital stay, complications, time until radiation therapy (RTx), Hauser Ambulation Index (HAI), Cobb angle, mortality, and survival.

Results: Among 59 MESCC surgeries, 21 (36%) had MUST-D and 38 (64%) had open surgery (60.8 *vs.* 59.2 years, P=0.62). Preoperative Spine Instability Neoplastic Score (SINS) (P=0.40) and index level of surgery (P=0.44) were similar between groups. The MUST-D group had reduced length of operation (P<0.001), anesthesia duration (P=0.004), hospital stay (P=0.01) and complications (P<0.001) compared to the control group. Trends toward decreased EBL were observed (P=0.06). Postoperatively, the MUST-D group had shorter time to RTx compared to the control group (P=0.03). Despite similar pre-operative ambulation, the MUST-D group had a shorter time to ambulation postoperatively compared to the control group (0.41 *vs.* 3.68 days, P=0.02). Moreover, the MUST-D group demonstrated improvement in 30-day HAI ambulation score, whereas the control group worsened (−1.60 *vs.* 0.33, P=0.008). Both groups had improved Cobb angle, with no new instability or focal kyphosis across a mean follow-up period of 1.51 years. No differences were observed in 1-year mortality (P=0.16) or Kaplan-Meier survival estimates (P=0.18). However, of patients who died, the MUST-D group demonstrated a longer time to death (P=0.04).

Conclusions: Our findings indicate that the MUST-D technique provides surgical advantages compared to standard open surgery for MESCC, with significant improvement in perioperative outcomes. Although both groups had similar 1-year mortality, the MUST-D cohort demonstrated shorter time to RTx, faster postoperative ambulation, improved 30-day ambulatory function, similar index level revision rates, and longer time to death compared to open procedures. With no inferior outcome recorded in our study, the MUST-D technique is observed as an improvement over standard approach. Thus, we propose the MUST-D technique as an alternative treatment modality for symptomatic MESCC decompression. Larger randomized prospective studies with robust clinical correlation are warranted to confirm these findings.

Keywords: Spine; metastatic epidural spinal cord compression (MESCC); minimally invasive surgery (MIS); cement augmentation

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Introduction

The spinal column is the third most common site of metastasis following the lung and liver (1,2). Spinal metastases affect 30–90% of all cancer patients, with approximately 10% of these patients experiencing symptomatic spinal cord compression (3). Furthermore, 94–98% of spinal cord compression cases display evidence of epidural and/or vertebral involvement (3). Symptomatic patients often present with severe back or neck pain and, to a lesser extent, radicular pain, extremity weakness, sensory disturbances, and/or bowel and bladder dysfunction (4,5).

The indications for surgical interventions for metastatic epidural spinal cord compression (MESCC) have evolved over the last 75 years with laminectomy procedures as the initial standard of care operation. However, these procedures often did not adequately decompress the primary tumor and further destabilized the spine. This technique was abandoned due to the worse outcomes compared to radiotherapy alone (6). The pivotal study by Patchell *et al.* demonstrated the superiority of direct surgical decompression and radiotherapy over radiotherapy alone for patients with MESCC in improving ambulation and pain control (7). This redirected a generation of oncologists and surgeons to perform instrumented vertebrectomies instead of laminectomy procedures alone (8).

The current goals for MESCC treatment are largely palliative, aiming to sustain or improve quality of life by preserving neurologic function, mechanical spinal stability, and pain reduction (9). Concerns with treatment include subsequent deformity from spinal instability, progression of neurological deficits, and complications from surgical, radiological, or oncological treatment. Active comorbidities further complicate treatment decisions, including the risk of blood clots from a baseline prothrombotic state, infection due to an immunosuppressive state from treatment regimens, and impairment in wound healing, creating higher surgical risk and complication rates (10,11). Thus, many patients are deemed non-operative candidates for open surgery due to age, comorbidities, metastatic burden, or limited life expectancy.

Open spine surgery for metastatic disease can have high rates of wound complications, often attributed to the reduction of circulation from midline incision or impaired healing after administration of radiation and chemotherapy (12,13). Therefore, postoperative cancer treatment is often delayed to reduce the risk of infection and dehiscence at the expense of prolonging immobilization and completion of adjuvant treatments (14). Delayed radiotherapy following surgery has been shown to increase the risk of local tumor progression with poorer local control and overall survival rates (15). In addition, postoperative ambulation function has been reported to be significantly associated with survival (16). When the primary treatment goal for MESCC is largely palliative, improving intraoperative variables, complication rates, and postoperative ambulation through less invasive surgical approaches may hold further importance in improving a patient's remaining quality of life.

Minimally invasive surgical (MIS) techniques expand the pool of potential operative candidates for cancer patients with limited life expectancy by reducing perioperative morbidity and accelerating recovery (17-19). Today, the guiding principle in selecting a surgical approach for symptomatic MESCC is both to obtain adequate decompression of neural elements and provide stabilization to the spine while minimizing the risks of complications (20). MIS treatments have been shown to have smaller incisions, preserve anatomy, reduce iatrogenic tissue trauma, and decrease postoperative pain (21). However, few papers to date have been published describing MIS techniques for tumor decompression without instrumentation (19,22). Weller *et al.* demonstrated the utilization of posterolateral decompression without stabilization in patients with limited life expectancies and showed improvement in neurological outcomes in all eight patients (23). Similarly, Deutsch *et al.* later presented a posterolateral vertebrectomy and decompression without stabilization using a MIS approach in a case series of eight patients with no neurological deterioration at 1-year (22). Despite these favorable outcomes, the current literature is limited to small case series with no larger study to corroborate these findings.

Herein, we describe the Microscopically-Assisted Uninstrumented Spinal Tumor Decompression (MUST-D) technique for tumor decompression and treatment of symptomatic MESCC in comparison to the traditional open surgical approach (22). The MUST-D approach incorporates a tubular retractor with a posterior oblique approach, splitting the paraspinal muscles instead of retracting the muscles as performed in conventional midline open approaches. The MUST-D technique also avoids pedicle screw instrumentation, using only direct vertebral augmentation (VA) using cement and a single screw anchoring to stabilize the vertebral cavity. This technique avoids delays in adjuvant treatment with the small incision positioned outside the usual linear accelerator (LINAC) radiation field.

The purpose of this study is to compare the surgical outcomes of patients undergoing MUST-D or standard open instrumented approach for MESCC treatment. Key outcomes include 1-year mortality and survival, time to death, time to adjuvant radiation therapy (RTx), mobility, and degree of postoperative spinal instability. Secondary outcomes include baseline demographics, intraoperative and perioperative variables, and complication rates. We present this article in accordance with the STROBE reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-24-135/rc).

Highlight box

Key findings

- Compared to standard open decompression with instrumented fusion for metastatic epidural spinal cord compression (MESCC), our proposed Microscopically-Assisted Uninstrumented Surgical Tumor Decompression (MUST-D) technique had shorter operating time, anesthesia duration, length of hospital stay, and time to ambulation.
- Despite no difference in mortality between groups, patients undergoing MUST-D surgery demonstrated significantly fewer complications, a shorter time to radiation therapy, improved 30-day ambulation, and no evidence of focal long-term instability.

What is known and what is new?

- The proposed MUST-D approach is a novel minimally invasive surgery (MIS) technique utilizing single-screw anchored vertebral augmentation without instrumentation for MESCC decompression.
- Direct surgical decompression with adjuvant radiotherapy has been previously shown to be superior to radiotherapy alone in improving ambulation and pain control for patients with MESCC.

What is the implication, and what should change now?

- Although 1-year mortality was not correlated with the surgical approach, the survival time was significantly longer with the MUST-D approach. The presence of spinal metastases does not usually correlate with survival, but in this case, the MIS approach did correlate with longer survival times and should be considered equivalent or superior to an open approach for survival benefit.
- The MUST-D surgical technique should be considered as first-line treatment for symptomatic focal MESCC to minimize complications, improve perioperative outcomes, and expedite adjuvant radiotherapy, especially for patients who may have been a poor candidate for a larger open approach.

Methods

This is a retrospective cohort study of patients undergoing MESCC decompression with the proposed MUST-D technique or standard open instrumented fusion at a single, multi-surgeon institution from November 2006 to June 2016. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was determined to be exempt from IRB oversight initially by the Icahn School of Medicine at Mount Sinai until expiration, and then by Advarra for the remainder of the study period. Individual consent for this retrospective analysis was waived.

MUST-D surgery was defined as MIS single-level partial vertebrectomy and cement augmentation with single screw anchoring. The MUST-D procedures were performed by the primary surgeon and open procedures by other surgeons at the same institution. These patients were identified through the Mount Sinai Data Warehouse. Demographic and clinical data were abstracted from patient charts. Identifiable markers were then removed prior to data input into password-protected databases. The final key was retained in a password-protected file separate from the primary data file.

HAI	
0	No impediment
1	No impediment except fatigue with activity
2	Abnormal gait, 25 feet <20 seconds
3	25 feet <20 seconds
4	Need cane, 25 feet <20 seconds
5	Bilateral supports, 25 feet <20 seconds
6	Bilateral supports, 25 feet >20 seconds
7	Few steps only, mostly wheelchair
8	Wheelchair only, independent transfer
9	Wheelchair only, unable to transfer

Figure 1 Grading system for the HAI to assess patient mobility and ambulation pre- and post-operatively (14). HAI, Hauser Ambulation Index.

Inclusion criteria for the study included: (I) symptoms indicating spinal instability or neural compression from apparent spinal metastasis or metastases. These include myelopathy, radiculopathy, or pathological fractures with radiographic signs of instability or deformity that causes pain; (II) radiographic evidence of MESCC, limited to no more than one full contiguous vertebral levels or involvement; (III) surgical confirmation of metastatic disease verified by the Department of Pathology at Mount Sinai Hospital. Patients were excluded if they lacked complete follow-up, such as post-discharge mortality, functional status, or neurological outcome. Patients with prior spinal surgery at the index level were also excluded, as were patients who required transthoracic vertebrectomy, or only underwent laminectomy, as the decompressive part of their treatment.

Data collection

Collected patient variables included baseline demographics, tumor histology, Spine Instability Neoplastic Score (SINS), Hauser Ambulation Index (HAI) score, and Cobb angle (24,25). The HAI assesses ambulation, functional status, and quality of life after symptomatic spinal metastatic disease treatment. The HAI evaluates mobility of patients regarding the time and degree of assistance on a 0 to 9 scale (*Figure 1*). A score of 0 indicates a fully active, asymptomatic independent ambulator, while a score of 9 indicates someone who is immobile and bedridden. The Cobb angle was measured on sagittal magnetic resonance imaging (MRI) and computed tomography (CT) as the angle resulting from the intersection of two perpendicular lines emanating from parallel lines constructed from the superior border of the superiorly affected vertebrae and the inferior border of the inferiorly affected vertebrae. The evaluation was based on pre-operative imaging within 30 days of surgery and post-operative imaging at least 30 days after surgery. Operative data included skin-to-closure surgical time, anesthesia duration, estimated blood loss (EBL), length of hospital stay, and level of operation. Outcome data included time to ambulation, time to RTx, 30-day postoperative complications, local recurrence, mortality, survival, and time to death.

Surgical approach

MUST-D surgery

A 1.7–2 cm incision was made 5–9 cm lateral to midline (lateral to the facet joints, depending on the thickness of the subcutaneous tissue) at the index level. Under fluoroscopic guidance, a Bovie cautery was used to carry the incision to the rib overlying the target area through the thoracolumbar fascia in a 45-degree oblique fashion medially aiming towards the costo-transverse and then ultimately towards the costo-vertebral junction at the index level. The METRx (Medtronic, Memphis, TN, USA) dilators were sequentially placed and then either a 16- or an 18-mm tubular working channels (5–8 cm long) were then passed over the dilator docking first on the transverse process. The operating microscope was used throughout the rest of the case. Once that lateral transverse process was resected, we advanced the working channel along the same axis towards the costo-vertebral junction and lateral pedicle (*Figure 2A,2B*). The medial rib head may need to be resected or displaced to allow advancement of the working channel.

Some pedicle and lateral vertebral body bones were removed to facilitate the tumor resection from within the vertebral body and epidural space, depending on tumor involvement, but the facets were usually left intact. Once all the soft tumor was removed (*Figure 2C*), if the resection cavity was not fairly well constrained, an Atlantis Vision (Medtronic, Memphis, TN, USA) 14–16 mm × 3.5 mm diameter screw was then placed into the contralateral cortical vertebral body, leaving the head about 6–8 mm proud, projecting into the resection cavity, but not past the posterior margin of the vertebral body (*Figure 2D*). At this point, poly-methyl methacrylate cement (Simplex-P, Stryker, Portage, MI, USA) was mixed, placed in small

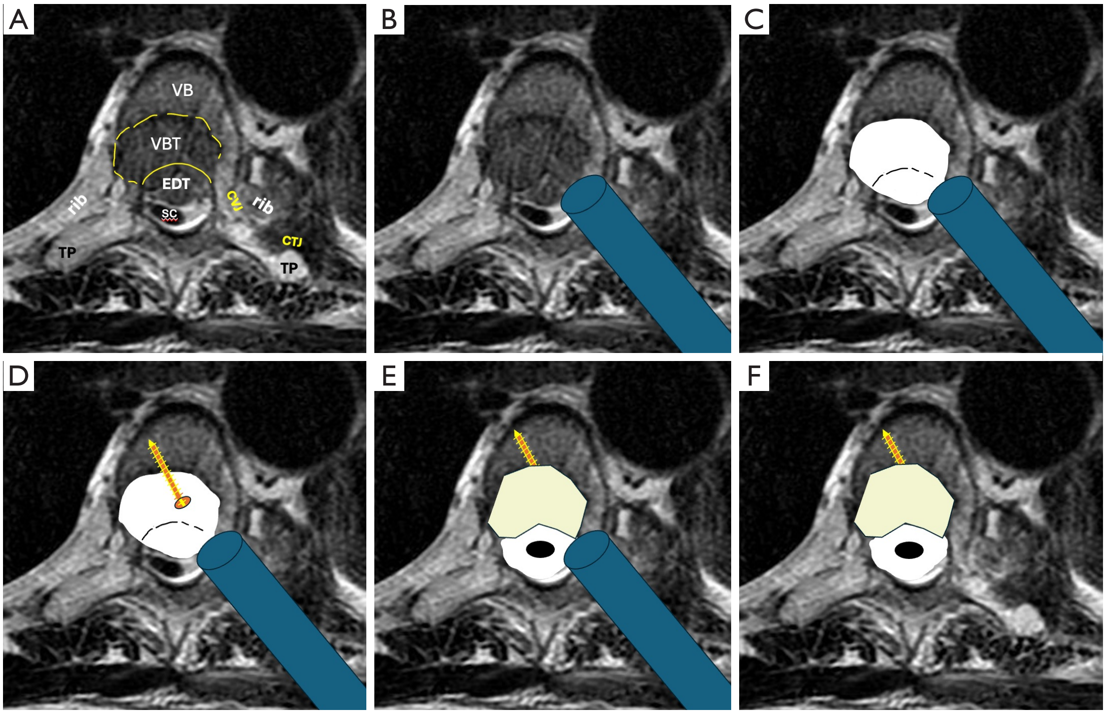

Figure 2 Axial sequence of T2 weighted MRI demonstrating surgical technique for MUST-D. (A) Axial view of the anatomical landmarks for surgical planning. Because the spinal cord is displaced to right side, the surgical approach will be from the left side along the CTJ, aiming for the CVJ. (B) Subsequent placement of METRx working channel via costo-transverse approach, resection of TP and part of rib, aiming for the CVJ and the base of the left pedicle. The nerve root at or below this pedicle on the side of the approach may or may not be sacrificed proximal to the dorsal root ganglion via clipping and then cutting with a scalpel. (C) Resection of EDT and VBT (white space), leaving VB anteriorly. Dashed lines represent hypothetical normal posterior VB margin/ventral spinal canal margin. (D) Interval placement of small (3.5 mm diameter, 14–16 mm length) screw halfway into VB anteriorly, leaving screw head in cavity but not projecting into spinal canal. Dashed lines represent hypothetical normal posterior VB margin/ventral spinal canal margin. SC appears still deformed in same position as pre-op due to presumption of manipulation for procedure. Note: if resection cavity is well bounded and enclosed by bone, screw is not necessary to contain PMMA. (E) Placement of PMMA cement down tube into VBT resection cavity and packing the cement around the screw head, into the cavity but not projecting into spinal canal. Dashed lines represent hypothetical normal posterior vertebral body margin/ventral spinal canal margin. Spinal cord is drawn to represent more normal position after manipulation and tumor resection completed. (F) Removal of the METRx tube. The spinal cord is drawn to represent a more normal position after manipulation and tumor resection are completed. Although a portion of the left pedicle, transverse process, and rib have been removed, the facets above and below were left mostly intact. Dashed yellow line represents margin between normal bone (VB) and metastatic tumor (VBT). Solid yellow line represents hypothetical line between normal spinal canal margin and EDT extension into canal, causing stenosis and compression on SC. VB, vertebral body; VBT, vertebral body tumor; EDT, epidural tumor; SC, spinal cord; TP, transverse process; CTJ, costo-transverse junction; CVJ, costo-vertebral junction; MRI, magnetic resonance imaging; MUST-D, Microscopically-Assisted Uninstrumented Spinal Tumor Decompression; METRx, Minimal Exposure Tubular Retractor system; PMMA, polymethyl methacrylate.

quantities consecutively into the cavity, and packed around the screw until it all hardened, so the cement was anchored by the screw without rotating or dislodging (*Figure 2E*). Once hemostasis was obtained, the working channel was removed (*Figure 2F*) and the skin was closed, and a simple dressing of Dermabond (J&J Ethicon, Raritan, NJ, USA) was applied and left on for a week or more. No subcutaneous drains were placed. Visualization of the placement of the screw is shown in *Figure 3A-3D*.

Control surgery

A midline incision was made from at least 4 levels above the

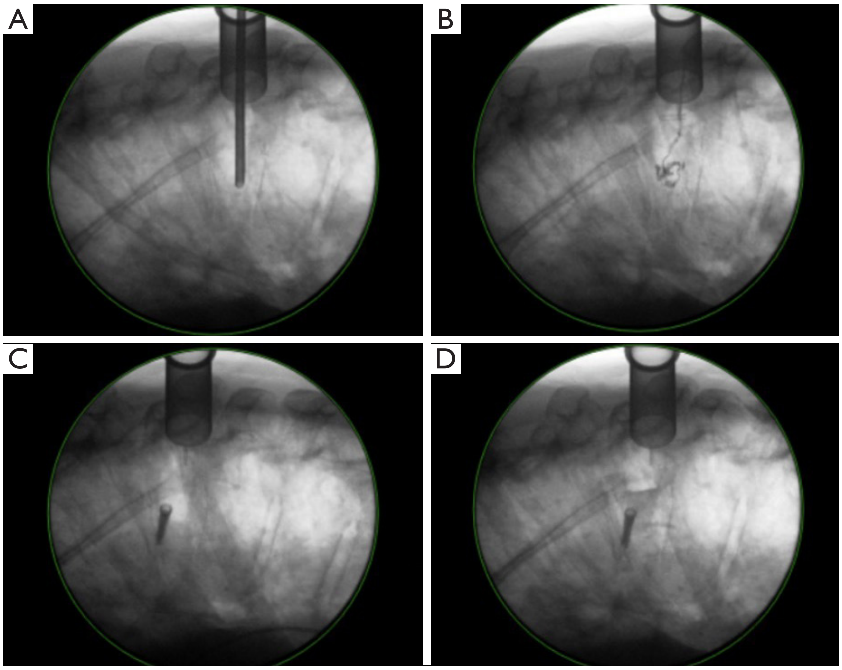

Figure 3 Serial intraoperative fluoroscopic imaging demonstrating key steps in the MUST-D surgical technique of single screw anchored vertebral augmentation without posterior fixation. (A) Suction catheter showing the extent of ventral cavity in the vertebral body after resection. (B) Cottonoid within in the resection cavity after achieving hemostasis. (C) Cement with screw placement into the remaining ventral vertebral body demonstrating that the screw did not exceed the anterior vertebral margin. (D) Cement backfilling but not extending past the posterior vertebral body. MUST-D, Microscopically-Assisted Uninstrumented Spinal Tumor Decompression.

target level, and at least 3 levels below the target level. The incision was carried further, dissecting the paraspinal muscles off the spinous processes and exposing the lamina, pars, and transverse processes bilaterally. Resection of the vertebral body tumor and epidural tumor in question was performed via a one (or more) of posterolateral approaches, including transpedicular vertebrectomy, costotransversectomy assisted vertebrectomy, or lateral extracavitary vertebrectomy, with or without laminectomy. After homeostasis was obtained, pedicle screw instrumentation was placed 2 or 3 levels above the resection level, and usually 2 below the target level, any available transverse process or facet bone surfaces were decorticated, a rod was placed bilaterally and secured, and some form of bone graft (allograft usually) was placed over the decorticated surfaces. The wounds were closed in a multilayered manner. Dressings and management of the drains and incisions were left to the individual surgeons.

Statistical analysis

Statistical analyses were performed using SAS software version 9.3 (SASv9.3, Cary, NC, USA). The specific statistical tests used include the Student's *t*-test for nominal data with a normal distribution, the Mann-Whitney *U* test for nominal data with large variance, the Chi-squared test for categorical variables, and the Pearson correlation coefficient test as appropriate. The Kaplan-Meier analysis survival curve was used to generate 1-year survival. Two-sided P values were employed when applicable. Statistical significance was defined as P<0.05.

Results

Patient demographics

During the study period, 59 patients with tissue-proven diagnosis of cancer and radiographic evidence of MESCC underwent either MUST-D or standard open surgery before radiotherapy treatment. There were 21 (36%) patients in the MUST-D group and 38 (64%) in the control. There were no differences in baseline demographics between groups (*Table 1*). The mean age at the time of surgery was 59.7±11.1 years (P=0.62). Thirty patients (51%) were male

Table 1 Patient demographics and tumor characteristics

Variables	MUST-D (n=21)	Control (n=38)	P value
Age (years)	60.8±9.20	59.2±12.1	0.62
Sex			0.15
Male	8 [38]	22 [58]	
Female	13 [62]	16 [42]	
Race			0.42
White	11 [52]	15 [39]	
Black	4 [19]	11 [29]	
Asian	2 [10]	1 [3]	
Other	4 [19]	11 [29]	
Representation over time			0.38
2007–2011	13 [62]	19 [50]	
2012–2016	8 [38]	19 [50]	
Histology			
Breast	6	7	
Lung	4	5	
HCC	7	6	
GI (non-HCC)	1	2	
Myeloma	1	4	
Lymphoma	1	2	
Adrenal cortical carcinoma	1	0	
Renal	0	5	
Prostate	0	3	
Thyroid	0	1	
Uterine	0	2	
Unknown carcinoma	0	1	
Level of index			0.44
Cervical	0 [0]	1 [3]	
Thoracic	16 [76]	29 [76]	
Lumbar	5 [24]	8 [21]	
Preoperative SINS	9.86±3.31	10.52±2.64	0.40
Preoperative focal cobb angle (degrees)	16.85±7.80	17.81±8.00	0.67

Values are presented as the mean ± standard deviation or number of patients as n [%] unless otherwise noted. MUST-D, Microscopically-Assisted Uninstrumented Spinal Tumor Decompression; GI, gastrointestinal; HCC, hepatocellular carcinoma; SINS, Spine Instability Neoplastic Score.

and 29 (49%) were female (P=0.15). Twenty-six (44%) were White, 15 (25%) Black, 3 (5%) Asian, and 15 (25%) Other (P=0.42). There was equal representation between groups over time. Pathologies were similar between both groups. There was no significant difference in the distribution of lumbar, thoracic, and cervical incidence between groups (P=0.44). The mean anatomical center of the operation (the point of maximum compression or vertebral involvement) was T8/9, with a range of C5 to S1. The MUST-D group ranged from T2 to S1. The control group ranged from C5 to S1. The control group had a mean of 5.79±3.15 levels fused. The mean SINS scores were similar between groups (P=0.40). There was no significant difference between pre-operative focal cobb angle (MUST-D n=20; Control n=36; P=0.67). The MUST-D and control groups had similar mean preoperative HAI scores of 3.40±2.77 and 4.42±3.23 respectively (P=0.32).

Intraoperative outcomes

The intraoperative outcomes are summarized in *Table 2*. The skin-to-closure time was shorter in the MUST-D group compared to the control group with a mean surgical time of 3.17±1.48 hours compared to 5.07±1.82 hours (P<0.001). The anesthesia duration was shorter in the MUST-D group compared to the control group, 5.43±1.85 *vs.* 7.20±2.09 hours (P=0.004). The MUST-D group trended towards lower EBL compared to the control group with 821.2±1,209 *vs.* 1,376±1,935 mL, respectively (P=0.06).

Perioperative outcomes

The mean length of hospital stay was shorter in the MUST-D group than in the control group, with 4.67±3.71 *vs.* 9.76±10.7 days (P=0.01). The MUST-D group had a shorter time to ambulation of 0.41±0.87 days compared to 3.68±5.62 days for the control group (P=0.02). There was a shorter time to initiation of adjuvant radiation treatment in the MUST-D group (n=14) of 25.9±12.0 days compared to the control group (n=19) of 39.3±19.5 days (P=0.03). No patients in the MUST-D group experienced serious complications or adverse events during the 30-day postoperative period compared to 15 (39%) patients in the control group (P<0.001). In the control group, 15 subjects experienced 16 events including 6 wound infections, 5 deep venous thromboses (DVTs), 4 pulmonary emboli, and 1 epidural hematoma (*Table 2*).

HAI ambulatory scores were evaluated at two different

Table 2 Intraoperative and postoperative outcomes

Variables	MUST-D (n=21)	Control (n=38)	P value
Intraoperative			
Skin-to-closure time (hours)	3.17±1.48	5.07±1.82	<0.001*
Duration of anesthesia (hours)	5.43±1.85	7.20±2.09	0.004*
Estimated blood loss (mL)	821.2±1,209	1,376±1,935	0.06
Perioperative			
Length of stay (days)	4.67±3.71	9.76±10.7	0.01*
Time to ambulation (days)	0.41±0.87	3.68±5.62	0.02*
30-day postoperative change in HAI†	–1.60	+0.33	0.008*
Time until start of RTx (days)	25.9±12.0	39.3±19.5	0.03*
30-day postoperative complications	0 [0]	15 [39]	<0.001*
Long-term			
Follow-up (years)	2.80±3.68	1.76±2.97	0.24
Recurrence at index level	7 [33]	10 [26]	0.58
Survival			
30-day mortality	0 [0]	2 [5.3]	0.29
1-year mortality rate	4 [19]	14 [37]	0.16
Time until death (years)	3.47±3.85	1.29±2.03	0.04*

Values are presented as the mean ± standard deviation or number of patients as n [%] unless otherwise noted. †, HAI grade improvement (–), deterioration (+); *, statistical significance, P<0.05 (determined by the Student *t*-test). MUST-D, Microscopically-Assisted Uninstrumented Spinal Tumor Decompression; HAI, Hauser Ambulation Index; RTx, radiation therapy.

time points: pre-surgery and 30 days post-surgery. All pre-operative HAI scores were recorded, yet the 30-day data was available for 15 (71%) patients undergoing MUST-D and 24 (63%) of the control group patients. The MUST-D group displayed improved ambulation scores from 3.4 to 1.8 (–1.60, P=0.01) while the control group ambulation scores were unchanged 4.42 to 4.75 (+0.33, P=0.43) at 30-day post-operatively. The 30-day ambulation scores were significantly better for the MUST-D group compared to the control group (P=0.008) (*Figure 4*).

Long-term outcomes

In the MUST-D group, the postoperative Cobb angle decreased from a mean of 16.85±7.80 to 14.82±9.10 degrees with a mean follow-up of 1.34 years and a median of 1.17 years (n=17; P=0.01). In the control group, the postoperative Cobb angle decreased from a mean of 17.81±8.00 degrees to a mean of 14.22±5.18 degrees with a mean follow-up of 1.69 years post-op and a median of 1.63 years (n=17; P=0.02).

The MUST-D cohort had 7 (33%) cases of local recurrence. Of these patients, 2 underwent a repeat MUST-D procedure, 4 underwent a repeat decompression with instrumentation and fusion, and 1 opted for no repeat operation with a mean of 1.89±1.25 years after the original procedure. In the control group, 10 (26%) had local recurrence. Of these patients, 5 required revision fusion and 5 had no revision surgery with a mean of 2.14±1.64 years after the original procedure. There was no significant difference in recurrence (P=0.58) or reintervention between groups (P=0.56) (*Table 2*).

Within the MUST-D group, 12 (57%) patients died between surgery and the time of data collection *vs.* 20 (55%) in the control group (P=0.89). Of all patients that died, postoperative time to death was significantly longer in the MUST-D group (3.47±3.85 years) compared to the control group (1.29±2.03 years, P=0.04). There was no difference

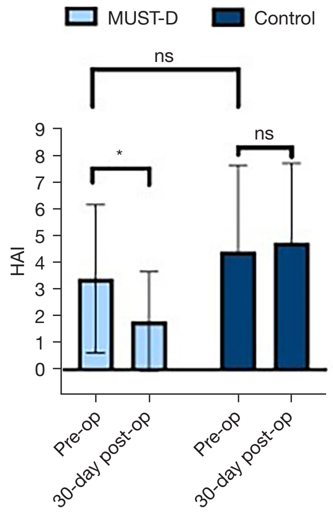

Figure 4 Comparison of preoperative and postoperative HAI scores between the MUST-D and control groups. Bars represent the mean and the error bars the SD. *, P<0.05; ns, not significant. A decrease in HAI represents an improvement in neurological function. HAI, Hauser Ambulation Index; MUST-D, Microscopically-Assisted Uninstrumented Spinal Tumor Decompression; SD, standard deviation.

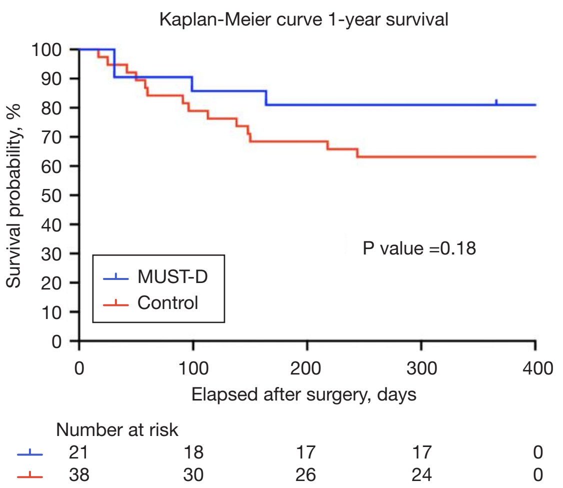

Figure 5 Kaplan-Meier curve showing postoperative 1-year survival analysis (days). MUST-D, Microscopically-Assisted Uninstrumented Spinal Tumor Decompression.

in 1-year mortality (P=0.16) or survival probability between groups as demonstrated by the Kaplan-Meier survival analysis (P=0.18) (*Figure 5*). Within 30 days post-operatively, 2 patients in the control group died, whereas no deaths occurred in the MUST-D group. In the control group, overall survival time was negatively correlated to the prevalence of complications within 30 days post-operatively (r=−0.384, P=0.02).

Discussion

In this study, we compared our proposed MIS VA technique to the standard open instrumented fusion approach for adequate decompression and stabilization of MESCC. Our findings indicate that the MUST-D approach results in improved intraoperative outcomes, fewer complications, and shorter hospital stays than standard open procedures. The MUST-D approach demonstrated improved short-term ambulation, as well as 3-year survival outcomes compared to the traditional approach.

There exists an extensive range of MIS techniques reported in the literature, with fluidity in what defines minimally invasive (26,27). The efficacy and outcomes of MIS techniques using non-percutaneous vertebral cement augmentation without extensive fixation compared to open approaches for tumor decompressions are largely underreported in the literature for patients with MESCC (19). Despite reports of complications from cement augmentation (28), including cement leakage and new fractures, none of the MUST-D patients in our study experienced any postoperative complications attributed to the use of VA. One reason may be related to the implementation of the anchoring screw used to stabilize the surrounding cement.

Intraoperative and perioperative outcomes

It is commonly reported in the literature that MIS approaches show significantly less blood loss (26,27,29-34). In terms of intraoperative outcomes, the MUST-D group demonstrated significantly shorter operative time and length of stay, which is consistent with other studies findings in MIS treatment of MESCC (27,29-34). In our study, while we saw a trend in lower blood loss in the MUST-D group compared to the control group (821.2±1,209 *vs.* 1,376±1,935 mL, respectively), this difference did not reach statistical significance. Two particular cases of well-vascularized tumors were noted within the MUST-D group.

Complications

Despite cancer patients' heightened risk of infection due to their adjunctive therapy and underlying malignancy, no postoperative complications were observed in the MUST-D group compared to 15 patients in the control group (39%). Other studies have similarly found significantly fewer complications with MIS procedures compared to open procedures (26,32,33,35). Our overall complication rate in the open group (40–44%) was comparable to the literature (32,34). We believe the use of a tubular retractor, featuring a smaller paramedian incision and muscle splitting technique, may have contributed to this outcome. The paramedian location provides better tissue coverage over the surgical trajectory, potentially reducing incisional complications from midline adjuvant radiotherapy. Additionally, the smaller incision likely minimized the incisional exposure for potential complications. We suspect that the discrepancy in major medical complications between the two approaches is likely related to the aforementioned intraoperative differences. Factors such as blood loss and duration of anesthesia exposure in the prone position often serve as independent predictors of postoperative complications. In addition, as supported by Kumar *et al.* and their results comparing MIS with open surgery for metastatic spine tumors, we also hypothesize that the lack of postoperative complications in the MUST-D group helped facilitate shorter times to adjuvant treatment compared to the control (36).

Ambulation

In our study, the MUST-D group displayed significantly faster time to ambulation (MUST-D, 0.41±0.87 days *vs.* control, 3.68±5.62 days, P=0.02). These findings are consistent with other literature demonstrating that MIS procedures lead to faster ambulatory initiation compared to traditional open surgery (29,37). In documenting the HAI ambulation scores to assess patient mobility, we observed no differences in baseline ambulation between the two groups. However, postoperatively, the MUST-D group displayed an improvement in HAI scores, while the control group slightly worsened. Conversely, the majority of the literature has found that MIS and open surgery are comparable in terms of functional outcomes (20,26,32,38). This discrepancy in findings may be due to the existing broad variation of MIS approaches. A majority of MIS approaches still utilize instrumentation for stabilization compared to our un-instrumented approach. In addition, there is a wide variation in how ambulatory status is defined and measured, including the use of several scoring systems (e.g., Karnofsky score, Frankel score, ASIA impairment score) (39). In our study, we chose to utilize the HAI because of its incorporation of a timed walking (24,40). Our finding of improved mobility in the MUST-D group contributes to an improved post-operative quality of life. We hypothesize the small incision, muscle splitting, and un-instrumented technique used in MUST-D resulted in less incisional and muscle dissection-related pain, facilitating quicker mobility.

Time to RTx

Within the analysis of adjuvant radiotherapy, other studies have found that MIS surgery for MESCC had a shorter time to start adjuvant RTx (36,41). Our results corroborate these findings that patients who underwent MUST-D surgery had a significantly faster time to radiotherapy compared to open surgery (25.9±12.0 *vs.* 39.3±20.8 days; P=0.03). Due to the variation in primary cancers in our patient population and limited medical records, we decided not to include further discrepancies between chemotherapy and immunotherapy in our analysis.

Long-term outcomes

Cobb angle

One of the critiques within the literature regarding un-instrumented techniques for MESCC decompression is the potential for long-term destabilization without adequate instrumentation. Despite these concerns, studies such as Deutsch *et al.* have demonstrated successful MIS MESCC decompression without both instrumentation or VA and no signs of postoperative instability or kyphosis, albeit being a small case series (22). Our study expands this to a larger patient population and incorporates cement augmentation as a proxy for standard instrumented fusion. There was no observable difference in preoperative Cobb angles between groups and both groups saw a subsequent decrease in Cobb angle postoperatively with no new focal instability within the MUST-D cohort specifically (*Figure 6A-6D*).

Survival

In our study, we found comparable mortality rates between MUST-D and the control group, which is expected given that there are no differences across primary tumor demographics. The 1-year Kaplan-Meier analysis did not demonstrate a difference in survival probability between groups (*Figure 5*). However, we observed a significantly longer time to death within the MUST-D group. Additionally, within the control group, survival was shown to be negatively correlated to complications. Paulino Pereira *et al.* similarly found, in a study of 647 patients

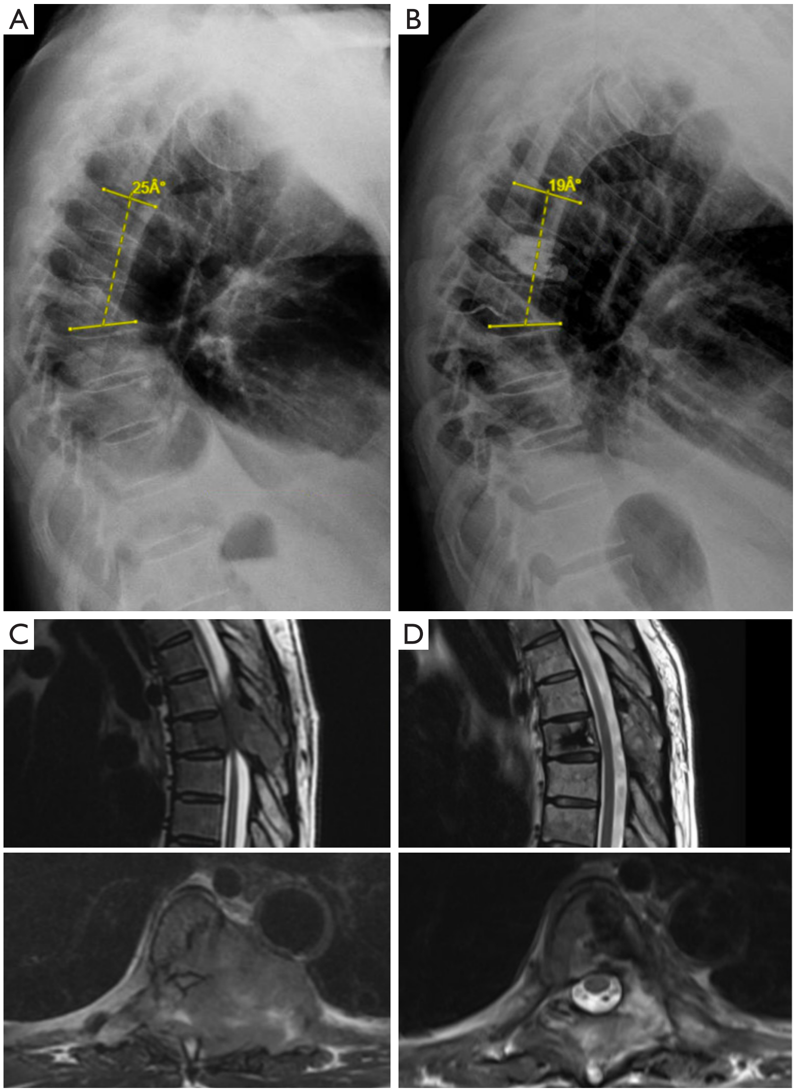

Figure 6 Illustrative case demonstrating preoperative and postoperative imaging of a MUST-D cohort patient showing degree of kyphosis and extent of metastatic tumor with spinal cord compression. (A) Preoperative standing radiograph with a regional Cobb angle of 25 degrees. (B) Greater than 1-year postoperative standing radiograph with regional Cobb angle of 19 degrees after undergoing a T7 to T8 hemilaminectomy and left T8 costotransversectomy transpedicular decompression for spinal cord decompression with T8 vertebroplasty. (C) Preoperative MRI of a different MUST-D cohort patient showing metastatic tumor with epidural spinal cord compression with significant involvement of T6. (D) 1-year postoperative MRI after undergoing a MUST-D procedure consisting of a left T5 to T7 hemilaminectomy and T6 costotransversectomy transpedicular decompression for spinal cord decompression with a vertebroplasty of T6. MUST-D, Microscopically-Assisted Uninstrumented Spinal Tumor Decompression; MRI, magnetic resonance imaging.

with MESCC, that 30-day complications were associated with worsened survival (42). Given the prevalence of complication rates, slower time to RTx, and 2 patient deaths within the 30-day post-operative period in the control group, we propose that post-operative comorbidities may contribute to the shorter duration of survival observed within the open procedure approach. Survival after surgery for metastatic disease has been predicted by various methods, including the Tomita and Tokuhashi scales, and our previously published system, the Jenkins Survival Index (JSI) (43,44). Despite this, the estimation of survival is very difficult and is largely influenced by the primary histology, the extent of tumor burden, and the patient's general condition (36). Nonetheless, MIS surgical treatments, such as the MUST-D approach, can still provide meaningful palliative benefits in the short term.

Limitations

Limitations of this study include that this was a retrospective study performed at a single academic medical center with a relatively small sample patient population. This was an unblinded study in which the surgeon uniformly offered and operated on all patients whom a MUST-D procedure was possible. Upon shared decision-making of risks, benefits, and alternatives, all patients opted for this approach. Some limitations are inherent to a retrospective cohort design including incomplete data. For example, standing radiographs were largely unobtainable due to severe neurological dysfunction, functional limitations, and lack of patient follow-up. As a result, we opted to review available CT and MRI imaging for consistent supine radiological assessment of the Cobb angle analysis. While the SINS scores were comparable between groups, there was still some variation in the tumor burden and index location, in which patients with cervical, thoracic, and lumbar cases were analyzed together. While this approach may be more suitable for one region than another, such distinctions have not been investigated thus far. Additionally, in reviewing multiple surgeons, we did not have uniform standardized PROMs. Future studies would address this shortcoming in a prospective, multi-center format. Given the lack of surgical hardware, fewer days of hospital stay, and shorter operative time shown in our study, we predict significant cost savings to both the patient and hospital system. Future studies should be performed to assess the cost-benefit analysis in utilizing the MUST-D technique for MESCC treatment.

Conclusions

The MUST-D minimally invasive surgical approach offers multiple potential advantages compared to the open surgical approach in the treatment of symptomatic metastatic epidural spinal disease. Our study demonstrates improved perioperative variables including length of operation, duration of anesthesia, hospital stay, and fewer complications in the MUST-D group. Although there were no differences in 1-year mortality rate or survival, the MUST-D group showed significantly faster initiation of adjunctive RTx and longer time to death compared to patients with open procedures. Mobility was also better in the MUST-D group both in time to ambulation and 30-day HAI score postoperatively. Further, there was no evidence of long-term postoperative destabilization via Cobb angle or any differences in revision rates observed between the MUST-D and open cohort. These findings further warrant strong consideration of the MUST-D surgical approach as an initial treatment modality for MESCC management. Prospective, randomized studies with protocols to standardize long-term radiographic and clinical outcomes are indicated to corroborate the benefits of the MUST-D surgical technique over open procedures in patients with MESCC.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://jss.amegroups.com/article/view/10.21037/jss-24-135/rc

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was determined to be exempt from IRB oversight initially by the Icahn School of Medicine at Mount Sinai until expiration, and then by Advarra for the remainder of the study period. Individual consent for this retrospective analysis was waived.

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