Complex wound closure by plastic surgery following resection of spinal neoplasms minimizes postoperative wound complications in high-risk patients

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OBJECTIVE Wound breakdown and infection are common postoperative complications following resection of spinal neoplasms. Accordingly, it has become common practice at some centers for plastic surgeons to assist with closure of large posterior defects after spine tumor resection. In this study, the authors tested the hypothesis that plastic surgery closure of complex spinal defects improves wound outcomes following resection of spinal neoplastic disease.

METHODS Electronic medical records of consecutive patients who underwent resection of a spinal neoplasm between June 2015 and January 2019 were retrospectively reviewed. Patients were separated into two subpopulations based on whether the surgical wound was closed by plastic surgery or neurosurgery. Patient demographics, preoperative risk factors, surgical details, and postoperative outcomes were collected in a central database and summarized using descriptive statistics. Outcomes of interest included rates of wound complication, reoperation, and mortality. Known preoperative risk factors for wound complication in spinal oncology were identified based on literature review and grouped categorically. The presence of each category of risk factors was then compared between groups. Univariate and multivariate linear regressions were applied to define associations between individual risk factors and wound complications.

RESULTS One hundred six patients met inclusion criteria, including 60 wounds primarily closed by plastic surgery and 46 by neurosurgery. The plastic surgery population included more patients with systemic metastases (58% vs 37%, $p = 0.029$), prior radiation (53% vs 17%, $p < 0.001$), prior chemotherapy (37% vs 15%, $p = 0.014$), and sacral region tumors (25% vs 7%, $p = 0.012$), and more patients who underwent procedures requiring larger incisions (7.2 ± 3.6 vs 4.5 ± 2.6 levels, $p < 0.001$), prolonged operative time (413 ± 161 vs 301 ± 181 minutes, $p = 0.001$), and greater blood loss (906 ± 1106 vs 283 ± 373 ml, $p < 0.001$). The average number of risk factor categories present was significantly greater in the plastic surgery group (2.57 vs 1.74 , $p < 0.001$). Despite the higher relative risk, the plastic surgery group did not experience a significantly higher rate of wound complication (28% vs 17%, $p = 0.145$), reoperation (17% vs 9%, $p = 0.234$), or all-cause mortality (30% vs 13%, $p = 0.076$). One patient died from wound-related complications in each group ($p = 0.851$). Regression analyses identified diabetes, multilevel instrumentation, and BMI as the factors associated with the greatest wound complications.

CONCLUSIONS Involving plastic surgery in the closure of spinal wounds after resection of neoplasms may ameliorate expected increases in wound complications among higher-risk patients.

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KEYWORDS spinal oncology; wound complications; complex spine surgery; spinal fixation; risk stratification

ABBREVIATIONS ASA = American Society of Anesthesiologists; EMR = electronic medical record; SSI = surgical site infection.

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PATIENTS undergoing resection of spinal neoplasms are typically considered to be at higher risk for postoperative wound complications than other spine surgery populations. Common contributors to increased risk of surgical site infection (SSI), wound breakdown, and need for reoperation in the setting of neoplastic spinal disease include larger posterior incision size, more significant disruption of bony and paraspinal tissue, and higher prevalence of medical pre- and postoperative risk factors.^{24,26,28} Many such risk factors (e.g., prior cancer treatment, smoking history, diabetes, and chronic steroid usage) are unavoidable or uncontrollable at the time of urgent resection. As a result, the spine surgeon's armamentarium for optimizing wound outcomes for these patients is often limited to intra- and postoperative management of the wound itself.

While simple layer-by-layer tissue reapproximation for primary closure of posterior defects remains the standard of care for most open spine surgery cases, mobilization of paraspinal muscle flaps for wound coverage during closure is an approach that has long been utilized in revision surgeries for management of postoperative wound dehiscence or infection.^{11,15,17,20,21,25,27} Such techniques are now widely utilized by plastic surgeons for repair, debridement, and salvage of infected or deteriorating back wounds. Indeed, these methods were founded on extensive pathobiology literature demonstrating that mobilized muscle flaps are more resistant to bacterial infection than simple layered closure at a wound site.^{5,12,22} More recently, other groups have published small retrospective reviews and single-surgeon case series demonstrating the safety and efficacy of prophylactic soft-tissue reconstruction with musculocutaneous flaps. These studies advocate muscle flap reconstruction as a primary closure technique for preventing infection in complex spine cases rather than exclusively as a secondary approach for reapproximating a wound after a complication has already occurred.^{6–9,13,14}

In June of 2015, our neurosurgery department began to increasingly involve plastic surgery in the primary closure of large spinal wounds believed to be at risk for complication after complex spine tumor resection. We now present the resultant single-institution, multisurgeon, retrospective case-control study comparing wound-related complication rates in consecutive patients who did or did not have primary plastic surgery closure of their complex posterior defect after resection of neoplastic disease. Furthermore, we stratified relative risk of poor wound outcome in the spinal oncology population in terms of number of risk factor categories present preoperatively and performed regression analyses to identify positive associations between individual known risk factors and various observed wound complications. These data motivate future studies focused on building a novel wound complication risk scoring system specific to this population.

Methods

Patient Population

We reviewed the electronic medical records (EMRs) of all patients who underwent spinal surgery for resection of a suspected tumor within the Department of Neurosurgery

at Rhode Island Hospital between June 1, 2015, and January 31, 2019. Patients were identified using a comprehensive list of all spine surgeries performed in the department over this period and by reviewing all procedure descriptions to identify language describing resection of a tumor or spinal mass. All records were reviewed to confirm the presence of tumor or suspected spinal mass prior to inclusion determination. There were no exclusion criteria based on availability of follow-up data. This study was approved by the Rhode Island Hospital IRB as a retrospective chart review of the EMR, which authorized exemption from informed consent requirements.

Surgical Technique

All patients who underwent wound closure with plastic surgery received immediate coverage with local muscle flaps. Flap options included paraspinal, latissimus dorsi, trapezius, and thoracolumbar flaps. The choice of flap depended on the location of the spinal wound. A typical back wound triaged for closure by plastic surgery after resection of a spinal tumor at our center is depicted in Fig. 1. Conversely, patients who underwent wound closure with neurosurgery alone were more likely to undergo simple layered reapproximation of muscle, fascia, and cutaneous tissue.

Data Collection

At least one of four independent chart reviewers studied all clinic and operative notes available in the EMR for included subjects. Demographic, baseline, and preoperative risk factor details were obtained from history and physical examination, and preoperative office visit notes. Surgical details were obtained from operative notes, and tumor diagnoses were confirmed from an uploaded pathology report in each case. References to postoperative wound complications in postoperative hospital, emergency department, or office visit notes were used to document these outcomes up to the most recent follow-up visit at the time of this submission. Outcomes of interest included surgical site infection (SSI), skin necrosis, wound dehiscence, hematoma, seroma, CSF leak, reoperation, and mortality. The first six of these were also grouped into a more expansive ninth outcome variable ("any wound complication"). As our institution is the leading comprehensive subspecialty center in our region, we expect that the vast majority of postoperative emergency and surgical care for these subjects was sought at our center and was therefore documented in our EMR.

Statistical Analyses

Descriptive analyses were conducted by grouping patients as a single cohort, and by separating them into two subpopulations defined by whether or not the patient's surgical wound was closed by a plastic surgeon or a neurosurgeon. Regression analyses of association between risk factors and individual outcomes were performed on the full patient cohort. Descriptive statistics were conducted using Microsoft Excel (version 16.16.4, Microsoft Corp.), and regression analyses performed in the StatsModel module of Python (version 3.6.5). Continuous variable data are re-

FIG. 1. Exemplary case of complex wound closure by plastic surgery following resection of a thoracic chordoma and placement of bilateral posterior hardware and fibular allografts. **A:** Posterior wound after hardware placement. **B:** Sutured subcutaneous paraspinous muscle flaps. Figure is available in color online only.

ported in terms of averages and standard deviations, while binary variable data are reported in terms of percentage of patients.

Risk Stratification

Spinal oncology patients often present with multiple preoperative risk factors for wound complication. However, after review of the available literature, it was determined that there is currently no adequate risk scoring system for spinal oncology patients that accounts for multistage wound complication risk and stratifies patients accordingly. Our literature review did identify known risk factors for the wound outcomes of interest.^{1,2,6,9,13,19,24,26,28,29} We then grouped preoperative risk factors categorically (Table 1). Three of the four categories, including medical history factors (smoking, diabetes, hypertension, obesity), chronic medications of risk (anticoagulation, steroids), and prior cancer treatments (chemotherapy, radiation, spine surgery), comprise known preoperative medical risk factors. The fourth includes procedure planning factors, comprising the number of spinal levels to be incised and anticipated instrumentation. By identifying the presence of these risk factors for each patient, we were able to quantify the number of risk factor categories present (out of four

TABLE 1. Key factors associated with wound complication risk in spinal oncology patients

Risk Factor Category
Past medical history factors
Smoking history?
Treatment for diabetes?
History of hypertension?
BMI > 30 kg/m ² ?
Medication factors
Chronic blood thinners?
Chronic steroids?
Prior treatment factors
Prior chemotherapy?
Prior radiation?
Prior spine surgery?
Size of posterior spine wound
No. of levels incised > 5?
No. of levels instrumented > 4?

Risk factors were grouped into four key categories easily assessable in the preoperative setting, so that the number of risk factor categories present could also be assessed as a composite risk metric.

key categories) and used this composite metric as a means of stratifying preoperative risk for intergroup comparison. We also conducted post hoc univariate and multivariate regression analyses to detect associations of individual risk factors, as well as the composite number of risk categories, with each of the negative wound outcomes we documented in the study.

Results

Patient Characteristics

A total of 106 patients with spine tumors were included in the study, including 60 patients who underwent primary wound closure with plastic surgery and 46 who underwent closure with neurosurgery. Demographic, medical history, and tumor diagnosis data are presented in Table 2. The two groups were not significantly different in terms of age (mean 58 ± 15.9 vs 57 ± 17.6 years, $p = 0.751$), sex (57% vs 43% male, $p = 0.182$), or BMI (mean 28.1 ± 5.4 vs 28.5 ± 6.1 kg/m², $p = 0.713$). Regarding past medical history data, the groups differed significantly in terms of past cancer treatments, including prior chemotherapy (37% in plastic surgery group vs 15% in neurosurgery group, $p = 0.014$) and prior radiation (53% vs 17%, $p < 0.001$). Patient groups were not significantly different in terms of American Society of Anesthesiologists (ASA) classification (mean 2.8 ± 0.6 vs 2.7 ± 0.8 , $p = 0.245$).

Overall, although the data set encompassed a wide variety of primary and metastatic spine tumor subtypes, the groups were significantly different in terms of diagnostic profile. While 58% of the patients in the plastic surgery group underwent spine surgery to treat metastatic disease, as opposed to a primary spine tumor, only 37% of the patients in the neurosurgery group did ($p = 0.029$). Furthermore, and consistent with the initial recommendation, the

TABLE 2. Demographic, physical, medical history, and tumor characteristic details for the full patient cohort, as well as for complex (plastic surgery) and simple (neurosurgery) wound closure subpopulations

Patient Characteristics	Total Cohort (n = 106)	Complex Closure Group (n = 60)	Simple Closure Group (n = 46)	p Value
Demographic & physical details				
Male, n (%)	57 (54)	34 (57)	20 (43)	0.182
Mean age $\pm$ SD, yrs	57 $\pm$ 16.7	58 $\pm$ 15.9	57 $\pm$ 17.6	0.751
Mean height $\pm$ SD, inches	66.3 $\pm$ 4.1	66.7 $\pm$ 3.9	65.8 $\pm$ 4.2	0.289
Mean weight $\pm$ SD, lbs	176.6 $\pm$ 39.4	175.8 $\pm$ 42.1	177.3 $\pm$ 37.5	0.855
Mean BMI $\pm$ SD, kg/m ²	28.2 $\pm$ 5.69	28.1 $\pm$ 5.4	28.5 $\pm$ 6.1	0.713
Mean ASA physical status $\pm$ SD	2.7 $\pm$ 0.7	2.8 $\pm$ 0.6	2.7 $\pm$ 0.8	0.245
Past medical history, n (%)				
Smoking history	58 (55)	35 (58)	23 (50)	0.398
Diabetes	13 (12)	5 (8)	8 (17)	0.162
Hypertension	42 (40)	22 (37)	20 (43)	0.482
CVA/stroke	8 (8)	3 (5)	5 (11)	0.261
Coagulopathy/chronic AC	23 (22)	13 (22)	10 (22)	0.992
Chronic steroid usage	17 (16)	10 (17)	7 (15)	0.842
Prior chemotherapy	29 (27)	22 (37)	7 (15)	0.014
Prior radiation	40 (38)	32 (53)	8 (17)	<0.001
Prior spine surgery	19 (18)	14 (23)	5 (11)	0.099
Tumor type, n (%)				
Primary spinal tumor	54 (51)	25 (42)	29 (63)	0.029
Spinal metastases	52 (49)	35 (58)	17 (37)	0.029
Tumor diagnosis, n (%)				
Schwannoma	17 (16)	4 (7)	13 (28)	0.002
Meningioma	5 (5)	0 (0)	5 (11)	0.009
Ependymoma	8 (8)	1 (2)	7 (15)	0.009
Chordoma	13 (12)	12 (20)	1 (2)	0.005
Spinal cord glioma	1 (1)	0 (0)	1 (2)	0.255
Lung metastasis	14 (13)	10 (17)	4 (9)	0.234
Prostate metastasis	9 (8)	3 (5)	6 (13)	0.144
Breast metastasis	7 (7)	4 (7)	3 (7)	0.977
Liver metastasis	2 (2)	1 (2)	1 (2)	0.851
Thyroid metastasis	2 (2)	2 (3)	0 (0)	0.215
Lymphoma	3 (3)	1 (2)	2 (4)	0.414
Renal cell carcinoma metastasis	9 (8)	9 (15)	0 (0)	0.006
Other primary tumor*	10 (9)	8 (13)	2 (4)	0.119
Other metastatic tumor†	6 (6)	5 (8)	1 (2)	0.177
Target lesion location, n (%)‡				
Cervical (C1–7)	15 (14)	9 (15)	6 (13)	0.777
Thoracic (T1–12)	57 (54)	28 (47)	29 (63)	0.095
Lumbar (L1–5)	27 (25)	15 (25)	12 (26)	0.900
Sacral/coccygeal	18 (17)	15 (25)	3 (7)	0.012

AC = anticoagulation; CVA = cerebrovascular accident.

Continuous variables reported as averages and standard deviations. The p values represent results of unpaired t-tests of difference between the two subpopulations with respect to the variable indicated (significance presumed if $p < 0.05$, and high significance presumed if $p < 0.001$). Boldface type indicates statistical significance.

* Other primary tumors included malignant peripheral nerve sheath tumor (n = 1), calcified synovial cyst (n = 1), osteoid osteoma (n = 1), solitary fibrous tumor (n = 1), hemangioma (n = 1), hemangioendothelioma (n = 1), giant cell tumor (n = 1), chondroblastoma (n = 1), lipoma (n = 1), and fibrous dysplasia (n = 1).

† Other metastatic tumors included melanoma (n = 1), high-grade liposarcoma (n = 1), endometrial cancer (n = 1), oropharyngeal cancer (n = 1), esophageal cancer (n = 1), and bile duct cancer (n = 1).

‡ Some target lesions span two spinal regions; thus, percentages sum to > 100%.

group of patients who underwent complex plastic closure had larger lesions more likely to exhibit aggressive pathology. While the neurosurgery closure group included significantly more schwannomas (28% of tumors vs 7%, $p = 0.002$), meningiomas (11% vs 0%, $p = 0.009$), and ependymomas (15% vs 2%, $p = 0.009$), the plastic surgery closure group included more chordomas (20% vs 2%, $p = 0.005$) and renal cell carcinoma metastases (15% vs 0%, $p = 0.006$). Tumor location did not differ significantly between groups, except that there was a higher proportion of sacral and coccygeal lesions in the plastic surgery closure group (25% vs 7%, $p = 0.012$), likely reflecting greater difficulty in wound closure and a perceived increased risk of wound infection for lesions closer to the anus.

Operative and Postoperative Characteristics

The plastic surgery and neurosurgery groups also differed significantly in terms of key neurosurgical details. Patients in the plastic surgery closure group were more likely to undergo a spondylectomy or corpectomy procedure as part of the index surgery (45% vs 20%, $p = 0.006$), and were more likely to have posterior fixation hardware placed (75% vs 52%, $p = 0.014$) and significantly longer incisions (mean 7.2 ± 3.6 vs 4.5 ± 2.6 spinal levels, $p < 0.001$). Patients in the plastic surgery closure group were also more likely to receive demineralized bone matrix (55% vs 33%, $p = 0.022$). Although all patients received intravenous infection prophylaxis, the use of intrawound vancomycin powder was significantly higher in the plastic surgery closure group (77% vs 46%, $p < 0.001$). Average total surgical procedure time was greater in the plastic surgery group (413 ± 161 vs 301 ± 181 minutes, $p = 0.001$) and involved significantly more blood loss (906 ± 1106 vs 283 ± 373 ml, $p < 0.001$). Taken together, these differences support the hypothesis that the procedures undergone by patients who received complex plastic surgery closure were more technically complex, even independent of other risk factors.

Additional operative and postoperative details for both groups are represented in Table 3, along with a breakdown of flap type for the 60 patients in the complex plastic surgery closure group. The majority underwent mobilization and local advancement of paraspinal muscle flaps (63%). The mean hospital length of stay before discharge was 9.2 ± 8.1 days in the plastic surgery closure group, and 6.8 ± 6.5 days in the neurosurgery closure group ($p = 0.106$). The combined mean follow-up visit period was 13.1 months (range 0.4–48.9 months) and was not significantly different between the neurosurgery and plastic surgery groups (12.0 vs 14.1 months, $p = 0.383$). A total of 14 patients (5 in the neurosurgery group and 9 in the plastic surgery group, $p = 0.538$) did not have office visits documented after discharge from the index operation.

Risk Distribution and Wound Outcomes

Using the categorization schema presented in Table 1, the number of preoperative risk factor categories present for each patient was computed. As seen in Fig. 2, the distribution of the number of risk categories across each group is approximately normal. The average number of

risk factor categories present in patients from the plastic surgery closure group was 2.57, as compared to 1.74 in the neurosurgery closure group. This difference between groups was highly significant ($p < 0.001$), suggesting higher preoperative risk in the plastic surgery group.

Despite higher approximated risk for poor wound outcome, the plastic surgery group did not show an expected higher frequency of wound complications in any of the predefined categories, or across all wound complications (Table 4). The overall rate of wound complications, i.e., the number of patients who experienced at least one wound complication, was 24% (28% in the plastic surgery group vs 17% in the neurosurgery group, $p = 0.145$). The plastic surgery group did have a higher rate of SSI (12% vs 9%, $p = 0.623$) and seroma (17% vs 7%, $p = 0.117$), although these differences were not statistically significant. Conversely, the neurosurgery closure group had slightly higher rates of wound dehiscence (13% vs 12%, $p = 0.832$), hematoma (7% vs 5%, $p = 0.719$), and CSF leak (7% vs 2%, $p = 0.204$). The rates of skin necrosis (1 patient in each group) were approximately equal (1.7% vs 2.2%, $p = 0.851$). Differences in rate of reoperation (17% in the plastic surgery group vs 9% in the neurosurgery group, $p = 0.234$) and all-cause mortality at the time of last follow-up (30% in the plastic surgery group vs 15% in the neurosurgery group, $p = 0.076$) were also not significantly different between groups. Of 25 patients who died, 1 patient in each group died of infection related to wound complications. All other deaths were attributed to treatment-resistant systemic metastatic disease or other medical events following surgery unrelated to the surgical wound.

Results from regression analyses are represented in Table 5. Across the full patient cohort (pooling both groups), all individual risk factors were associated with several of the wound outcome variables tested. Factors associated with the most (5 or more) wound complications included smoking, diabetes, hypertension, preoperative chemotherapy or radiation, high preoperative BMI, size of wound, and number of levels instrumented. Diabetes, high BMI, and multilevel instrumentation were all associated via multivariate regression with multiple wound complications. This finding is consistent with other studies and makes sense in light of leading hypotheses regarding the association of obesity and impaired glucose metabolism with reduced lymphocytic defense against surgical pathogens.^{4,10} Overall, skin necrosis and CSF leak were the complications associated with the fewest risk factors. These complications were also observed with the lowest frequency across our data. Furthermore, univariate regression of the number of risk factor categories with each outcome showed significant associations ($p < 0.05$) with all wound outcomes tested. As expected, the number of risk factor categories was not significantly associated with outcome by multivariate regression because this composite variable is a linear combination of other dependent risk variables. These results indicate that the number of risk factor categories present was a robust predictor of outcome.

Discussion

This study supports the hypothesis that plastic surgery

TABLE 3. Operative and postoperative details for full patient cohort, as well as for complex (plastic surgery) and simple (neurosurgery) wound closure subpopulations

Operative & Postop Details	Total Cohort (n = 106)	Complex Closure Group (n = 60)	Simple Closure Group (n = 46)	p Value
Procedures performed, n (%)				
Laminectomy/laminotomy	91 (86)	49 (82)	42 (91)	0.161
Facetectomy/foraminotomy	13 (12)	7 (12)	6 (13)	0.832
Fusion/arthrodesis	53 (50)	34 (57)	19 (41)	0.119
Spondylectomy/corpectomy	36 (34)	27 (45)	9 (20)	0.006
Wound size (mean ± SD)				
No. of levels spanned by lesion	2.4 ± 1.7	2.4 ± 1.8	2.4 ± 1.6	0.851
No. of levels incised	6.1 ± 3.5	7.2 ± 3.6	4.5 ± 2.6	<0.001
Length of closure, cm	—	22.6 ± 7.1	Not reported	—
No. of levels instrumented	4.1 ± 3.7	5.1 ± 3.8	2.9 ± 3.2	0.002
Instrumentation & materials, n (%)				
Placement of any instrumentation	69 (65)	45 (75)	24 (52)	0.014
Placement of screws & rods	60 (57)	42 (70)	18 (39)	0.001
Placement of screws & plates	16 (15)	7 (12)	9 (20)	0.264
Placement of expandable cage	28 (26)	18 (30)	10 (22)	0.343
Use of demineralized bone matrix	48 (45)	33 (55)	15 (33)	0.022
Antibiotics, n (%)				
Use of vancomycin powder	67 (63)	46 (77)	21 (46)	<0.001
Use of vancomycin nonpowder	73 (69)	49 (82)	24 (52)	<0.001
Use of other antibiotic infusion	106 (100)	60 (100)	46 (100)	—
Closure technique, n (%)				
Simple layered closure	—	—	46 (100)	—
Closure w/ paraspinous flaps	—	38 (63)	—	—
Closure w/ trapezius flaps	—	8 (13)	—	—
Closure w/ latissimus flaps	—	3 (5)	—	—
Closure w/ gluteal flaps	—	6 (10)	—	—
Closure w/ rotational flap	—	1 (2)	—	—
Closure w/ V-Y flap	—	1 (2)	—	—
Closure w/ local advancement flap NOS	—	3 (5)	—	—
Other intraop details (mean ± SD)				
Procedure duration, min	364 ± 178	413 ± 161	301 ± 181	0.001
Estimated blood loss, ml	635 ± 918	906 ± 1106	283 ± 373	<0.001
Postop course				
Mean hospital stay duration ± SD, days	8.1 ± 7.5	9.2 ± 8.1	6.8 ± 6.5	0.106
Mean follow-up period ± SD, mos	13.1 ± 11.7	14.1 ± 12.7	12.0 ± 12.3	0.383
Postop chemotherapy, n (%)	28 (26)	19 (32)	9 (20)	0.135
Postop radiation, n (%)	43 (41)	31 (52)	12 (26)	0.006

NOS = not otherwise specified.

Continuous variables are reported as averages with standard deviations. The p values represent results of unpaired t-tests of the difference between the two subpopulations with respect to the variable indicated. Boldface type indicates statistical significance.

involvement in the primary closure of complex wounds following resection of spinal tumors is beneficial, especially among the highest-risk patients. A limited number of reports from other comprehensive spinal oncology centers have documented similar findings regarding wound complication rates. The largest series of wound closures by plastic surgery, reported by a group from Johns Hopkins (Carl et al. 2017), retrospectively reviewed the charts of 288 patients over a 12-year period and published a reoper-

ation rate of 27%, infection rate of 24%, wound dehiscence rate of 17%, and CSF leak rate of 7%.⁶ Our complex plastic surgery closure population's complication rates were comparable or lower, despite the fact that the study population of Carl et al. included fewer patients with metastatic lesions (22.6%) and had lower baseline rates of multiple major wound complication risk factors (12.2% chronic steroids, 35.3% preoperative radiation, 23.6% chemotherapy, 12.8% smoking). Another recent study of 55 patients by a

FIG. 2. Bar graph representing the number of risk categories present among patients in the complex plastic closure ($n = 60$) and neurosurgery closure ($n = 46$) groups. Bars represent percentage of patients in each group in which each number of risk factor categories is present. Continuous lines represent approximate distribution of number of risk categories in each group, with averages indicated by points (2.57 risk categories present in the plastic surgery group and 1.77 risk categories present in the neurosurgery group). The difference in average number of risk categories present in each group is statistically significant ($*p < 0.001$). Figure is available in color online only.

group at Cornell (Franck et al. 2018) reported even lower infection rates (1.7%) than our study, but similar rates of reoperation (11.7%) and seroma (15%) in an oncological population.¹³ This study population also had lower baseline rates of some particularly relevant wound complication risk factors (13% diabetes, 30% smoking history). It is not unexpected that rates will vary somewhat with practice group and institution.

Notably, we are not aware of any previous studies that have directly compared wound outcomes between patient cohorts who did or did not undergo complex plastic closure for neoplastic disease. This gap in the literature may be due, in part, to bias between groups in terms of underlying baseline wound complication risk, a potentially important confounding variable that, unless clearly quantified and reported, would make the results of such a study difficult to interpret. Furthermore, we found no validated risk scoring systems previously published that stratify baseline risk for wound complication arising from multiple sources in the spinal oncology population. To solve this problem in the present work, we accounted for consensus factors identified by the spine surgery and spinal oncology literature as likely contributing to higher rates of wound complications in this population, and pooled factors into a categorical composite measure counting the number of risk categories (out of four) that were present before surgery. We also compared the prevalence of individual risk factors between groups.

By quantifying risk in this way, we were able to characterize the risk bias between our two cohorts, and thereby better contextualize differences in outcome between the two. While there were not significant differences between populations in terms of rate of any wound outcome docu-

mented in our study, there was a highly significant difference in number of risk factor categories present (1.77 in the neurosurgery group vs 2.57 in the plastic surgery group, $p < 0.001$), indicating that patients in the plastic surgery group had more types of relevant risk factors than patients in the neurosurgery group. Accordingly, we report retrospective evidence that having plastic surgery involvement in wound closure may reduce wound complication rates in spinal oncology patients with high baseline risk. While this trend, observed in a multipractitioner data set, is not likely attributable to difference in skill between practitioners of neurological or plastic surgery, it may suggest the importance of muscle flaps in improving wound complication profiles among this population. This makes sense given the relevant background literature on musculocutaneous flap utilization in spinal wound reapproximation.^{5–9,12–14,22} Moreover, our study suggests that patients with complex spinal oncology may be better treated in a multidisciplinary environment that capitalizes on the specific, unique expertise of each surgical group involved. The criteria to be used for determining need for multidisciplinary surgical care on a case-by-case basis are yet to be standardized.

Quantifying preoperative risk categorically as we have done in this study may hold particular utility for spinal oncology, as this strategy incorporates medical history, surgical planning, and physiological factors that are common and easily identifiable in the preoperative setting for this population. Grouping factors categorically ensures that no single class of factors has a disproportionate weight on the risk approximation, even in the presence of multiple positive factors within a given category. Furthermore, our regression analyses suggest that number of risk factor cat-

TABLE 4. Composite risk rating, wound complication rates, and outcomes for the full patient cohort, as well as for complex (plastic surgery) and simple (neurosurgery) wound closure subpopulations

No. of Risk Factor Categories & Outcome Distributions	Total Cohort (n = 106)	Complex Closure Group (n = 60)	Simple Closure Group (n = 46)	p Value
No. of risk factor categories, n (%)				
0	7 (7)	0 (0)	7 (15)	—
1	22 (21)	7 (12)	15 (33)	—
2	32 (30)	21 (35)	11 (24)	—
3	32 (30)	23 (38)	9 (20)	—
4	13 (12)	9 (15)	4 (9)	—
Average	2.21	2.57	1.74	<0.001
Wound complication rates & outcome, n (%)				
Any wound complication	25 (24)	17 (28)	8 (17)	0.145
SSI	11 (10)	7 (12)	4 (9)	0.623
Skin necrosis	2 (2)	1 (2)	1 (2)	0.851
Dehiscence	13 (12)	7 (12)	6 (13)	0.832
Hematoma	6 (6)	3 (5)	3 (7)	0.719
Seroma	13 (12)	10 (17)	3 (7)	0.117
CSF leak	3 (3)	1 (2)	3 (7)	0.204
Need for reoperation	14 (13)	10 (17)	4 (9)	0.234
Mortality (all cause)	18 (17)	18 (30)	7 (15)	0.076
Mortality (wound-related)	2 (2)	1 (2)	1 (2)	0.851

Results of unpaired t-tests for significance of difference between the two subpopulations found to be highly significant ($p < 0.001$) with respect to risk rating, but not with respect to any of the measured wound complication rates. Boldface type indicates statistical significance.

egories present may be a measure particularly well tuned to estimating risk of wound complication in the spinal oncology population. Were data like those presented in this study used to develop a risk scoring system based on these principles, such a system could be easily implementable as a useful clinical tool. However, future studies should more thoroughly test for associations between these variables (as well as other variables not tested in this study but reported in the broader spine surgery literature) and wound outcomes.^{1,3,4,16,18,19,23,29} All risk variables tested in this study were reported in the spinal oncology literature previously, but comparison of their relative associations with wound outcomes was limited here by modest sample size ($n = 106$ overall, $n = 46$ vs $n = 60$ in each cohort) and low incidence of individual complications. Furthermore, in these data, there were few patients positive for all four risk categories (15% in the plastic surgery group, 9% in the neurosurgery group), possibly due to a subset of the highest-risk patients having been excluded from surgery, and therefore excluded from this study. Building on the results of our analyses in future prospective and larger retrospective studies will be essential for developing useful prognostication systems. Such tools could be especially useful for subpopulations of particular interest within neurosurgical oncology, such as patients preoperatively treated with chemotherapy or radiation.

In this study, we focused on quantifying preoperative risk as a means of standardizing groups for comparison of outcomes. However, limitations of our retrospective study include lack of control for technical variability between multiple practitioners as well as possible sources

of selection bias. Our data suggest that there may be bias between groups in terms of specific measures taken to prevent wound infection when treating patients perceived to be at high risk. For example, while intraoperative antibiotics were administered to all patients (100%) across both groups, patients in the plastic surgery group were significantly more likely to get intraoperative vancomycin, either as a wound powder (77% vs 46%, $p < 0.001$) or in other forms (82% vs 52%, $p < 0.001$). Furthermore, cases in the neurosurgery group were typically performed using simple layered closure, while plastic surgery practitioners used musculocutaneous flap techniques for closure, and the majority of cases in which wound drains were placed also involved plastic surgery. These differences in wound care observed between groups may highlight more granular differences in practice that could be individually assessed in future studies as the underlying causes of better outcomes in the plastic surgery group; the present study, however, considers them as collectively attributable to the composition of the surgical team. Another source of selection bias may include the level of training of surgical practitioners closing wounds in each group. As in any academic institution, including our own, a surgical trainee (i.e., resident or fellow) almost always participates in wound closures by both neurosurgery and plastic surgery, making it difficult to differentiate groups. However, an attending physician is always present for closure in either group. In general, the effect of surgical practitioner level of training on wound outcomes in spinal surgery represents another avenue of future investigation.

In light of data collected during this study, such con-

TABLE 5. Results of univariate and multivariate linear regression models assessing association between individual outcome variables (wound complications, reoperation, mortality) with individually identified risk factors and the composite number of risk factor categories present across the full patient cohort (n = 106)

Risk Factor	SSI	Skin Necrosis	Dehiscence	Hematoma	Seroma	CSF Leak	Reoperation	Mortality	Any Wound Complication
Smoking	U	—	U	U	U	—	U	U	U
Diabetes mellitus	M	U	M	U	—	U	M	M	M
Hypertension	U	—	U	U	U	—	U	U	U
Anticoagulation	U	—	U	—	—	—	U	U	U
Chemotherapy	U	—	U	U	U	—	U	U	U
Radiation	U	—	U	U	U	—	U	U	U
Preop BMI	U	—	U	U	M	U	U	M	U
Prior spine surgery	U	—	U	—	—	—	U	—	—
Age	U	—	U	U	U	—	U	U	U
No. of levels									
Incised	U	—	U	U	U	—	U	U	U
Tumor location	U	—	U	U	U	—	U	U	U
Instrumented	U	—	M	—	M	U	U	M	U
Duration of procedure	U	—	M	—	U	—	U	U	U
Estimated blood loss	U	—	U	—	—	—	U	U	U
No. of risk categories	U	U	U	U	U	U	U	U	U

M = significance ($p < 0.05$) of association by multivariate regression; U = significance ($p < 0.05$) of association by univariate regression; — = nonsignificance by both univariate and multivariate regression.

foundings biases between neurosurgical and plastic surgery care teams with respect to wound care speak more to the need for greater standardization in wound complication prophylaxis than to the efficacy of individual surgical techniques. However, by showing through post hoc regression analyses that the risk variables studied were associated with wound outcome in the same cohort of patients, we demonstrated that these potential biases probably had a limited effect on our results. Overall, stratifying risk using a composite scoring system specifically catered to the spinal oncology population may be a reasonable approach to prognosticating for these patients, and specifically for deciding whether a more sophisticated wound closure technique performed by a multidisciplinary surgical team may be the superior wound closure option for individual cases. Such complex wound care may be especially important for yet unidentified subgroups of patients, like those exposed to longer hospital stays and prolonged periods of stasis.

Conclusions

To our knowledge, the present study is the first to compare wound outcomes specifically between patients who did or did not undergo complex plastic surgery closure of their posterior spine wound following spine tumor resection. By stratifying preoperative risk for this implicitly high-risk population, we were able to document the bias between cohorts in terms of likelihood of complication and demonstrate the mitigation of this risk by the complex plastic surgery closure strategy. At other spinal oncology centers with similar resources, complex plastic surgery wound closure via flap mobilization should be considered in patients with neoplastic spinal disease and multiple types of baseline risk factors. While we provide strong

preliminary evidence that the identified risk factors and categorical stratification presented are indeed associated with wound complication, these data should be further validated in future studies in order to derive a risk scoring system for wound outcome prediction for this population.

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Disclosures

Dr. Oyelese reports being a consultant for Brainlab.

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Conception and design: Leary, Boyajian, Syed, Oyelese, Woo, Gokaslan, Fridley. Acquisition of data: Leary, DD Liu, Boyajian, Crozier. Analysis and interpretation of data: Leary, DD Liu, Syed, Crozier, Oyelese, Woo, Gokaslan, Fridley. Drafting the article: Leary, DD Liu, Fridley. Critically revising the article: Leary, DD Liu, Boyajian, Syed, Camara-Quintana, Niu, Svokos, Oyelese, PY Liu, Woo, Gokaslan, Fridley. Reviewed submitted version of manuscript: Leary, Syed, Woo, Gokaslan, Fridley. Approved the final version of the manuscript on behalf of all authors: Leary. Statistical analysis: Leary, DD Liu. Administrative/technical/material support: Camara-Quintana, Niu, Svokos, Crozier, Oyelese, PY Liu, Woo, Gokaslan, Fridley. Study supervision: Syed, Camara-Quintana, Niu, Svokos, Oyelese, PY Liu, Woo, Gokaslan, Fridley.

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