

Minimally invasive “separation surgery” plus adjuvant stereotactic radiotherapy in the management of spinal epidural metastases

ABSTRACT

Aim: This study aimed to describe the application of minimally invasive surgery (MIS) in separation surgery combined with postoperative stereotactic body radiation therapy (SBRT) in patients with symptomatic metastatic epidural spinal disease.

Methods: Three techniques are described: (1) MIS posterior separation surgery alone, (2) MIS posterolateral separation surgery with percutaneous pedicle screw placement, and (3) MIS lateral corpectomy with percutaneous pedicle screw placement. Seven representative cases are presented in which the above techniques were applied and after which postoperative SBRT was performed.

Results: The seven representative patients (3 male, 4 female) had a mean age of 54 years (range, 46–62 years). Two patients had a primary diagnosis of cholangiocarcinoma and in one patient each a diagnosis of breast, renal, lung adenocarcinoma, melanoma, and urothelial squamous cell carcinoma as their primary tumor. All patients had additional multiorgan disease apart from the metastatic spine involvement. Three patients underwent operations in the lumbar spine, two in the thoracic spine, and one in each of the thoraco-lumbar and lumbo-sacral spine. The average operating time was 149 ± 60.3 min (range, 90–240 min). The mean estimated blood loss was 188.8 cc. The mean length of stay in the hospital was 4 days (range, 3–7 days). There were no surgical complications. All patients received postoperative SBRT (typically 24 Gy in 3 fractions) at a mean of 43.2 days after surgery (range, 30–83).

Conclusions: Early reports such as this suggest that MIS techniques can be successfully and safely applied in accomplishing “separation surgery” with adjuvant SBRT in the management of metastatic spinal disease. The potential advantages conferred by MIS techniques such as shortened hospital stay, decreased blood loss, reduced perioperative complications, and earlier initiation of adjuvant radiation are highly desirable in the treatment of this challenging patient population.

Keywords: Adjuvant stereotactic body radiation therapy, metastatic epidural spinal cord compression, minimally invasive separation surgery

INTRODUCTION

Metastatic epidural spinal cord compression (MESCC) is estimated to occur in between 5% and 10% of patients with cancer, most commonly of the breast, prostate, and lung, and in up to 40% of patients who have preexisting bone metastases outside the spine.^[1] Surgical intervention, followed by radiation and/or chemotherapy, provides improvement in pain, neurologic function, and quality of life (QoL) in patients with symptomatic MESCC.^[2,3] These goals are achieved by direct spinal cord decompression, cytoreduction, and instrumented mechanical stabilization

of the spine. More recently, the treatment paradigm of “separation surgery” has evolved in which a clear margin around the thecal sac and nerve roots is established, thereby

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permitting treatment with postoperative stereotactic body radiotherapy (SBRT).^[4,5] This surgical strategy supplants more aggressive gross total surgical resection techniques and in so doing reduces overall surgical morbidity while still achieving extremely high rates of local tumor control regardless of tumor histology.^[4,5]

Separation surgery including spinal instrumentation typically utilizes conventional open surgical approaches. The desire to reduce surgical morbidity further has stimulated interest in accomplishing the same goals through minimally invasive surgery (MIS). The evolution of MIS techniques in general permits satisfactory neural decompression and spinal stabilization across the gamut of spinal pathology, while offering reductions in blood loss, length of stay, recovery time, and complications^[6-9]—all highly desirable features when treating patients with potentially limited life expectancies.

A number of reports have described MIS techniques in treating metastatic spinal disease.^[9-17] However, there is a paucity of literature on the concomitant use of MIS separation surgery and adjuvant SBRT.^[14] In this paper, we describe the various minimally invasive surgical techniques employed to achieve separation surgery and spinal stabilization followed by postoperative stereotactic radiotherapy.

METHODS

We retrospectively identified representative patients who underwent MIS separation surgery and adjuvant SBRT to highlight the various techniques available. Clinical, radiological, surgical, and adjuvant therapy data were obtained from the electronic medical record for these patients.

Surgical techniques

For patients with symptomatic metastatic epidural spine disease who are deemed reasonable candidates for surgical intervention, careful preoperative imaging evaluation is obviously critical for operative decision-making. Most cases require a posterolateral approach for circumferential decompression and spinal instrumentation, the latter due to neoplastic spinal instability or iatrogenic spinal instability from adequate decompression. However, in select cases that demonstrate epidural involvement that is not circumferential, alternate techniques may be used, such as simple posterior decompression alone for purely dorsal disease or lateral approaches for purely ventral/ventrolateral disease.

Typical surgical adjuncts such as a radiolucent operating room (OR) table, intraoperative neuromonitoring, and

standard MIS tubular retractor systems are utilized routinely in the procedures described below. Although not absolutely necessary, we have found the addition of image-guided navigation relying on intraoperative cone-beam computed tomography (CT) and navigated instrumentation systems extremely helpful in (1) achieving adequate tumor resection, (2) ensuring accuracy of instrumentation placement, and (3) reducing the occupational radiation exposures normally associated with MIS procedures.^[18]

Posterior MIS separation surgery alone

For patients with purely posterior/posterolateral epidural disease without instability, a posterior decompression alone can be employed. After appropriate intraoperative localization of the level of interest, a unilateral incision of 2–3 cm in length is made approximately 2–3 cm off the midline, and the MIS dilating system is used to dock a tubular retractor (fixed or expandable depending on the extent of disease and surgeon's preference) using fluoroscopy. Either magnifying loupes or the operative microscope may be used for visualization. The decompression employs the well-described technique of a unilateral approach for bilateral decompression in which a hemilaminectomy is performed ipsilaterally, the retractor is then angled to view the contralateral side of the spinal canal, and the undersurface of the spinous process and contralateral lamina (and contralateral facet if needed) is drilled away. The exposed epidural tumor can then be removed in an intralaminar fashion using curettes, pituitary rongeurs, and suction. After resection of the tumor, hemostasis is achieved and the wound is closed in layers. Adjuvant SBRT may be delivered as early as 1 week following surgery, as wound healing is rarely a problem with this type of MIS approach [Figure 1].

Posterolateral MIS separation surgery with percutaneous screws

Percutaneous screws are planned when the patient presents with neoplastic instability in addition to epidural disease or when surgical decompression will precipitate iatrogenic instability [Figure 2]. A tubular-based retractor system is used as described above for MIS posterior separation surgery, except that the incision is placed 3–4 cm off the midline, and in the case of circumferential compressive disease, bilateral tubular approaches are often used. Both transpedicular or costovertebral resections are viable through the MIS approach and include removal of the posterior longitudinal ligament and any required portion of the vertebral body. Intervertebral strut placement (e.g., expandable cage) is not typically required after separation surgery but can even be placed through expandable MIS retractors if necessary. Posterolateral arthrodesis can be performed through the tubular retractors when deemed necessary.

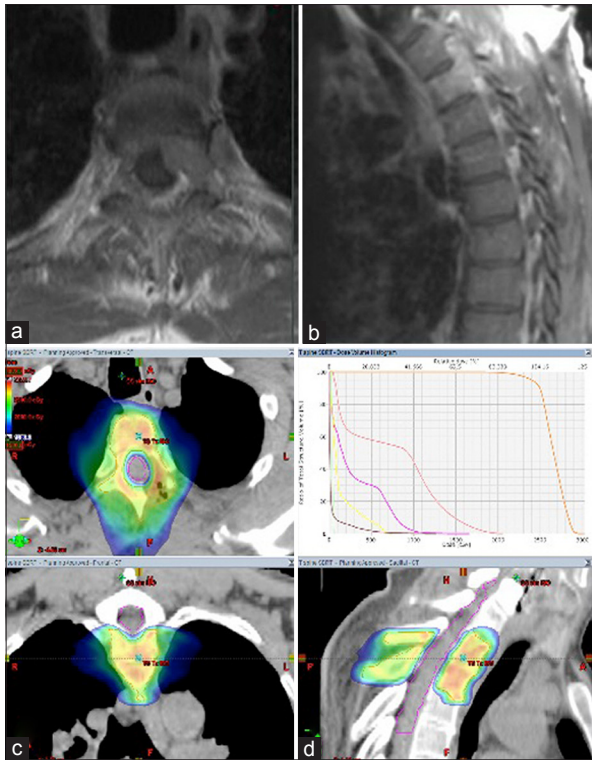


Figure 1: Axial (a) and sagittal (b) T1-weighted magnetic resonance imaging with gadolinium demonstrating a T3 melanoma metastasis with epidural spinal cord compression. The patient underwent a left T3 minimally invasive separation surgery (tubular transpedicular decompression without fixation for clearance) followed by (c and d) stereotactic radiosurgery –24 Gy in 3 fractions

After completing the MIS separation surgery, percutaneous pedicle screws are placed through the bilateral paramedian incisions mentioned above. Alternatively, a single midline skin incision may be used with subcutaneous undermining and bilateral fascial dilations (without subperiosteal muscle elevation). Screw placement under fluoroscopy is performed as previously described.^[19] When using image-guided navigation, however, our workflow proceeds initially with placement of a reference array either on a percutaneous placed iliac pin or on a spinous process clamp. Intraoperative cone-beam CT is then performed and the images are transferred to the computer-based navigation system. Navigated awl-tip taps are used to prepare the pedicles, and screws are placed after the decompression is complete. Kirschner wires are used only in cases of complex anatomy. The navigation system is also used to perform the tubular dilation for the retractors, further reducing occupational radiation exposures. The entire procedure can be performed with only a handful of fluoroscopy images taken just prior to obtaining the intraoperative CT. Percutaneous rod placement, reduction, and final tightening are performed in a routine manner, and the wounds are closed as described above.

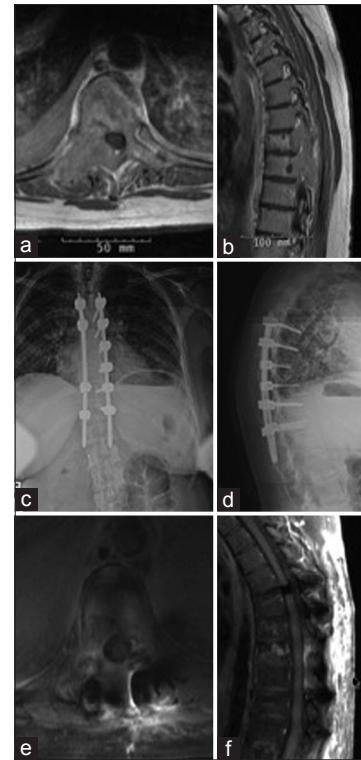


Figure 2: Axial (a) and sagittal (b) T1-weighted magnetic resonance imaging with gadolinium demonstrating a T8 and T9 lung adenocarcinoma invading the vertebral body and destruction of the right T8 and T9 pedicles with epidural extension of the tumor causing cord compression. (c and d) Postoperative radiographs depicting pedicle screw fixation after minimally invasive separation surgery. A T8 and T9 laminectomy, right T8 and T9 transpedicular decompression of the spinal cord, and percutaneous posterior instrumentation from T6 to T11 were performed. Sagittal (e) and axial (f) T1-weighted magnetic resonance imaging with gadolinium 5 months postresection and stereotactic body radiation therapy of metastatic lung adenocarcinoma

MIS lateral corpectomy with percutaneous screws

For patients with pathological burst fractures, purely ventral disease, or the need for anterior reconstruction, the MIS lateral approach can offer a significant reduction in morbidity compared to open thoracotomy or laparotomy.^[17,20] A retropleural approach is used to access thoracic levels as high as T4 and a retroperitoneal, transpoas approach is used to access lumbar levels as low as L4 [Figure 3]. The patient is carefully positioned in a true lateral decubitus position (as for MIS lateral approaches for degenerative disease)^[21] with either the side of most neoplastic involvement or the more anatomically favorable approach side positioned up.

A small oblique incision is marked over the level and confirmed with fluoroscopy. At the thoracic or upper lumbar levels, a small portion (~3 cm) of overlying rib is resected and saved for morcellized autograft. In the lumbar spine, the typical transpoas approach is taken using intraoperative-evoked electromyography monitoring.^[21,22] Serial dilation is performed

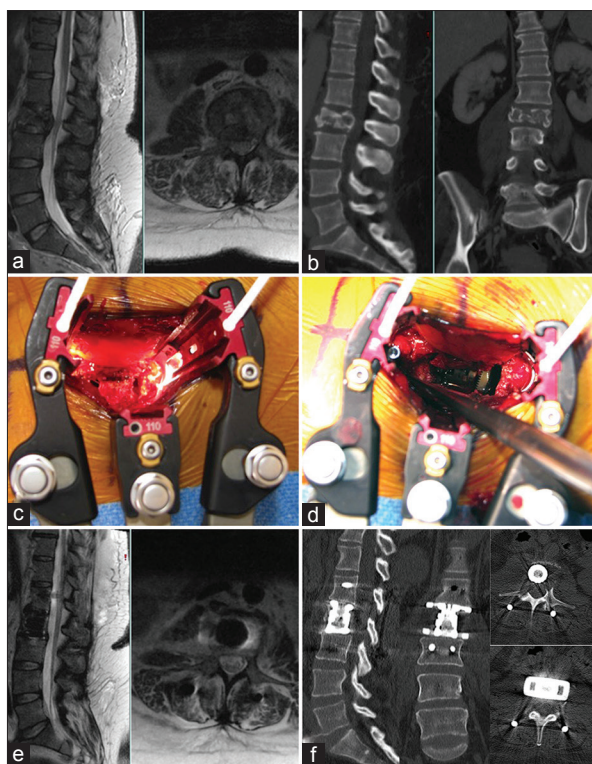


Figure 3: Preoperative axial and sagittal (a) magnetic resonance imaging and sagittal and coronal (b) computed tomography scan of a 49-year-old female with metastatic breast cancer. (c and d) intraoperative images demonstrating an minimally invasive surgery lateral corpectomy with cage placement. Postoperative (e) magnetic resonance imaging and (f) computed tomography scan showing good decompression with anterior and posterior stabilization to enable adjuvant stereotactic radiosurgery soon after

and then retractor is docked over the diseased vertebral body and expanded and locked in place. The pedicle (and rib head for thoracic levels) is dissected out and then discotomies above and below are completed. A high-speed drill is used to remove the involved ipsilateral pedicle exposing the exiting nerve root and the thecal sac. Osteotomes, pituitary rongeurs, and curettes are then used to remove the vertebral body piecemeal. Retropulsed bone fragments and tumor tissue are displaced away from the thecal sac ventrally into the corpectomy defect using curettes. In such a manner, the spinal canal is decompressed. Further, the contralateral vertebral body wall is then removed. The anterior vertebral body wall may also be removed or taken to a thin shell of cortex to protect the visceral structures. The endplates are then prepared for interbody arthrodesis, and an intervertebral strut cage of the surgeon's choice is packed with local rib autograft and inserted into the intervertebral space under fluoroscopy to a tight fit [Figure 2].

The retractor system is removed, and in the case of parietal pleural defects during thoracic approaches, intrapleural air and blood are evacuated using a red rubber catheter submerged in an irrigation basin while a Valsalva maneuver

is performed. The catheter is quickly removed and the last fascial stitch is tied down. The patient is then carefully turned to the prone position, and percutaneous pedicle screws are placed at adjacent levels as described above.

RESULTS

Table 1 shows the demographic and surgical details of seven representative patients (3 male, 4 female) with a mean age of 54 years (range, 46–62 years). Two patients had a primary diagnosis of cholangiocarcinoma and in one patient each a diagnosis of breast, renal, lung adenocarcinoma, melanoma, and urothelial squamous cell carcinoma as their primary tumor. All patients had additional multiorgan disease apart from the metastatic spine involvement. Three patients underwent operations in the lumbar spine, two in the thoracic spine, and one in each of the thoraco-lumbar and lumbo-sacral spine. The average operating time was 149 ± 60.3 min (range, 90–240 min). The mean estimated blood loss was 188.8 cc. The mean length of stay in the hospital was 4 days (range, 3–7 days). There were no surgical complications.

All patients received postoperative SBRT at a mean of 43.2 days after surgery (range, 30–83). Time to SBRT was dictated by a radiation oncologist and patient convenience since we allowed initiation of SBRT from a surgical perspective as early as 2 weeks postoperatively. The planned treatment volume was determined based on merged preoperative MRI and postoperative CT myelography. All treatments were administered on the Varian TrueBeam (Palo Alto, CA, USA). A hypofractionation scheme (typically 24 Gy in 3 fractions) was employed in all cases as per treating physician's preferences and given the complex treatment planning associated with spinal instrumentation and circumferential disease. There were no complications related to SBRT.

One patient was unable to walk prior to surgery and three patients required the use of a walker or cane. Of these four patients, three regained independent ambulation. The mean Karnofsky Performance Status (KPS) score prior to surgery was 58.6 (range, 40–90). The mean KPS postoperatively at last follow-up was 66.7 (range, 50–90).

The mean follow-up for all patients was 218.1 days (range, 41–620). At the time of latest follow-up, five patients were still alive. Three patients were admitted to hospice or died due to their metastatic disease burden. No patients became disabled or died secondary to their spine disease. The overall survival time in those who died was 115.5 days, (range, 80–151). The progression-free survival of their spine disease was also 115.5 days, (range, 80–151).

Table 1: Clinical characteristics and outcomes of patients undergoing minimally invasive separation surgery for metastatic epidural cord compression

Age/sex	Primary cancer	Spinal diagnosis	Surgical procedure	Operative time (min)	Estimated blood loss (ml)	Length of stay (days)	Adjuvant therapy
63/male	Melanoma	Left T3 MESCC	Left T3 MISS Transpedicular decompression	90	50	3	24 Gy in 3 fractions
52/female	Urothelial	L2 pathological burst fracture, epidural thecal sac compression	Bilateral MISS transpedicular decompression, L1-L3 percutaneous screws	90	100	7	24 Gy in 3 fractions
56/female	Lung	T8, T9 MESCC	T8, T9 MISS Transpedicular decompression, T6-T11 percutaneous screws	150	300	4	24 Gy in 3 fractions
46/male	Renal Cell	T10 MESCC	T10 MISS; lateral corpectomy, T8-T10 posterior fusion	240	700	7	20 Gy in 5 fractions
57/female	Cholangiocarcinoma	Right S1 lesion	Right MIS partial corpectomy and L5-S1 fusion	110	100	3	24 Gy in 3 fractions
58/male	Cholangiocarcinoma	L2 pathological burst fracture, epidural thecal sac compression	L2 MISS, T12-L3 percutaneous screws	150	60	3	24 Gy in 3 fractions
49/female	Breast	L2 pathological burst fracture, epidural thecal sac compression	Right L2 DLIF corpectomy, L1-L3 percutaneous screws; all lateral	240	100	3	24 Gy in 3 fractions

MESCC - Metastatic epidural spinal cord compression; MISS - Minimally invasive separation surgery; DLIF - Direct lateral interbody fusion; MIS - Minimally invasive surgery

DISCUSSION

Metastatic epidural spinal cord compression

The indications for surgery in patients with MESCC are intractable pain, neurological deficit, spinal instability, need for diagnosis, and local tumor control.^[23] The key predictive factors of survival and good outcome include a KPS score ≥ 80 and preoperative ambulatory and motor status.^[24] Adjuvant radiation following epidural spinal cord decompression for tumor is a powerful tool used to achieve local disease control and preserve neurological function. This concept of separation surgery followed by SBRT in the treatment of MESCC has gained credence over the past few years.^[4,5,25,26] The goal of this combination treatment is to achieve better tumor control than that seen with conventional external beam RT, especially since SBRT allows the residual tumor to be irradiated at cytotoxic doses while sparing critical normal structures such as the spinal cord. This is possible because separation surgery affords at least a 2–3-mm separation of the tumor from the dural surface. This strategy is of particular benefit in patients with radio-resistant tumors causing high-grade extradural spinal cord compression and avoids the increased surgical morbidity associated with gross total or even *en bloc* tumor resection.^[27]

Advantages of minimally invasive separation surgery

“Separation surgery,” which decompresses the thecal sac, is typically accomplished through a posterolateral bone

resection that is tailored on a case-to-case basis. Epidural tumor is circumferentially resected starting from the normal dural planes. In addition, the posterior longitudinal ligament is resected to create a margin with respect to the anterior dura and allows for spinal cord decompression. Depending on the extent of the disease, a corpectomy may be performed, and posterior segmental instrumentation is placed accordingly.^[4,5,26,28] All these goals can now be accomplished in select cases using MIS techniques through posterolateral approaches but also through true lateral approaches providing excellent anterior decompression and stabilization.

Performing MIS surgery is ideal for minimizing tissue disruption and expediting recovery from surgery. Long-term results from MIS and open surgery for degenerative conditions have proven very similar. However, in the short term, compared to conventional open approaches, MIS techniques can reduce blood loss, operative times, postoperative pain, narcotic use, length of stay, postoperative surgical site infections, and medical resource use and time to adjuvant treatments.^[6,14,25,26,29,30] These characteristics are particularly salient in oncology patients, for whom surgery is targeted at pain relief and preservation of function rather than cure during their limited life expectancy.

Posterior and posterolateral minimally invasive separation surgery

Our experience is similar to that of Saigal *et al.*,^[15] who found that, compared to open approaches, minimally invasive transpedicular corpectomy leads to effective neurological improvement and pain alleviation with a trend toward reduced operative times, blood loss, and complication rates. Extracavitary transpedicular corpectomy with expandable cage placement allows for circumferential decompression and anterior column reconstruction from a posterior approach with a reduction in morbidity when compared with traditional open surgery. This is especially evident in the thoracic spine where traditional anterior and posterior open techniques are associated with significant morbidity.^[31,32]

Posterolateral approaches have the advantage of avoiding injury to structures within the thoracic and abdominal compartments and allow posterior fixation to be performed in the same position as the ventral decompression and reconstruction. Donnelly *et al.*^[29] described a minimally invasive muscle sparing, posterior-only approach for L1 transpedicular hemicorpectomy and expandable cage placement, L1 laminectomy, and T11-L3 posterior instrumented stabilization. The surgical corridor was achieved through the Wiltse muscle plane between the multifidus and longissimus muscles so that minimal muscle detachment was required to achieve transpedicular access to the anterior and middle spinal columns. The L1 nerve root was completely skeletonized to allow adequate lumbar hemicorpectomy, tumor resection, and expandable titanium cage insertion. Finally, percutaneous pedicle screws and rods were inserted from T11 to L3 for stabilization.

Lau and Chou^[33] compared outcomes of patients who underwent mini-open versus traditional open transpedicular corpectomy for spinal metastases in the thoracic spine. Compared with the open group, the mini-open group had significantly less blood loss (917.7 ml vs. 1697.3 ml, respectively, $P = 0.019$) and a significantly shorter hospital stay (7.4 days vs. 11.4 days, respectively, $P = 0.001$). There was a trend toward a lower perioperative complication rate in the mini-open group (9.5%) compared with the open group (21.4%).

The above series were performed with more aggressive resections intended than typically employed in the more recently described “separation surgery.” Massicotte *et al.*^[14] described a minimally invasive approach in the treatment of spinal metastases with epidural disease and mechanical instability using a combined minimal access spine surgery technique followed by SBRT. These procedures were performed in an outpatient setting. Their technique was

based on a tubular retraction system to gain access for decompression but was different from the techniques presented here as mechanical stabilization was achieved using methyl methacrylate applied under direct visualization. There was one mortality following cement extravasation.

MIS lateral corpectomy

A few cadaver studies and case reports have recently described the feasibility of an MIS lateral corpectomy.^[17,20] Smith *et al.*^[34] demonstrated excellent outcomes using this approach in three cases of tumor, infection, and trauma. Due to advances in retraction and instrumentation as well as the fiber-optic light source, MIS approaches allow for a much smaller incision and a smaller amount of rib resection through the lateral approach. However, the procedure is technically demanding and has a steep learning curve. In a recent series where the authors performed an MIS lateral corpectomy for tumor, trauma, or infection, the overall complication rate was 12.5% which included dural tear 2.5%, intercostal neuralgia 2.5%, deep vein thrombosis 2.5%, pleural effusion 1.3%, wound infection 1.3%, hardware failure 1.3%, and hemothorax 1.3%.^[35] Nonetheless, the advantages of this technique are that it obviates the needs for an access surgeon and the added benefit that an interbody cage can be placed through a small incision allowing for a posterior stabilization with percutaneous screws in the same position if the surgeon desires.

Percutaneous pedicle screw placement

Percutaneous pedicle screw fixation is another attractive tool in the palliative treatment of MESCC after decompression for painful and unstable vertebral body lesions.^[36,37] This technique is associated with decreased multifidus atrophy, blood loss, and better outcomes relative to open screw placement.^[38-40] A recent study compared open versus minimally invasive pedicle screw placement in patients with metastatic spine disease.^[41] While there was an improvement in pain, neurological status, and independent ambulation in both groups, the latter had significantly less blood loss and average time to initiate radiotherapy. In select cases, percutaneous screws may be used as stand-alone procedures where there is instability but no obvious epidural compression by tumor. Kwan *et al.*^[42] and Lee *et al.*^[43] demonstrated the safety and efficacy of using long segment percutaneous pedicle screw constructs in patients with spinal metastasis. We used image-guided navigation for percutaneous screw placement in all our cases that required posterior instrumentation. This technology offers the advantage that both percutaneous spinal stabilization and MIS direct neural decompression can be achieved with minimal radiation exposure to the OR staff.

Limitations of the study

The study has its limitations inherent to its retrospective nature. The small sample size and the short duration of follow-up do not explore the full potential of this novel approach. Postoperative radiation was given in a highly variable timeframe, between 1 month and 3 months after surgery, not fully exploring the potential benefits of the MIS approach. However, these delays were due to individual patient conditions and were beyond our control. The aim of this paper is in fact to describe the technical nuances with good illustrations of MIS approaches as an adjuvant to SBRT and a combined holistic approach of dealing with spinal metastases. This we believe is different from previous reports that used open approaches followed by SBRT for the same conditions.

CONCLUSIONS

We describe the feasibility of MIS “separation surgery” plus adjuvant SBRT in the management of patients with symptomatic metastatic epidural spinal disease. While this treatment strategy may not affect progression-free or overall survival, the short-term benefits of MIS techniques such as reduced length of stay, blood loss, perioperative morbidity, and time to initiation of adjuvant therapy remain highly desirable in this patient population. Further comparative studies are required to confirm these advantages compared to open surgery and to better define which subpopulations of patients can most benefit from these techniques.

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Conflicts of interest

There are no conflicts of interest.

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