Surgical Resection With Radiation Treatment Planning of Spinal Tumors

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BACKGROUND: The clinical paradigm for spinal tumors with epidural involvement is challenging considering the rigid dose tolerance of the spinal cord. One effective approach involves open surgery for tumor resection, followed by stereotactic body radiotherapy (SBRT). Resection extent is often determined by the neurosurgeon's clinical expertise, without considering optimal subsequent post-operative SBRT treatment.

OBJECTIVE: To quantify the effect of incremental epidural disease resection on tumor coverage for spine SBRT in an effort to working towards integrating radiotherapy planning within the operating room.

METHODS: Ten patients having undergone spinal separation surgery with postoperative SBRT were retrospectively reviewed. Preoperative magnetic resonance imaging was coregistered to postoperative planning computed tomography to delineate the preoperative epidural disease gross tumor volume (GTV). The GTV was digitally shrunk by a series of fixed amounts away from the cord (up to 6 mm) simulating incremental tumor resection and reflecting an optimal dosimetric endpoint. The dosimetric effect on simulated GTVs was analyzed using metrics such as minimum biologically effective dose (BED) to 95% of the simulated GTV (D_{95}) and compared to the unresected epidural GTV.

RESULTS: Epidural GTV D_{95} increased at an average rate of 0.88 ± 0.09 Gy_{10} per mm of resected disease up to the simulated 6 mm limit. Mean BED to D_{95} was 5.3 Gy_{10} (31.2%) greater than unresected cases. All metrics showed strong positive correlations with increasing tumor resection margins (R^2: 0.989-0.999, $P < .01$).

CONCLUSION: Spine separation surgery provides division between the spinal cord and epidural disease, facilitating better disease coverage for subsequent post-operative SBRT. By quantifying the dosimetric advantage prior to surgery on actual clinical cases, targeted surgical planning can be implemented.

KEY WORDS: Radiation dosimetry, Spine, Spine separation surgery, Stereotactic body radiosurgery, Surgery, Treatment planning, Neurosurgery

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The prevalence of spinal metastases has been estimated to occur in over 50% of all cancer patients with 10% to 20% presenting as clinically symptomatic.[1] Metastatic epidural spinal cord compression (MESCC) is a complication of spinal metastases where epidural disease compresses the spinal cord and can cause in its most severe manifestation complete or hemi-paresis and loss of autonomic functions.[2,3] With an aging demographic, increased survival due to more effective systemic therapies and better detection of disease with routine spinal magnetic resonance imaging (MRI), the incidence of spinal metastases is expected to rise dramatically.[4,5]

The goal of treatment for spinal metastases is to locally control the tumor while sparing the surrounding normal tissues and reduce pain. Although conventional palliative radiation has been used for several decades, the treatment is

ABBREVIATIONS: BED, biologically effective dose; **CT,** computed tomography; **CTV,** clinical target volume; **DVH,** dose volume histogram; **GTV,** gross tumor volume; **MESCC,** metastatic epidural spinal cord compression; **MRI,** magnetic resonance imaging; **OAR,** organs-at-risk; **PTV,** planning target volume; **SBRT,** stereotactic body radiotherapy; **SINS,** Spinal Instability Neoplastic Score; **TPS,** treatment planning system

limited with respect to durable pain and local control.[6] The technique of spine stereotactic body radiotherapy (SBRT) was developed to improve upon historical control rates, and represents a paradigm shift in the management of selected patients with spinal metastases. Spine SBRT has only come about in the past 2 decades when technology permitted millimetric precision in delivery, and highly conformal dose distributions such that the tumor can be dose escalated (well beyond biologically effective doses [BED] associated with palliative radiation) while sparing the surrounding critical organs-at-risk (OAR).[6]

With respect to epidural disease, tumor at the spinal cord interface is inherently underdosed in order to respect spinal cord tolerance, and it has been shown that if the epidural disease is downgraded (separated from intimate contact with the surface of the spinal cord), then local control can be improved.[7] This relationship may be due to removal of epidural disease, which has been implicated as an indicator of treatment failure, or better dosimetry. It is likely that both factors are critical to improve outcomes post-SBRT and, as a result, there is a great deal of emphasis on the management of epidural disease as a direct consequence of SBRT. Development of "separation surgery" for spinal metastases is one such innovation.[8] Here, the surgical intent is not to radically achieve gross total resection of the tumor with a large open invasive procedure, but to decompress the spinal cord circumferentially, reconstitute the cerebrospinal fluid space, instrumenting as needed and minimize the invasiveness of the procedure. The fundamental intent has therefore shifted to increasing the margin between the spinal cord and the epidural disease to improve tumor coverage, when subsequently treated with SBRT. Although the amount of tissue requiring resection can be estimated based on the extent of preoperative epidural disease, this has not been determined in a precise and systematic fashion in vivo to facilitate optimal dosimetry for postoperative SBRT. In this retrospective study and review, we demonstrate the utility of spine separation surgery with respect to optimizing dosimetry for spine SBRT in actual patients with simulated incremental epidural disease resection.

METHODS

This retrospective study approved by our local institutional research board consisted of a 10-patient cohort having undergone spinal separation surgery with subsequent planned SBRT between January 1, 2015 and December 31, 2016. Informed consent was not obtained since the study involved retrospective review of existing patient data. Only patients who received pre- and postoperative MRI as part of their standard clinical care were included. Patient demographics comprising tumor histology, age, gender, Spinal Instability Neoplastic Score (SINS) and Bilsky grade were collected. Briefly, the SINS score assesses tumor-related instability with a score ranging from 0 to 18 and is based on lesion location, type of pain (ie, mechanical or non-mechanical), lesion characteristics (ie, lytic, blastic, or mixed), radiographic spinal alignment, presence and degree of vertebral body collapse and involvement of posterolateral spinal elements.[9] The Bilsky criteria is a validated 6-point epidural spinal cord compression grading system based on the T2-weighted MRI, and has been shown to have high inter-rater and intra-rater reliability.[10] Briefly, the Bilsky grade ranges from 0 to 3, where 0 represents no epidural disease; 1a, 1b, and 1c represent epidural disease approaching the spinal cord but not compressing it; and a score of 2 and 3 represents epidural spinal cord compression with and without CSF effacement, respectively.[10]

Clinical Course: Radiation Treatment Planning

Treatment planning comprised computed tomography (CT) simulation with a slice thickness of 1 mm. Patients underwent thin-slice axial T1 (2-mm slice thickness) and T2 volumetric MRI (3-mm slice thickness) focused on the treatment target and extending at least 1 vertebral body above and below the target. Rigid coregistration of the postoperative treatment planning MR to the postoperative treatment planning CT was performed, using a standard clinical treatment planning system (TPS; Pinnacle[3] v9.2, Philips, Philips Healthcare, Andover, Massachusetts). Coregistration was performed manually within the clinical software by aligning the bone-soft tissue interface of the target and adjacent vertebral bodies on MRI to the bony anatomy as visualized on CT. The alignment of the intervertebral space was also considered. Each clinical coregistration was confirmed by the treating radiation oncologist prior to contouring. Gross tumor volumes (GTV) and clinical target volumes (CTV) were contoured by a board-certified radiation oncologist. The planning target volume (PTV) comprised the CTV plus a 2-mm uniform expansion. The goal of dose prescription was to maximize the dose to the GTV, CTV, and PTV while minimizing OAR dose to the spinal cord, esophagus, bowel, liver, and kidneys.[11] In the presence of poor image quality associated with hardware-associated artifacts on MRI, a CT myelogram was performed to adequately visualize the spinal cord and associated structures. All patients were treated at our institution with the dose prescriptions based on the discretion of the treating physician and consistent with previously described guidelines for postoperative/retreatment patients.[12-14] Patients were typically treated with 24 Gy in 2 fractions (12 Gy × 2) to the PTV with a max point dose tolerance of 17 Gy to the spinal cord planning OAR volume PRV (1.5-mm margin beyond the MRI defined cord). Patients undergoing repeat SBRT due to treatment failure were typically treated with 30 Gy in 4 fractions with a max point dose tolerance of 16.2 Gy to the spinal cord PRV. Cord constraints were applied to the cord PRV and thecal sac based on dose to the point max without considering volume or length of cord treated as previously described.[13,14] With regard to immobilization, head and shoulder immobilization was achieved using a thermoplastic mask from above the T4 spine level. Below T4, the BodyFIX® (Elekta Instrument AB, Stockholm, Sweden) vacuum patient position and immobilization system was used. Treatment was delivered via beam intensity modulated therapy with 9 or 11 beam field geometries for all patients.

Retrospective Review: Radiation Treatment Planning

For the purpose of this retrospective study, the preoperative T1 and T2 MRI were fused to the postoperative treatment planning CT using the aforementioned TPS. Following fusion, epidural disease gross tumor volume (Epidural GTV) and spinal cord PRV were contoured. Spinal cord PRV overlapping with the PTV was excluded from the PTV during treatment planning. Incremental 1-mm contours representing incremental tumor resection from 1 to 10 mm were generated to simulate the effect of incremental epidural disease resection. The dose contours were

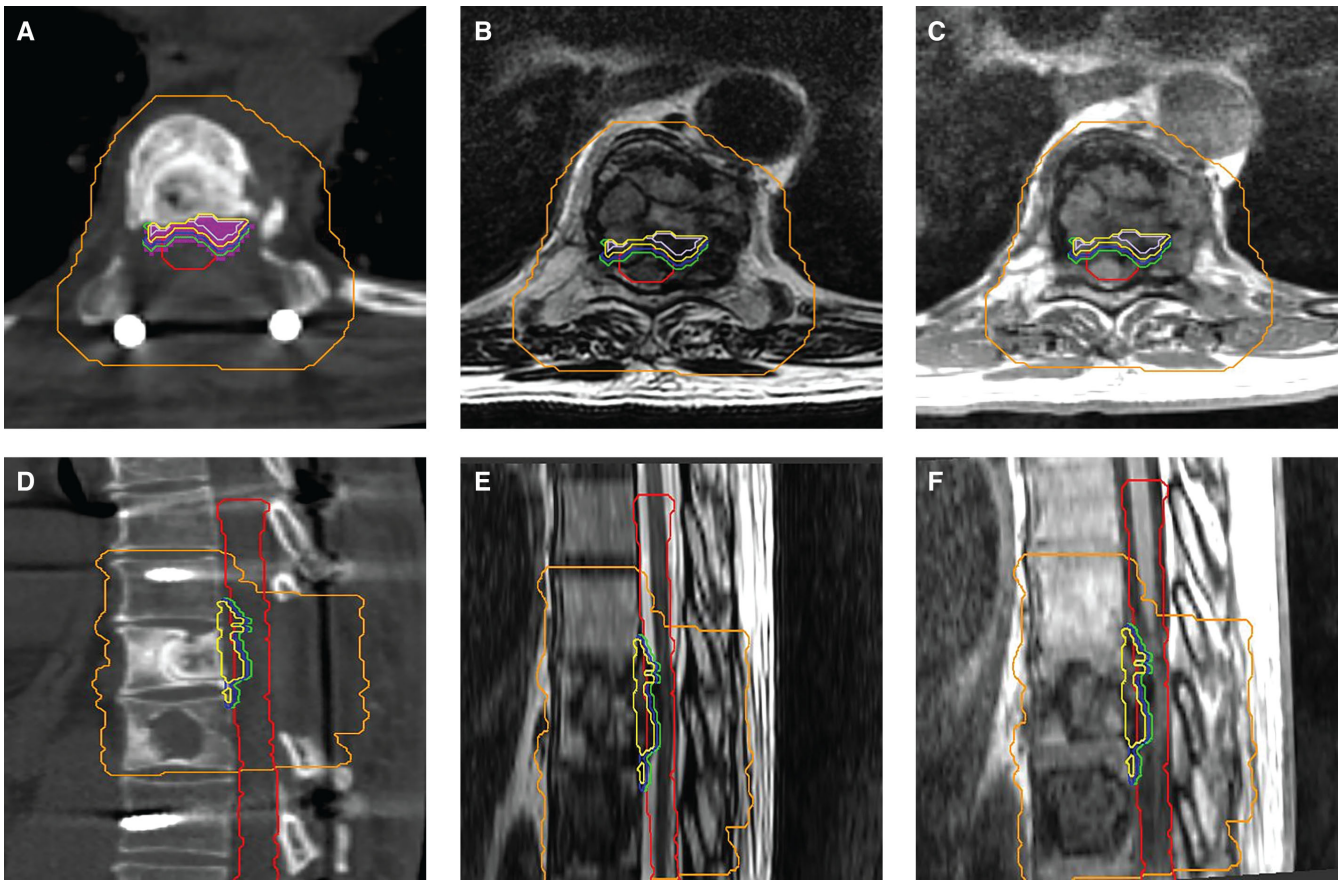

FIGURE 1. *T9 vertebral body postlaminectomy and cord decompression/tumor resection.* **A** *and* **D**, *Axial and sagittal CT image of the vertebral body with bilateral inserted pedicle screws. PTV encompasses the entire vertebral body (orange). Outline of the spinal cord PRV shown in red with epidural GTV (purple colorwash) and incremental millimeter epidural disease contours (green—1 mm, blue—2 mm, yellow—3 mm, lavender—4 mm).* **B** *and* **E**, *T2 MRI image used for fusion and epidural disease contouring.* **C** *and* **F**, *T1 MRI image used for fusion and epidural disease contouring.*

modeled after the surgical approach, whereby the surgeon would begin resection at the cord-epidural disease interface with the sole objective to create separation between the spinal cord and the epidural disease as shown in Figure 1. Typically, the goal of the surgery is to create a 2- to 3-mm space between the disease and the spinal cord allowing for the delivery of maximal high dose radiation to the target. This is achieved via laminectomy with instrumented fusion to maintain spinal stability and the epidural disease is resected circumferentially. Although typical surgical margins achieved in spine separation surgery are 2 to 3 mm, exaggerated contours were simulated to evaluate the dosimetric effect of aggressive surgical resection.

The dose volume histograms (DVH) for the simulated resected GTV were generated within the clinically delivered treatment plan. Specifically, the following metrics were extracted from the DVH for each case: D_{min} (minimum dose to the region of interest), D_{98} (dose to 98% of the regions of interest), D_{95}, and D_{50} for epidural GTV. The BED was calculated for each metric using an α/β equal to 10 for tumor and 2 for spinal cord late toxicity as published previously.[13,15] A best line linear fit was applied to each set of dosimetric data as a function of resection amount. Pearson's correlations were performed evaluating the relationship between degree of epidural disease resection and dose for all dosimetric variables. All analyses were performed using SPSS statistics (Version 24; IBM, Armonk, New York). $P < .05$ was considered significant.

RESULTS

Baseline tumor and patient characteristics of the 10 patients reviewed in the present study are summarized in Table 1. Four patients were treated with 24 Gy in 2 fractions and 3 patients were treated with 30 Gy in 4 fractions. The remaining patients were treated with varying fractionation schemes based on the attending physician's discretion as indicated in Table 1. Mean epidural disease volume was 4.16 ± 2.04 cm^3. The mean minimum dose to the epidural GTV of all patients treated with 24 Gy in 2 fractions was 9.1 ± 1.5 Gy with a corresponding mean dose of

TABLE 1. Baseline Tumor and Patient Characteristics for 10 Patients Undergoing Spine Separation Surgery With Subsequent Stereotactic Body Radiotherapy.

Patient no.	1	2	3	4	5	6	7	8	9	10
Age	62	69	57	57	70	46	70	67	59	58
Tumor Histology	Lung	Renal Cell	Breast	Breast	Renal Cell	Renal Cell	Thyroid	Rectal	Squamous Cell	Breast
Prescription Dose (Gy)/Fractions	30/5	24/2	24/2	30/4	24/2	30/4	28/2	24/2	25/5	30/5
Prescribed BED (Gy_{10})	48.0	52.8	52.8	52.5	52.8	52.5	67.2	52.8	37.5	48.0
Epidural Disease Volume (cm^3)	5.93	4.64	1.60	6.44	4.63	0.64	5.64	3.61	6.39	3.54
Max Radiation Dose to Cord PRV (Gy)	18.6	12.2	12.0	18.1	12.2	16.3	14.6	14.6	13.5	21.8
Max BED to Cord PRV (Gy_2)	61.8	49.4	48.0	59.1	49.4	49.5	67.9	67.9	31.7	69.3
Baseline SINS Score	6	1	4	8	12	10	7	9	9	9
Bilsky Score	2	2	1C	2	3	1B	1C	2	1C	2

TABLE 2. Mean (95th Percentile) BED to D_{min}, D_{98}, D_{95}, and D_{50} for the epidural GTV and Simulated Incremental Tumor Resection Margins with Corresponding mean Epidural GTV Resection Volumes.

	Epidural GTV Volume (cm^3)	BED D_{min} (Gy_{10})	BED D_{98} (Gy_{10})	BED D_{95} (Gy_{10})	BED D_{50} (Gy_{10})
Epidural GTV	4.3	14.5 (18.4)	16.1 (21.0)	17.0 (22.6)	25.6 (36.2)
Epidural GTV—1 mm	3.5	14.9 (19.2)	16.9 (22.2)	17.7 (23.8)	26.4 (37.9)
Epidural GTV—2 mm	2.8	15.3 (20.0)	17.5 (23.1)	18.6 (25.2)	27.5 (40.3)
Epidural GTV—3 mm	2.2	15.8 (21.1)	18.3 (25.1)	19.5 (27.0)	28.7 (42.3)
Epidural GTV—4 mm	1.6	16.4 (22.4)	18.6 (27.2)	20.2 (29.4)	30.0 (44.7)
Epidural GTV—5 mm	1.2	17.1 (24.1)	19.5 (30.1)	21.0 (32.2)	31.2 (46.8)
Epidural GTV—6 mm	0.8	18.2 (28.2)	20.4 (32.7)	22.3 (35.5)	33.3 (49.2)
Absolute BED increase up to 6 mm (Gy_{10})	NA	3.7	4.3	5.3	7.7
% BED increase up to 6 mm	NA	25.8	26.6	31.2	30.1
Absolute BED increase per mm up to 6 mm (Gy_{10})	NA	0.62	0.72	0.88	1.28
% BED increase per mm up to 6 mm	NA	4.3	4.4	5.2	5.0
R2	NA	0.983	0.998	0.998	0.992
P Value	NA	<.001	<.001	<.001	<.001

14.9 ± 1.9 Gy. Epidural GTV in patients receiving 30 Gy in 4 fractions had mean minimum dose of 12.1 ± 1.3 Gy with a corresponding mean dose of 17.8 ± 1.7 Gy.

Epidural GTV and Incremental Dose Margins

The volumetric and dosimetric data for the epidural disease and each incremental resection margin are shown in Table 2. Consistent gains were observed up to 10 mm with respect to D_{min}, reflected by an increase in BED coverage of the epidural GTV of approximately 1 Gy per mm. Diminishing dosimetric returns were seen with increased tumor resection beyond 6 mm using the alternative metrics ($D_{98,}$ $D_{95,}$ D_{50}), due to sufficient separation between the epidural disease component and the spinal cord or due to minimal residual epidural disease component (Table 2). Increased BED coverage of the epidural GTV was recognized ranging from 3.7 Gy_{10} (~0.6 Gy_{10} per mm) for D_{min} to 7.7 Gy_{10} (~1.3 Gy_{10} per mm) for D_{50}. All dosimetry metrics exhibited strong positive correlations with increasing tumor resection margins up to 6 mm (adjusted R^2—0.989-0.999, $P < .001$). D_{min}, D_{98}, D_{95}, and D_{50} as a function of millimeter epidural GTV margins are shown in Figure 2. Absolute and percent dose characteristics for all patients are shown in Figure 3. Due to the diminishing benefit beyond a certain threshold where sufficient separation is achieved, dosimetric resection contours beyond 6 mm were not included in the statistical analysis.

Representative Study

Patient 1 was a 68-yr-old male with multiple osteolytic metastases in the lumbar and thoracic spine including a large T9 lesion extending into the spinal canal and causing MESCC. Primary histology was renal cell carcinoma. Due to vascularity of the T9 lesion, the patient underwent a successful embolization prior to laminectomy with bilateral instrumented T8, T11, and T12 fusion with gross tumor resection. Follow-up treatment planning MRI shows nearly complete decompression of the tumor at T9 approximately 1 month after surgery. Patient then underwent SBRT with a PTV prescribed to the entire T9 and T10 vertebral bodies. Treatment planning was performed using the donut configuration described previously by Al Omair and colleagues[16] with a dose prescription of 24 Gy in 2 fractions and a max point dose tolerance of 17 Gy to the spinal cord PRV. The BED to D_{min} for the PTV was 15.1 Gy_{10}. At the 1-yr follow-up MRI, no

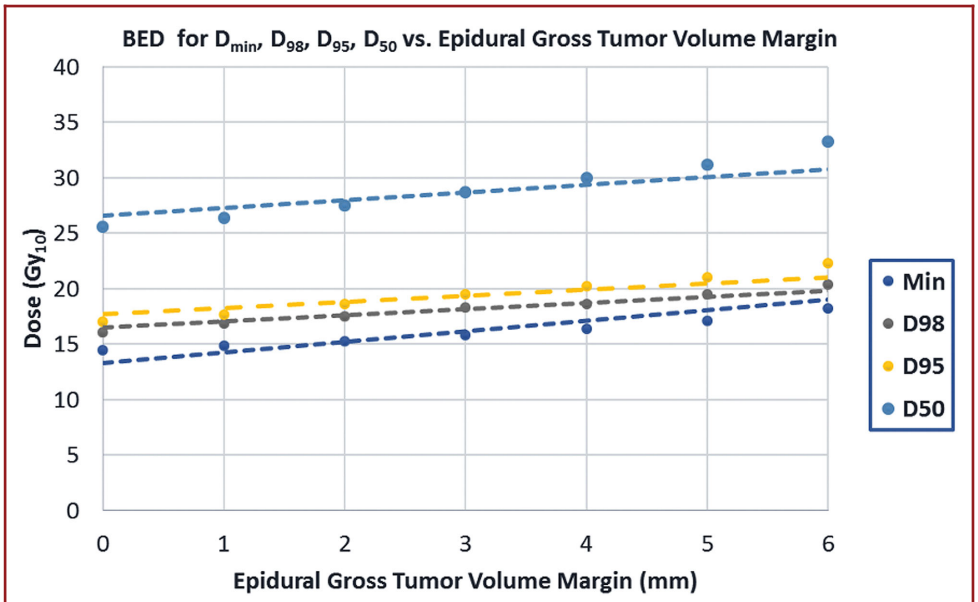

FIGURE 2. *BED to D_{min}, D_{98}, D_{95}, D_{50} as a function of millimeter epidural GTV margins. Linear increases in all parameters with greatest impact of D_{50}. Data shown only up to 6 mm of resected epidural GTV.*

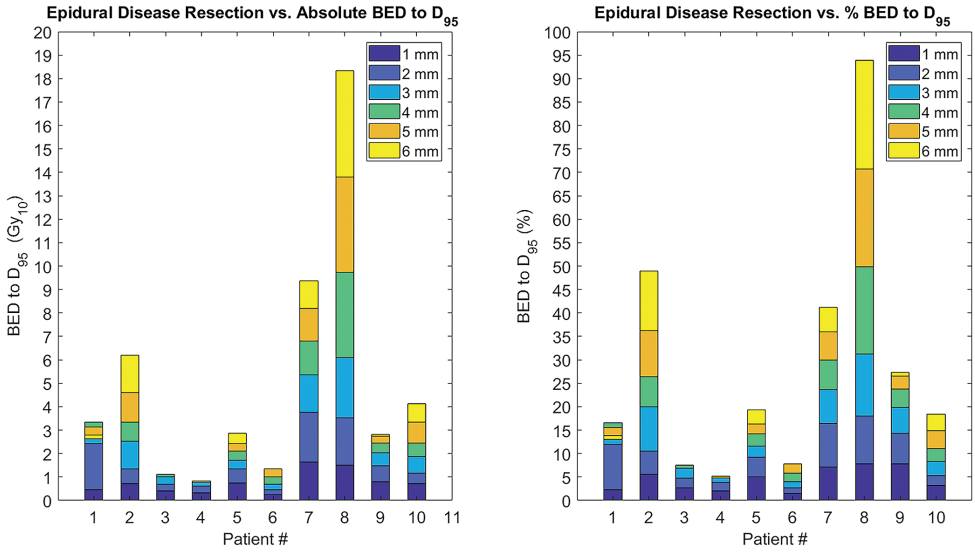

FIGURE 3. *Absolute BED to D_{95} (left panel) and % BED to D_{95} (right panel) characteristics for all 10 patients from zero resection to 6 mm resection using simulated 1 mm incremental tumor resection contours. Data shown only up to 6 mm of resected epidural GTV.*

interval changes were noted and the T9 lesion was classified as stable disease. The epidural GTV and incremental dose volumes for patient 1 are shown in Figure 1. Increased dose coverage of the epidural GTV was recognized ranging from 3.3 Gy_{10} (0.6 Gy_{10} per mm) for D_{min} to 5.0 Gy_{10} (0.83 Gy_{10} per mm) for D_{50} over 6 mm. DVHs representing the normalized contour volume and absolute epidural disease volume vs dose are shown in Figure 4.

DISCUSSION

In this report, we established a patient-specific relationship between the extent of epidural tumor resection following spine separation surgery, and increased dose coverage of residual epidural disease. This data has the potential to change practice, as the current surgical paradigm does not appreciate the

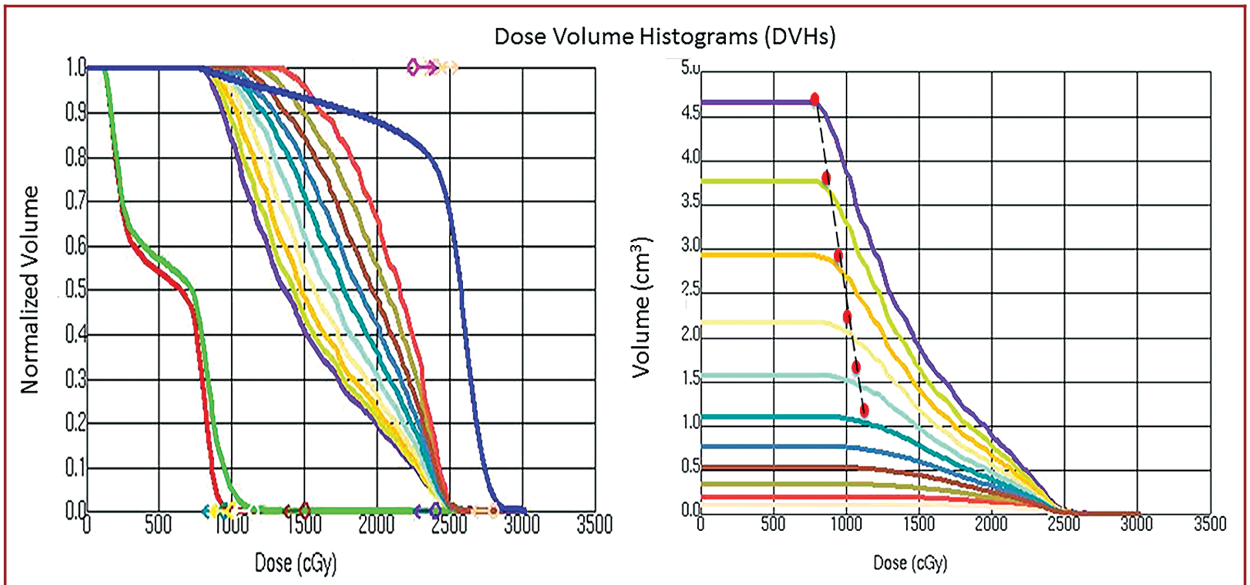

FIGURE 4. *DVHs for patient 1. Left panel: normalized contour volume vs dose for cord (red), cord PRV (green), incremental epidural GTV (purple–orange), and PTV (blue). Cord and Cord PRV limited to <1000 cGy. Epidural disease contours show DVH shift from left to right from ~1500 cGy (Epidural GTV) to ~2200 cGy (Epidural GTV—10 mm) with increasing tumor resection margins indicating increase in deliverable dose. Right panel: actual contour volume vs dose for incremental epidural GTV (purple–orange). Epidural disease shows DVH shift from left (Epidural GTV) to right (Epidural GTV—10 mm) with decreasing epidural disease volume indicating increase in deliverable dose.*

impact of the surgical resection on the dosimetric coverage of the target.

In order to optimize coverage of the epidural disease, the dose delivered to the spinal cord PRV is typically maximized while respecting the rigid published constraint. In this regard, spine SBRT is unique and consistent with the isotoxic dose prescription approach to increase the therapeutic ratio as conventionally the objective of the dose prescription is to minimize the dose to the OAR rather than to maximize dose to a certain dose tolerance of the organ.[17] Therefore, for spine SBRT when the dose prescription is 24 Gy in 2 fractions and the spinal cord PRV is limited to 17 Gy, the treatment plan is designed to maximize the dose to the spinal cord PRV up to 17 Gy with the secondary objective of maximizing dose prescription coverage to the PTV.[17,18]

As presented in this work, the improvement in dose coverage in the case of a 6-mm tumor resection is substantial with an increase in BED for D_{min} of ~4 Gy. Dose increases per fraction beyond a threshold may allow recruitment of additional cell kill mechanisms such as vascular damage via ceramide-mediated apoptosis.[19,20] Previous work published by our group[21] has established a relationship between irradiation of the tumor and vascular changes following treatment using MR perfusion and permeability particularly above a threshold of 10 Gy in a single fraction.

Previous studies have shown the distinct advantage of spine separation surgery in improving local control following SBRT, by providing increased distance between the radiosensitive spinal cord and the GTV.[16,22-24] Work by Lovelock et al[25] and Kumar et al[26] have shown a correlation between D_{min} and local failure for D_{min} doses of <15 Gy in 1 fraction and <23.1 Gy in 3 fractions, but little work has been done with regard to establishing the dosimetric impact of spine separation surgery. Our work builds on the prior studies by establishing a definitive dose-resection relationship ranging from 4.3% to 5.2% increase in dose per millimeter (Table 2), which can inform the surgeon about the extent of surgical decompression required. We also observed consistent gains in D_{min} up to 6 mm. Beyond 6 mm, there was little dosimetric advantage which likely reflects maximal epidural tumor resection given that the absolute epidural volume rapidly decreased from a mean of 4.3 cm^3 to 0.7 cm^3 (Table 2; Figure 4) within the first 6 mm. These gains were not seen consistently in all patients (ie, some patients received maximum benefit with resection margins of less than 6 mm); however, this does highlight the value of our method to allow a pathway for the radiation oncologist to not only individualize dose and dose distribution for each patient's tumor, but also specify an optimized surgical plan for the surgeon to perform separation surgery to "just the right amount" of epidural disease resection.

This study retrospectively determined the in vivo relationship between the degree of epidural disease resection and dosimetric outcomes. The results of the present manuscript may further our understanding of previous studies, which have focused only on the relationship between surgical resection and local control. With extended survival in patients with metastatic disease secondary

to improved systemic therapy, there is a need to optimize the management of patients with spinal metastases. By combining a limited surgery with SBRT, we can minimize exposure to the surgical wound to decrease complication rates and optimize local control while sparing the spinal cord from high dose radiation.[12] Consequently, the operating surgeon can be better informed as to the adequate extent of surgical resection based on dosimetric objectives.

The advantage of a larger distance between the postoperative CTV and the reconstituted thecal sac, or cord PRV, is that it provides a separation of dose between the critical neural structure and the tumor. Effectively, a greater dose can be delivered to residual disease for a given cord constraint. What is interesting here is that there is anatomic variation between the cases and the typical rule of 10% to 15% gain in dose per millimeter reported previously is not observed for all patients (Figure 3).[27,28] This reflects the complexity of the spine SBRT dose distribution and anatomic factors that come into play for spine SBRT.

Limitations

The current study is subject to limitations. First, use of a preoperative MRI for delineation of the spinal cord PRV and epidural GTV fused to a postoperative SBRT treatment planning CT image is not ideal, particularly in the presence of artifacts secondary to the insertion of surgical hardware and significant anatomic changes as a result of the surgery (ie, bone removal, tumor resection etc).[29,30] Further, as the spinal cord undergoes decompression, the location of the spinal cord is expected to shift over time and, therefore, the geometric constraints of the cord applied preoperatively are no longer valid. This cord shift has not been quantified within the context of this study, but previous studies have correlated the extent of decompression, as indicated by the spinal cord/thecal sac diameter ratio commonly referred to as the space available for the spinal cord (s/c ratio).[31] The extent of posterior cord shift has also been characterized in the context of laminoplasty in cervical spine for benign disease.[32]

The statistical power of the current analysis is limited due to the small number of patients (n = 10) analyzed and significant variability between patients. This limitation is apparent despite the dosimetric benefit of spine separation surgery suggested in this study. For example, the advantage of spine separation surgery may not be impactful in the presence of limited tumor volume or where the epidural disease component is not directly touching the spinal cord (ie, patient #3 and #6; Figure 3). In contrast, greater benefit was seen in patients with extensive epidural disease (patient #8). This result is consistent with clinical outcomes demonstrating superior local control in patients with high grade epidural disease (Bilsky 2 or 3) who have been downgraded to a Bilsky 0 or 1 via separation surgery, which is then followed by postoperative SBRT.[16] Therefore, this work must be considered within a larger clinical framework comprised of large and diverse cohort of patients presenting with various degrees of epidural disease presentation facilitating subgroup analysis.

CONCLUSION

Spine separation surgery provides division between the spinal cord and epidural disease, facilitating better disease coverage for radiotherapy. This study suggests the potential of SBRT dosimetry planning to further inform surgical planning in the context of separation surgery for spinal metastases. Further work on software tools to model decompression and reconstitution of the cerebrospinal fluid space a priori based on the preoperative MRI, and then linked to the decompression as it is being performed in real time, will be needed to determine the ideal surgical plan for separation with intraoperative confirmation of extent of epidural resection. This study provides the background to develop such a clinical solution and highlights the need to incorporate radiation dose planning software with surgical planning and neuronavigation software for spinal tumor resection.

Disclosure

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENTS

In patients with Bilsky grade 2 or 3 metastatic epidural spinal cord compression, the gross tumor volume (GTV)/clinical target volume (CTV) is compressing the spinal cord and if stereotactic body radiation therapy (SBRT) is to be given, the epidural disease immediately adjacent to the spinal cord will have to be significantly underdosed in order to respect the spinal cord tolerance. Clinical experience with separation surgery and postoperative SBRT has been reported by Memorial Sloan-Kettering Cancer Center and University of Toronto with promising results.[1, 2] Colleagues from University of Toronto showed that postoperative epidural grade determined local control after spine SBRT.[3] This is the first ever study quantifying the advantage of separation surgery in term of improvement of postoperative spine stereotactic body radiation therapy dosimetry. This study further validates that adequate resection of epidural disease to create a gap between the CTV and the spinal cord is crucial in the improvement of local control with SBRT. The feedback radiation oncologists provide to neurosurgeons is as important as the feedback the latter provide to the former in the joint management of patients with spinal metastases. With a well-planned separation surgery based on anticipated SBRT dosimetric planning, the therapeutic ratio can be enhanced, resulting in better patient outcomes. We are moving toward interdisciplinary management, implying an interactive process, instead of just multidisciplinary management of spinal metastases.

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In stereotactic body radiation therapy (SBRT) for spinal tumors, the spinal cord represents a critical structure constraint to delivery of an optimal dose to the adjacent tumor volume. Typically, meeting spinal cord constraints and also delivering an effective dose to the epidural disease require careful planning and occasionally some degree of compromise of one objective or the other. Using a cohort of 10 patients who underwent spinal separation surgery followed by postoperative SBRT, the authors demonstrate an increase in the epidural gross tumor volume (GTV) D95 at a mean rate of 0.88 $\pm$ 0.09 Gy_{10} per millimeter (mm) of resected tumor up to a simulated 6 mm separation from the spinal cord.

For the purposes of SBRT for spinal metastases, the study demonstrates the advantages of separation surgery up to a 6-mm distance between GTV and the spinal cord. The study should not necessarily be construed as defining a surgical cessation point at 6 mm of clearance of the tumor from the cord particularly if additional resection would be feasible and accomplished in a neurologically preserving fashion. However, it does suggest that using modern radiosurgical delivery platforms and adhering to contemporary SBRT principles, separation of the GTV from the cord beyond 6 mm produces diminishing returns at least from a dosimetric standpoint to the metastatic tumor and the spinal cord.

The authors are to be commended for their meticulous work. In the increasingly multidisciplinary and multimodality care of spinal metastases patients, this research provides important guidance to spinal surgeons and those performing spinal SBRT. Further validation of this work will likely be forthcoming in dose planning studies and clinical trials.

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This paper studies the dosimetric advantage of increasing the dimension of the barrier between epidural tumor and spinal cord via separation surgery in patients with spinal metastases. It also presents a novel technique utilizing preoperative MRIs and fusing them to postoperative CT scans, and describes how this can help with targeted surgical planning. The gist of the project is 2-fold. First, it shows that that increasing the distance between tumor and spinal cord up to 6 mm facilitates increasing doses of radiation postoperatively. Lastly, the study describes the advantage of their technique in preoperative planning prior to separation surgery, where a surgeon can utilize their method to predict the dimension of the barrier needed to optimize stereotactic radiation therapy postoperatively. In this way, surgeons can rely on this technique rather than the current goal of 2–3 mm between spinal cord and tumor.

Even with the limitations inherent in studying the small number of patients with heterogeneous neoplastic pathologies, the preliminary analysis present in this manuscript is thought provoking and challenges our current "standard of care" in treating patients with spinal metastases. The technique described by the authors has much potential to change spine oncology practice, and we look forward to seeing the larger study the authors are planning to validate the results presented in this work.

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This manuscript provides insight as to how much resection is necessary to optimize dosimetry for spine stereotactic radiosurgery. Often times, patients come in with significant epidural disease or cord compression, necessitating resection to restore neurological function and alleviate symptoms. However, postoperatively, there may still be significant disease as there is no benchmark or goal as to how much resection is ideal. While radiosurgery can be performed even with a fair amount of epidural disease, we know from numerous studies that epidural disease does ultimately impact local control due to underdosage of tumor close to the cord. Local control is what we strive for with the use of stereotactic radiosurgery. This research provides a common goal for spine surgeons and radiation oncologist to strive for as to the extent separation surgery needed. Although the cord will shift back due to resection, which is an understandable limitation of the study, it is clear from the data that 6 mm of separation from the cord is the ideal to maximize dosimetry. Even though achieving this may be difficult, the data shows that more separation of disease from the cord should be favored over a very limited resection.

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