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Decompression surgery for spinal metastases: a systematic review

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OBJECTIVE The aim of this study was to systematically review the literature on reported outcomes following decompression surgery for spinal metastases.

METHODS The authors conducted MEDLINE, Scopus, and Web of Science database searches for studies reporting clinical outcomes and complications associated with decompression surgery for metastatic spinal tumors. Both retrospective and prospective studies were included. After meeting inclusion criteria, articles were categorized based on the following reported outcomes: survival, ambulation, surgical technique, neurological function, primary tumor histology, and miscellaneous outcomes.

RESULTS Of the 4148 articles retrieved from databases, 36 met inclusion criteria. Of those included, 8 were prospective studies and 28 were retrospective studies. The year of publication ranged from 1992 to 2015. Study size ranged from 21 to 711 patients. Three studies found that good preoperative Karnofsky Performance Status (KPS ≥ 80%) was a significant predictor of survival. No study reported a significant effect of time-to-surgery following the onset of spinal cord compression symptoms on survival. Three studies reported improvement in neurological function following surgery. The most commonly cited complication was wound infection or dehiscence (22 studies). Eight studies reported that preoperative ambulatory or preoperative motor status was a significant predictor of postoperative ambulatory status. A wide variety of surgical techniques were reported: posterior decompression and stabilization, posterior decompression without stabilization, and posterior decompression with total or subtotal tumor resection. Although a wide range of functional scales were used to assess neurological outcomes, four studies used the American Spinal Injury Association (ASIA) Impairment Scale to assess neurological function. Four studies reported the effects of radiation therapy and local disease control for spinal metastases. Two studies reported that the type of treatment was not significantly associated with the rate of local control. The most commonly reported primary tumor types included lung cancer, prostate cancer, breast cancer, renal cancer, and gastrointestinal cancer.

CONCLUSIONS This study reports a systematic review of the literature on decompression surgery for spinal metastases. The results of this study can help educate surgeons on the previously published predictors of outcomes following decompression surgery for metastatic spinal disease. However, the authors also identify significant gaps in the literature and the need for future studies investigating the optimal practice with regard to decompression surgery for spinal metastases.

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KEY WORDS spinal metastases; decompression; spinal cord compression; survival; ambulation

The spine is the most common site of bony metastases, with 50% of all skeletal metastases occurring in the spine.[9,14] Among patients whose cause of death is malignant neoplasm, an estimated 30.6% have spinal metastases based on microscopic examination.[27] Certain primary tumors, such as lung, breast, and prostate, have a higher frequency of metastases to the spinal column.[44]

Spinal cord compression is a common complication among patients with spinal metastases. Metastatic epidural spinal cord compression (MESCC) has been reported in

ABBREVIATIONS ASIA = American Spinal Injury Association; ECOG = Eastern Cooperative Oncology Group; EORTC = European Organisation for Research and Treatment of Cancer; EORTC QLQ-BM22 = EORTC Bone Metastases module; EORTC QLQ-30 = Quality of Life questionnaire; KPS = Karnofsky Performance Status; MESCC = metastatic epidural spinal cord compression; PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analyses; PSA = prostate-specific antigen; RR = risk ratio.

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5%–10% of all cancer patients.[26] Spinal cord compression can cause disability and significantly impair quality of life.[42] Although some patients with spinal metastases can be treated nonoperatively, patients who present with spinal cord compression often require surgical intervention to preserve neurological function.[14]

Decompression surgery is the standard surgical technique used to treat metastatic disease of the thoracic and lumbar spine.[10] Location of metastatic disease determines the approach for decompression surgery. A ventral or dorsal approach, or both, can be used in the cervical, thoracic, and lumbar spine, depending on several factors. These include location of compression, goals of reconstruction if necessary, type of tumor, surgeon expertise, and patient-specific factors (e.g. comorbidities of body habitus).[8]

Although outcomes following decompression surgery have been reported in the literature for 5 decades, a systematic review of predictors of outcome following decompression surgery for spinal metastases has not been performed. The present study systematically reviews the current literature and examines reported outcomes following decompression surgery for spinal metastases. Specifically, we highlight predictors of survival and predictors of ambulation, as well as surgical techniques, neurological function outcomes, primary tumor histology outcomes, and miscellaneous outcomes.

Methods

Study Search

A systematic review was conducted in accordance with the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). We conducted database searches of MEDLINE, Scopus, and Web of Science using the following search algorithm: (decompr* OR separat*) AND (spine or spina*) AND metasta* AND (surge* OR surgi*). This search returned 4148 citations (Fig. 1). The search period ended on January 22, 2016.

Inclusion and Exclusion Criteria

Clinical studies reporting outcomes of decompression surgery for spinal metastases were included within the study. Animal, in vitro, biomechanical, non–English language studies, book chapters, and case reports (defined as $n < 10$) were excluded. Due to the limited amount of data available, both retrospective and prospective studies were included.

Data Collection

Two reviewers (D.B. and K.P.) independently evaluated the initial 4148 retrieved citations. After removing 1914 duplicates, the titles and abstracts of 2234 publications were screened.[24] Of these studies, 2119 citations did not meet the inclusion criteria. The full text of the remaining 115 articles was assessed. This resulted in 36 eligible articles included in the final analysis. The following data were collected from the eligible articles: publication year, study type, number of patients, primary cancer histology, and outcomes reported. We assessed the level of evidence in the included articles using the Oxford Centre for Evidence Based Medicine Level of Evidence 2 classification system (http://www.cebm.net/ocebm-levels-of-evidence/). The risk of bias was not assessed because most included studies were retrospective case series that have strong inherent bias. Following initial review, studies were categorized into one or more of the following categories: predictors of survival, predictors of ambulation, surgical technique, neurological function, primary tumor histology, and miscellaneous outcomes.

Results

Study Characteristics

A total of 36 studies met inclusion and exclusion criteria. Of the 36 included studies, 8 were prospective studies and 28 were retrospective studies. The year of publication ranged from 1992 to 2015. Study size ranged from 21 to 711 patients. Data extracted from these reports are presented in Tables 1–6.

Predictors of Survival

Nineteen studies reported predictors of survival for patients with spinal metastases who underwent decompression surgery (Table 1).[2,3,5,7,15,18,19,21,25,28,30–32,34,35,37,38,40,43] Of these, 16 studies were retrospective; 1 was a longitudinal observational study; 1 was a randomized, multiinstitutional, nonblinded trial; and 1 was a semiprospective study that included both retrospectively and prospectively collected data. Surgical interventions included decompression with and without instrumentation and radiotherapy. Primary histology of tumors varied widely; however, prostate cancer (14 studies), lung cancer (13 studies), breast cancer (10 studies), and renal cancer (6 studies) were commonly reported in the included studies.

In a multivariable analysis of 105 patients with predominantly lung cancer as the primary tumor site, Chong et al.[5] found that a limited number (< 3 levels) of spinal metastases and postoperative adjuvant therapy (local irradiation only, chemotherapy only, or irradiation and systemic chemotherapy) were associated with increased survival (HR of 0.53 and 0.48, respectively, both $p < 0.05$). Padalkar et al.[28] studied 102 patients and found that metastases to internal organs ($p < 0.001$) and increased number of extraspinal bony metastases ($p < 0.01$) were significantly associated with worse odds of survival. In a longitudinal observational study, Park et al.[31] used a multivariable analysis to find that time to neurological deficit (risk ratio [RR] 2.28, $p = 0.02$), postoperative chemotherapy (RR 6.58, $p < 0.001$), and postoperative Eastern Cooperative Oncology Group (ECOG) performance status (RR 2.73, $p = 0.04$) were independent predictors of increased survival time. No study reported a significant effect of time-to-surgery following the onset of spinal cord compression symptoms on survival.[36] Quraishi et al.[36] reported that there was no significant difference between 3 groups treated with surgery within 24 hours, between 24 and 48 hours, and over 48 hours from acute presentation of neurological symptoms with respect to survival ($p = 0.99$). Finally, in a randomized, multiinstitutional, nonblinded trial, Patchell et al.[32] found that surgical treatment followed by radiotherapy compared with radiotherapy alone resulted

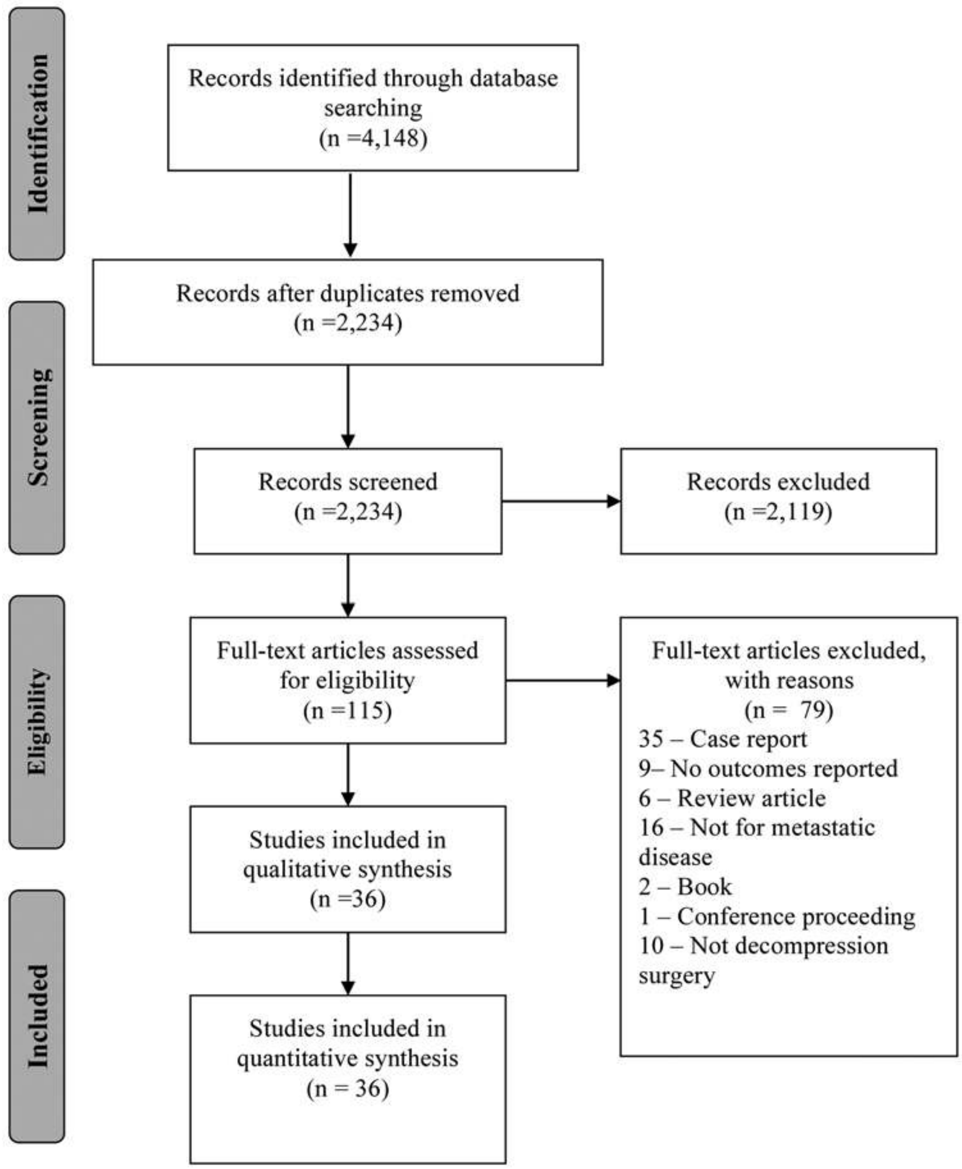

FIG. 1. PRISMA flow diagram for selection of studies based on inclusion criteria during systematic review.

in increased median survival time (126 days vs 100 days, respectively; RR 0.6, $p = 0.03$).

Several studies established scoring systems for prediction of survival following decompression surgery for various primary tumor sites. Crnalic et al.[7] established a scoring system for prediction of survival following decompression surgery based on the results of survival analyses of patients with prostate cancer metastatic to the spine. The authors included the hormone status of patients' prostate cancer, preoperative Karnofsky Performance Status (KPS), evidence of visceral metastasis, and preoperative serum prostate-specific antigen (PSA) in calculating the new prediction score.[7] The authors found that hormone status was strongly associated with survival in their patients as well as in 2 other studies of spinal cord compression in patients with prostate cancer. Consequently, the authors assigned maximal weight to hormone status in their score.[7] Additionally, the authors noted that KPS was the strongest predictor of survival in the their hormone-refractory patients.[7]

Lei et al.[21] sought to establish a scoring system for survival and functional outcome among patients undergoing posterior decompression surgery for lung cancer metastatic to the spine. The authors found that preoperative ambulatory status ($p < 0.01$), visceral metastases ($p < 0.001$), and time to developing motor deficits ($p < 0.001$) were significant predictors of survival and were therefore included in the scoring system.[21] In a separate study, Lei et al.[19] also created a scoring system to predict survival prognosis among patients with metastatic non–small cell lung cancer causing spinal cord compression who underwent surgical decompression. The authors included the following components as part of their scoring system: ECOG performance status ($p = 0.02$), number of involved verte-

TABLE 1. Predictors of survival

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Survival Data
Bakker et al., 2014	Retrospective review	3	21		Decompression surgery	Kidney		Univariate analysis: Cervical localization: HR 43.7, 95% CI 2.2–866; p = 0.01; curative intent: HR 0.3, 95% CI 0.1–0.9; p = 0.03; Frankel Grade C/D vs E: HR 3.2, 95% CI 1.05–9.49; p = 0.04; Motzer intermediate: HR 13.46, 95% CI 1.63–111; p = 0.01 (reference group Motzer favorable risk); high risk: HR 38.4, 95% CI 3.42–431; p = 0.003 (reference group Motzer favorable risk) Multivariable analysis: Motzer intermediate HR 17.4, 95% CI 1.82–166; p = 0.01; high risk HR 39.3, 95% CI 3.10–499; p = 0.005
Chaichana et al., 2009	Retrospective review	3	114	58	Decompression surgery	Lung (27); breast (26); prostate (20); kidney (21); GI (13); melanoma (7)	Wound dehiscence 10%; postop CSF leaks requiring operative intervention 3%; epidural hematoma requiring operative intervention 1%; periop death 3%	Lung vs breast vs prostate vs kidney vs GI vs melanoma median survival (mos): 4.3 vs 21 vs 3.8 vs 19.8 vs 5.1 vs 40.9 Breast cancer group lived significantly longer after surgery than patients w/ primary lung (p = 0.002), prostate (p = 0.004), or GI (p = 0.01) cancer Patients w/ primary kidney cancer lived significantly longer than patients w/ lung (p = 0.001), prostate (p = 0.006), or GI (p = 0.02) cancer Patients w/ melanoma lived significantly longer than patients w/ lung (p = 0.0006), prostate (p = 0.03), or GI cancer (p = 0.05)
Chong et al., 2012	Retrospective observational study	3	105	58.3	Single-stage PDS, corpectomy	Lung cancer (43%); hepatobiliary cancer (25%); CRC (6.7%); breast cancer (3.8%); stomach cancer (3.8%); cervical cancer (2.9%); esophageal cancer (2.9%); kidney (1.9%); thyroid cancer (1.9%); gingival cancer (1); melanoma (1); mesothelioma (1); mixed germ cell tumor (1); osteosarcoma (1); prostate cancer (1); sarcoma (1); thymic cancer (1); undifferentiated carcinoma (1)	Surgical complications (11); CSF leakage (4); postop epidural hematoma (4); wound dehiscence (2); pneumothorax (1)	Median OS of patients after surgery: 6 mos 1-yr survival rate: 34%; 2-yr survival rate: 14% Factors affecting patient's OS significant in univariate analysis only (p < 0.05): Age (<60 vs ≥60) yrs: HR 1.64, 95% CI 1.00–2.68; p = 0.05 Primary cancer (rapid vs moderate & slow): HR 0.49, 95% CI 0.27–0.92; p = 0.03 Visceral metastases (yes vs no): HR 0.58, 95% CI 0.35–0.96; p = 0.04 Factors affecting patient's OS significant in both univariate & multivariate analyses (p <0.05): No. of spinal metastases (<3 vs ≥3): HR univariate 2.28, 95% CI 1.33–3.90; p <0.01. HR multivariate 1.94, 95% CI 1.10–3.43; p = 0.02 Postop adjuvant therapy (yes vs no): HR univariate 3.69, 95% CI 2.10–6.49; p <0.01. HR multivariate 3.23, 95% CI 1.80–5.77; p <0.01

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TABLE 1. Predictors of survival

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Survival Data
Crnalic et al., 2012	Retrospective review	3	68	Median hormone naive: 77; median hormone refractory: 71	Posterior decompression (42); posterior decompression & stabilization w/ pedicle screws or w/ pedicle screws & hooks (26)	Prostate	Systemic complications (11); local complications (11); systemic & local (2)	HR single regression: KPS (80–100 vs 50–70): HR 4.66, 95% CI 1.9–11.44; p = 0.001 Visceral metastases (absent vs present): HR 2.52, 95% CI 1.35–4.7; p = 0.004 Serum PSA (<200 vs ≥200): HR 2.08, 95% CI 1.13–3.82; p = 0.019 Age (<71 vs ≥71 yrs): HR 0.95, 95% CI 0.55–1.65; p = 0.85; Time to primary Dx (<36 vs ≥36 mos): HR 0.96, 95% CI 0.55–1.67; p = 0.88 Ambulatory vs nonambulatory: HR 1.5, 95% CI 0.67–3.37; p = 0.32 Multiple regression: KPS (80–100 vs 50–70): HR 3.97, 95% CI 1.57–10.04; p = 0.004 Visceral metastases (absent vs present): HR 1.8, 95% CI 0.93–3.46; p = 0.08 Serum PSA (<200 vs ≥200): HR 1.47, 95% CI 0.79–2.75; p = 0.22 Age (<71 vs ≥71 yrs): HR 0.89, 95% CI 0.49–1.64; p = 0.72 Time to primary Dx (<36 vs ≥36): HR 1.29, 95% CI 0.70–2.39; p = 0.41 Ambulatory vs nonambulatory: HR 0.9, 95% CI 0.38–2.17; p = 0.82

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TABLE 1. Predictors of survival

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Survival Data
Ju et al., 2013	Retrospective review	3	27 (31 procedures)	Median 65	Decompression surgery	Prostate (27)	16 complications occurred in 35% (11/31 procedures); death w/in 30 days of surgery of an unreported cause (1); acute inpatient rehabilitation after surgery (14) 52% Major complications: instrumentation failure requiring reop; pneumothorax; spinal hematoma; small-bowel obstruction; deep wound infection; GI bleeding necessitating nasogastric tube placement; pulmonary embolism Minor complications: durotomy status after intraop closure; wound infection responsive to treatment w/ antibiotics; UTI; pleural effusion; thrombocytopenia & anemia requiring multiple postop transfusions; transient lt recurrent laryngeal nerve dysfunction; instrumentation failure Significant factors associated w/ increased incidence of complications Age <65 yrs: OR 0.3, 95% CI 0.003–0.4; p = 0.005 Instrumentation spanning ≥7 spinal levels: OR 7.0, 95% CI 1.2-41.4; p = 0.03	Median survival time of all patients after 1st spinal surgery was 10.2 mos, 95% CI 5.0–15.8 mos Significant univariate predictors of survival: Preop PSA ≥150: HR 3, 95% CI 1–9.4; p = 0.05 Previous prostatectomy: HR 3.0, 95% CI 1.1–8.5; p = 0.04 Significant univariate & multivariate predictor of survival: Univariate: preop KPS ≥80%: HR 3.3, 95%CI 1.1–9.9; p = 0.03 Multivariate: preop KPS ≥80%: HR 6.1, 95% CI 1.3–28.5); p = 0.02

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TABLE 1. Predictors of survival

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Survival Data
Laufer et al., 2010	Retrospective review	3	39	Median 61	Decompression surgery	Renal (12); prostate (7); neuroendocrine (4); head & neck (4); GI (4); sarcoma (2); thyroid (2); breast (1); cervical SCC (1); lymphoma (1); melanoma (1)	Major surgical complication rate (5%)	Median time btwn 1st op & 1st reop at same spinal level due to tumor recurrence was 8.3 months. 29 patients (74%) died by the time study was conducted. Median survival time after 1st op performed at level of interest was 21.6 mos (95% CI 16.5–34.2 mos), & after 2nd op it was 12.4 mos (95% CI 7.5–20.0 mos). The median survival time after last op was 9.1 mos (95% CI 6.4–13.7 mos). The median postop survival time did not significantly decrease w/ an increasing no. of recurrences. In patients w/ prostate cancer, median survival after 1st reop was 8.2 mos (95% CI 3.8–14.1 mos) & 6.0 mos after last operation (lower 95% confidence limit 2.4 mos—upper bound after 1st reop could not be estimated since >50% of these patients were ambulatory at the conclusion of the study (lower 95% confidence limit 5.7 mos). In patients w/ renal cancer, outcomes were even more favorable. The median survival time after 1st reop was 13.7 mos (95% CI 6.4–21.8 mos), & after last operation was 9.2 mos (lower 95% confidence limit 6.3 mos—upper bound could not be calculated).
Lei et al., 2015[21]	Retrospective review	3	73 test group (n = 37); validation group (n = 36)	Median 57	Posterior decompression & spine stabilization	Lung cancer	Postop wound infections (2); death w/in 4 wks (1)	Test group: univariate analysis of preop factors for survival in lung cancer patients w/ MSCC at 6 & 12 mos: Ambulatory vs nonambulatory at 6 mos: 67% vs 33%; at 12 mos: 31% vs 13% (p = 0.0054) ECOG performance status (1–2 vs 3–4) at 6 mos: 73% vs 14%; at 12 mos 35% vs 0% (p = 0.0002) No. of involved vertebrae (1–2 vs ≥3) at 6 mos: 78% vs 22%; at 12 mos: 36% vs 7% (p = 0.0028) Visceral metastases (no vs yes), at 6 mos: 77% vs 26%; at 12 mos 36% vs 11% (p = 0.0118) Time to developing motor deficits (≤14 vs >14 days) at 6 mos 28% vs 72%; 6% vs 40% at 12 mos (p ≤ 0.0001) Median OS was 6.2 mos (95% CI, 2.9–8.8 mos) in the test group & 6.0 mos (95% CI 4.3–7.9 mos) in the validation group.

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TABLE 1. Predictors of survival

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Survival Data
Lei et al., 2015[19]	Retrospective review	3	64	Median 57	Posterior decompression & spine stabilization	Non–small cell lung cancer		Univariate analysis for survival (simple Cox regression): Preop ambulatory status: HR 2.24, 95% CI 1.3–3.86; p = 0.004 ECOG performance: OR 2.78, 95% CI 1.54–5.02; p < 0.001 No. of involved vertebrae: HR 2.46, 95% CI 1.39–4.35; p = 0.002 Visceral metastases vs none: HR 2.29, 95% CI 1.33–3.94; p = 0.003 Time to develop motor deficits: HR 3.44, 95% CI 1.9–6.22; p <0.001 Multivariate analysis for survival (multiple Cox regression): Preop ambulatory status excluded ECOG performance: HR 2.18, 95% CI 1.15–4.16; p = 0.017 No. of involved vertebrae: HR 2.05, 95% CI 1.11–3.76; p = 0.021 Visceral metastases vs none: HR 2, 95% CI 1.10–3.62; p = 0.022 Time to develop motor deficits: HR 2.7, 95% CI 1.45–5.03; p = 0.002 For all patients, the overall median survival time was 6.3 mos (95% CI 4.5–7.4 mos), 6-mo & 12-mo survival rates were 52.6 & 23%, respectively.
Moulding et al., 2010	Retrospective review	3	21	52.9	Surgical decompression & instrumentation for high-grade, epidural, spinal cord compression from tumor, followed by single-fraction high-dose spinal radiosurgery (dose range 18–24 Gy, median 24 Gy)	Melanoma 5 (23.8%); renal cell 4 (19%); sarcoma 3 (14.3%); 1 angiosarcoma 1; leiomyosarcomas 2; colorectal carcinoma 2 (9.5%); thyroid 1 (4.8%); teratoma 1 (4.8%); hemangiopericytoma 1 (4.8%); cholangiocarcinoma 1 (4.8%); adenoid cystic carcinoma 1 (4.8%); hemangioma (epithelioid) 1 (4.8%); prostate 1 (4.8%)	Acute Grade 1 skin reactions (3); acute neuritic pain immediately after radiosurgical treatment (1); Grade 2 esophagitis (dysphagia, burning) (3); Grade 4 esophagitis (1)	Median survival time after adjuvant radiosurgery: 24 Gy: 310 days, 95% CI 169–NR 18 or 21 Gy: 180 days, 95% CI 146–NR All: 310 days, 95% CI 169–NR 1-yr risk of local failure according to radiosurgical dose group: 24 Gy: 6.3%, 95% CI (0–18.5%) 18 or 21 Gy: 20.0%, 95% CI (0–59%) All patients: 9.5%, 95% CI (0–22.3%)

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TABLE 1. Predictors of survival

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Survival Data
Padalkar & Tow, 2011	Retrospective review	3	102	Median 58.5	Decompression w/ instrumentation (in some)	Lung, osteosarcoma, stomach, bladder, esophagus, pancreas 20 (19.6%); liver, gallbladder, unidentified 6 (5.9%); others 30 (29.4%); kidney, uterus 10 (9.8%); rectum 3 (2.9%); thyroid, breast, prostate, carcinoid tumor 33 (32.4%)		Odds of 6-mo survival according to Tomita score: Score 0–3 OR 36.7, 95% CI 3.9–346.2; p = 0.002 Score 4–6 OR 26.2, 95% CI 2.9–239.5; p = 0.004 Score 7–8 OR 7 95% CI 0.8–61.1; p = 0.078 Median survival: KPS p < 0.001 Extraspinal bone metastases: p = 0.006 No. of vertebral levels involved: p = 0.08 Metastases to internal organ: p = 0.0002 Presence of spinal cord palsy: p = 0.1 Type of primary tumor: p = 0.9
Park et al., 2011	Retrospective review	3	103	54.6	Decompression & fixation	Breast (7); colon (6); hepatobiliary (8); kidney (11); liver (15); lung (23); lymphoma (1); multiple myeloma (12); prostate (1); stomach (6); thymus (2); thyroid (2); uterus (1); bladder (1); unknown origin (7)	Surgical complications requiring 2nd op, such as wound infections, extensive bleeding, & symptomatic recurrence 9.7% (10)	Significant predictors of OS (multivariate Cox proportional hazard model): Primary origin w/ good prognosis: HR 0.627, 95% CI 0.479–0.899; p = 0.039) High Tokuhashi score: HR 0.524, 95% CI 0.335–0.820; p = 0.005) Postop ambulation, w/ or w/o aid: HR 1.59, 95% CI 1.021–2.645; p = 0.048
Park et al., 2015[31]	Prospective observational study	2	50	58	Wide decompression surgery + fixation procedure	Non–small cell lung cancer	Major complications 34.0% (17/50), 30-day mortality rate 10.0% (5/50)	Median survival after surgery: Time from neurological deficit ≥72 hrs: 3.1, 95% CI 1.9–4.3; p = 0.002 Responsiveness to chemo: progressive disease 2.4, 95% CI 1.4–3.4; p < 0.001 Chemo postop 9.9, 95% CI 6.8–13; p < 0.001 Preop ambulatory status 9.9 95% CI 6.1–13.7; p = 0.031. Median OS time after surgery was 5.2 mos, 95% CI 2.36–5.84. Estimated survival rates at 3, 6, & 12 mos were 66.0%, 49.4%, & 22.4%, respectively.

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TABLE 1. Predictors of survival

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Survival Data
Patchell et al., 2005[32]	Randomized, multiinstitutional, nonblinded trial	1	101	Median 60 for both groups	Surgery followed by RT (50); RT alone (51)	RT group/surgery group: Lung (13), (13); breast (6), (7); prostate (10), (9); other genitourinary (6), (5); GI (4), (2); melanoma (3), (3); head & neck (2), (1); unknown (3), (5); other (4), (5)	Wound infections (3); failure of fixation requiring additional surgery (1); extended hospital stays (>20 days) occurred in 7 patients in the surgery group & 11 in the RT group	Surgical treatment resulted in significant differences in: Maintenance of continence: RR 0.47, 95% CI 0.25–0.87; p = 0.016 Maintenance of ASIA grade: RR 0.28, 95% CI 0.13–0.61; p = 0.001 Maintenance of Frankel grade: RR 0.24, 95% CI 0.11–0.54; p = 0.0006 Survival time: RR 0.6, 95% CI 0.38–0.96; p = 0.033 30-day mortality rates were 6% in surgery group & 14% in RT group (p = 0.32). At Day 30 after treatment, % of patients w/ Frankel grades at or above study entry level was significantly (p = 0.0008) higher in surgery group than in RT group (91% vs 61%).
Quraishi et al., 2013[35]	Semi-prospective study	2	201	61	Decompression & stabilization	Breast (29); hematological (28); renal (26); prostate (26); lung (23); GI (11); sarcoma (9); others (49)	Overall complication rate 19% (39/201); wound infection (15); included chest infection (8); neurological worsening (4); failure of the metal work (4); pulmonary embolization (3)	Group 1 vs 2 vs 3 neurological outcomes postop (Frankel Grades A–E): A: 2 vs 6 vs 0, p = 0.34 for 1 vs 2 B: 6 vs 2 vs 1, p = 0.70 for 2 vs 3 C: 20 vs 9 vs 2, p = 0.001 for 1 vs 3 D: 33 vs 35 vs 10 E: 23 vs 31 vs 21 Mean survival days 84 vs 83 vs 34, p = 0.001
Quraishi et al., 2015[34]	Retrospective cohort review	3	101	64.7	Decompression w/ & w/o stabilization	Breast (14); lung (10); prostate (21); renal (11); myeloma (1); GI (8); other (25); unknown (11)	Group 1 (low-grade compression) vs Group 2 (high grade) Overall complication rate Group 1 vs 2: 25% vs 42.6% (p = 0.12) Postop wound infection Group 1 vs 2: 2.5% vs 16%	Group 1 (low-grade compression) vs Group 2 (high grade) Overall median survival: 326 days Mean survival Group 1 vs 2: 444 vs 412 days (p = 0.62) Median survival Group 1 vs 2: 376 vs 326 days
Rades et al., 2012	Retrospective review	3	126		Surgery+RT (42); RT alone (84)	Breast cancer (15); prostate cancer (30); myeloma/lymphoma (18); lung cancer (24); other tumors (39)	Wound infections, extensive bleeding, postop pneumonia, & pulmonary embolism in 7 patients (14%) of the Surgery+RT group	Survival rates for the entire cohort were 55% at 6 mos & 42% at 12 mos. Improved survival was associated with the following significant variables: female sex (p = 0.012), better ECOG performance status (p <0.001), favorable primary tumor type (p <0.001), involvement of only 1–2 vertebrae (p <0.001), absence of other bone metastases (p <0.001), absence of visceral metastases (p < 0.001), ambulatory status prior to therapy (p <0.001), slower development of motor deficits (p <0.001) & longer course of RT (p <0.001).

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TABLE 1. Predictors of survival

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Survival Data
Rades et al., 2011	Retrospective review	3	67		Surgery+RT	Non–small cell lung cancer (36); CUP origin (13); RCC (9); CRC (9)	Surgical complications such as wound infections requiring a 2nd surgery, extensive bleeding, postoperative pneumonia, & pulmonary embolism occurred in 9 patients (13%) in the Surgery+RT group.	Univariate analysis survival: Surgery+RT vs RT at 6 mos: 50 vs 46; at 12 mos: 38 vs 24 (p = 0.2) ≤60 vs >60 yrs at 6 mos: 49 vs 45; at 12 mos: 26 vs 31 (p = 0.85) Female vs male at 6 mos: 36 vs 50; at 12 mos: 29 vs 28 (p = 0.8) ECOG 1–2 vs 3–4 at 6 mos: 78 vs 27; at 12 mos: 57 vs 10 (p <0.001) NSCLC vs CUP vs RCC vs CRC at 6 mos: 41 vs 56 vs 59 vs 44; at 12 mos: 27 vs 20 vs 39 vs 34 (p = 0.57) No. of involved vertebrae 1–2 vs ≥3 at 6 mos: 56 vs 40; at 12 mos: 40 vs 19 (p = 0.003) Other bone metastases no vs yes at 6 mos: 62 vs 36; at 12 mos: 42 vs 17 (p <0.001) Visceral metastases no vs yes: at 6 mos: 78 vs 17; at 12 mos: 42 vs 17 (p <0.001) Not ambulatory vs ambulatory: at 6 mos, 19 vs 63; at 12 mos, 10 vs 38 (p <0.001) Time development of motor symptoms 7 vs >7 days: at 6 mos, 17 vs 68; at 12 mos 5 vs 44 (p <0.001) Interval btwn surgery & RT ≤2 vs >2 wks: at 6 mos, 53 vs 41; at 12 mos, 41 vs 27 (p = 0.36) The survival rates for the entire cohort were 47% at 6 mos & 28% at 12 mos. The treatment regimen was not significantly associated w/ survival (p = 0.20).
Spencer et al., 2014	Retrospective review	3	711		Decompression &/or radiation	Prostate		Predictor of surgery+RT vs no treatment: Age 70–74 vs 65–69: OR 0.52 95% CI 0.28–0.96 Age 75–79 vs 65–69: OR 0.68, 95% CI 0.34–1.33 Age 80–84 vs 65–69: OR 0.23, 95% CI 0.10-0.55 Age ≥85 vs 65–69: OR 0.06, 95% CI 0.01–0.27 Unknown tumor grade: OR 2.30, 95% CI 1.15–4.62 ≥2 vs 0 comorbidities: OR 0.4, 95% CI 0.20-0.78

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TABLE 1. Predictors of survival

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Survival Data
Vanek et al., 2015[43]	Retrospective review	3	166	62	Decompression	Kidney (30); lung (19); breast (25); hemoblastoses (45); prostate (20); rectum (9); thyroid gland (3); thymoma (3); GI (1); gynecology (1); carcinoid (1); others (9)	Overall complication rate: 20% (34); postop hematoma (6); deterioration in Frankel grade (4); wound healing complication (13); failure of instrumentation (4); any other medical complication (7); symptomatic tumor recurrence 6% (10)	Age (per unit survival): HR 1.02, 95% CI 1.00–1.04; p = 0.017 Frankel A–C: HR 2.03, 95% CI 1.30–3.15; p = 0.002 Tokuhashi <8: HR 3.49, 95% CI 1.97–6.20; p < 0.001 Tokuhashi 9–11: HR 1.61, 95% CI 0.94–2.76; p = 0.081

chemo = chemotherapy; CRC = colorectal cancer; CUP = cancer of unknown primary; Dx = diagnosis; GI = gastrointestinal; OS = overall survival; MSCC = metastatic spinal cord compression; NSCLC = non–small cell lung carcinoma; NR = not reached; PDS = posterior decompression and stabilization; RCC = renal cell carcinoma; RT = radiotherapy; SCC = small cell carcinoma; UTI = urinary tract infection.

* Presented as the mean, unless indicated otherwise.

brae (p = 0.02), visceral metastases (p = 0.02), and time to developing motor deficits (p < 0.01).

Three studies found that good preoperative KPS (≥ 80%) was a significant predictor of survival.[7,15,28] Padalkar and Tow[28] determined that a high preoperative KPS was significantly associated with increased median survival times (median survival 13 months [95% CI 10.0–16.0 months]) compared with a moderate (50%–70%) KPS (median survival 4 months [95% CI 2.0–6.0 months]) and a poor (10%–40%) KPS (median survival 2 months [95% CI 1.0–3.0]) in patients treated with decompression and instrumentation for spinal metastases (p < 0.001).

Two studies investigated survival based on Tokuhashi scores. Park et al.[30] reported that the median overall survival times were significantly longer in patients with high (9–11) preoperative Tokuhashi scores (15.0 months [95% CI 9.3–20.7 months]) relative to patients with low (0–8) preoperative Tokuhashi scores (9.0 months [95% CI 7.5–10.5 months]) (p < 0.01). Similarly, Vanek et al.[43] found that Tokuhashi scores were a significant and independent predictor of survival following decompression surgery for spinal metastases (p < 0.001).

One study found an association between Motzer scores and survival. Bakker et al.[2] determined that among patients with renal cell carcinoma metastatic to the spine, intermediate (HR 17.4 [95% CI 1.82–166], p = 0.01) and high (HR 39.3 [95% CI 3.10–499, p < 0.01]) Motzer scores were significantly associated with worse odds of survival (median survival of 6 months and 2 months, respectively).

Predictors of Ambulatory Status or Motor Function

Sixteen studies reported predictors of postoperative ambulatory status and motor function following decompression surgery for spinal metastases (Table 2).[1,3,4,13,16–20,22,29–31,33,38,39] Fifteen studies were retrospective, and one was a longitudinal observational study. Eleven studies[1,3,4,18,20,22,29–31,33,39] reported outcomes following surgery alone, and 5 studies[13,16,17,19,38] reported the effects of decompression surgery with radiotherapy. Primary tumor sites included lung (15 studies), breast (13 studies), prostate (12 studies), gastrointestinal (8 studies), and renal (4 studies).

Eight studies reported that preoperative ambulatory or preoperative motor status was a significant predictor of postoperative ambulatory status (Table 2).[4,13,16,20,29–31,33] Chaichana et al.[4] reported that preoperative ability to walk (RR 2.3 [95% CI 1.3–4.4], p < 0.01) was a positive predictor of postoperative ambulatory status, whereas pathological compression fracture of the vertebral body (RR 0.5 [95% CI 0.2–0.9], p < 0.01) was a negative predictor of postoperative ambulatory status.[4] Kondo et al.[16] found that visceral metastases to vital organs (p < 0.01), primary renal tumors (p = 0.04), severe preoperative paralysis (p < 0.0001), and poor preoperative performance status (p < 0.0001) were significant negative predictors of postoperative ambulatory status among patients who received intraoperative radiotherapy combined with posterior decompression and stabilization.[16] Ghogawala et al.[13] determined that lower preoperative Frankel grade was a significant predictor of postsurgical ambulatory status (p < 0.01). Lei et al.[20] demonstrated that metastasis to the lumbar spine (OR 1.9 [95% CI, 1.1–3.3], p = 0.02), better preoperative

TABLE 2. Predictors of ambulatory status or motor function

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Histology	Complications	Ambulation Outcomes
Abel et al., 2008	Retrospective review	3	34	60	PDS	Prostate gland carcinoma (7); renal carcinoma (4); lung carcinoma (6); plasmacytoma (5); breast carcinoma (3); other (8); unknown (1)	Deep vein thrombosis (2); lung embolism (1); upper GI bleeding (1); pneumonia associated w/ lung atelectasis (1); deep wound infection necessitating revision surgery (1)	At admission, 3 patients were able to walk; 31 were not ambulatory. 4 patients regained ambulation; in 2 patients who could walk this function was preserved. 1 patient lost his ability to walk after surgery due to intraspinal hemorrhage.
Chaichana et al., 2009	Retrospective review	3	114	58	Decompressive surgery	Lung (27); breast (26) prostate (20); kidney (21); GI (13); melanoma (7)	Wound dehiscence 10%; postop CSF leaks requiring operative intervention 3%; epidural hematoma requiring operative intervention 1%; periop death 3%	Ambulatory outcomes (lung vs breast vs prostate vs kidney vs GI vs melanoma): Ambulatory postop (%): 89 vs 81 vs 70 vs 76 vs 85 vs 71 Maintained ambulation (%): 95 vs 90 vs 93 vs 94 vs 92 vs 80 Regained ambulation (%): 57 vs 0 vs 17 vs 20 vs 0 vs 50
Chaichana et al., 2008	Retrospective review	3	78	55.7 ambulatory preop; 57.3 nonambulatory preop	Decompression	Lung (19); breast (13); prostate (15); renal (10); thyroid (3); GI (4); sarcoma (6); other (8)	Ambulatory, nonambulatory: periop mortality 1% (2), 1% (4); wound dehiscence 1% (2), 3% (13); CSF leak 0% (0), 3% (13); retroperitoneal hemorrhage 1% (2), 0% (0); pseudomeningocele 1% (2), 0% (0)	Univariate analysis significant predictors of ambulation: Preop RT: RR 0.547, 95% CI 0.255–1.017; p = 0.06 Duration of Sx for <48 hrs: RR 2.147, 95% CI 1.103–1.463; p = 0.03 Metastatic prostate tumor: RR 0.529, 95% CI 0.275–1.148; p = 0.10 Thoracic component: RR 0.003, 95% CI 0.001–0.668; p = 0.01 Follow-up RT: RR 1.946, 95% CI 0.966–5.041; p = 0.06 Significant multivariate analysis predictors of ambulation: Ability to walk: RR 2.320, 95% CI 1.301–4.416; p <0.01 Pathological compression of fracture: RR 0.471, 95% CI 0.235–0.864; p = 0.01
Ghogawala et al., 2001	Retrospective review	3	85	55, 63, 62 (RT, RT/surgery, surgery/RT)	1) RT alone (23); 2) RT followed by surgery (28); 3) early surgery followed by RT (34)	Lung; breast; prostate; unknown; other	Major wound complications (13)	Because the Frankel grade on admission was a strong predictor of posttreatment ambulatory status (p = 0.006, Cochran-Armitage) & continence (p = 0.003), all analyses were stratified by Frankel grade. The odds for posttreatment ambulation & continence were higher when surgery was the initial treatment (ambulation: OR 3.8, 95% CI 1.06–14; p = 0.04; continence: OR 53.9, 95% CI 51.2–13; p = 0.03). The odds for a better neurological outcome during treatment also were higher when surgery was the initial treatment (OR 5.8, 95% CI 5 1.9–17; p = 0.0002).

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TABLE 2. Predictors of ambulatory status or motor function

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Histology	Complications	Ambulation Outcomes
Kondo et al., 2008	Retrospective review	3	96	Median 64	Posterior decompression & intraop irradiation posterior instrumentation (77)	Radioresistant tumors: large intestine/rectum (12); kidney (10); thyroid (6); liver (7) Radiosensitive tumors: breast (18); prostate (11); malignant lymphoma (4); myeloma (3); lung (10); esophagus (3); others (12)	Surgical complications 15%	Risk factors for postop ambulatory status: Kidney vs nonkidney site: $p = 0.04$ Visceral metastases: $p = 0.007$ Frankel A or B vs C: $p < 0.0001$ Preop performance 4 vs ≤3: $p < 0.0001$ Bone metastases other than spine: $p = 0.3$ Multiple spinal metastases ≥3, $p = 0.1$ Prior external RT, $p = 0.97$
Landmann et al., 1992	Retrospective review	3	127	Median 63	Decompressive laminectomy + postop irritation (127 cases); RT alone (26 patients) 17%	Prostate (39); breast (34); lung (18); lymphoma (9); unknown (8); kidney (7); myeloma (7); bladder (3); thyroid (3); miscellaneous (12)	Recurrence in original treatment 6% (8); recurrences w/in the original treatment field after irradiation alone 8% (2); rapid progression of pain & neurological deficit 27% (7/26) in patients who started therapy w/ RT	Motor function before & after laminectomy w/ postop irradiation (n = 127): No deficit before treatment: 96% vs 4% (no deficit after treatment vs mild deficit/ambulatory after treatment) Mild deficit (ambulatory) before treatment: 59% vs 39% vs 2% vs — (no deficit after treatment vs mild deficit/ambulatory after treatment vs paraparetic/not ambulatory after treatment vs paraplegic after treatment) Paraparetic (not ambulatory) before treatment: 26% vs 56% vs 16% vs 2% (no deficit after treatment vs mild deficit/ambulatory after treatment vs paraparetic/not ambulatory after treatment vs paraplegic after treatment) Paraplegic (not ambulatory) before treatment: — vs 56% vs 22% vs 22% (no deficit after treatment vs mild deficit/ambulatory after treatment vs paraparetic/not ambulatory after treatment vs paraplegic after treatment)

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TABLE 2. Predictors of ambulatory status or motor function

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Histology	Complications	Ambulation Outcomes
Laufer et al., 2010	Retrospective review	3	39	Median 61	Decompression surgery	Renal (12); prostate (7); neuroendocrine (4); head & neck (4); GI (4); sarcoma (2); thyroid (2); breast (1); cervical SCC (1); lymphoma (1); melanoma (1)	Major surgical complication rate 5%	5 patients were nonambulatory prior to their last operation, & their condition did not improve postop. Among the remaining 34 patients, 22 (65%) remained ambulatory at the time of death or at the time of last follow-up. Within this group, the patients remained ambulatory for 85% of the duration btwn the last operation & death (median 100%). Fourteen (48%) of the 29 patients who died were ambulatory until the time of death. Among the patients who lost the ability to ambulate prior to death, the median time btwn loss of ambulation & death was 1 mo (range 0–3 mos). 10 patients were alive at the time of analysis & 8 (80%) of them were ambulatory, w/ a median follow-up of 26 mos. Prior to the 1st reop, 36 patients had ECOG grades of 0–2, & 3 patients had ECOG grades of 3 or 4 (Table 3). Prior to their last operation, 31 patients (79%) were ASIA Grade E & 8 patients were ASIA Grade D. 38 patients had the same (30) or improved (8) ECOG grade after the last operation. 1 patient had a 2-point decline in his ECOG grade, which occurred after the 3rd operation. His postop course was complicated by a CSF leak that required a rotational flap and a postoperative malignant pleural effusion.
Lei et al., 2015	Retrospective review	3	95	Median 57	Posterior decompression & spine stabilization	Breast cancer (20); thyroid cancer (15); lung cancer (40); others (20)	Surgery-related complications 18.9% (18)	Motor function improvement univariate correlates: Non–cervical spine metastasis: p = 0.02 Favorable tumor type: p = 0.04 Ambulatory status before surgery: p <0.01 Better ECOG performance status: p <0.01 Absence of visceral metastasis: p <0.01 Longer interval btwn tumor diagnosis & surgery: p <0.01 Slower development of motor deficits: p <0.01 Administration of targeted therapy: p <0.01 Multivariate analysis of motor function: Analysis of motor function, metastatic location: OR 1.93, 95% CI 1.12–3.33; p = 0.02 Preop ambulatory status: OR 2.80, 95% CI, 1.17–6.71; p = 0.02 Time to motor deficit: OR 5.75, 95% CI 2.22–14.89; p <0.01

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TABLE 2. Predictors of ambulatory status or motor function

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Histology	Complications	Ambulation Outcomes
Lei et al., 2015	Retrospective review	3	64	Median 57	Posterior decompression & spine stabilization	Non–small cell lung cancer		Univariate analysis of preop variable on survival: Nonambulatory vs ambulatory at 6 mos: 64% vs 41%; at 12 mos 32% vs 14% (p = 0.003)
Majeed et al., 2012	Retrospective review	3	55	63	Anterior & posterior stabilization	Myeloma (11); breast cancer (9); lymphoma (8); lung cancer (7); renal cell cancer (7); prostate cancer (5); bladder cancer (3); melanoma (1); pancreatic cancer (1); esophageal cancer (1); endometrial cancer (1); carcinoma of the tongue (1)	Superficial wound infections (8)	Red group has KPS <50%, yellow group has scores 50–70%, green group >70%. 8/15 (53%) patients in red group achieved independent mobility status at 6 wks. Yellow group 13/20 (66%) achieved independent mobility at 6 wks. 3 deteriorated due to progressive tumors, 4 did not improve or deteriorate in green group. 15/20 (75%) maintained independent mobility status in patients <65 yrs. 10/30 had independent mobility status at presentation. At 6 wks, 21 improved to independent mobility status. Among patients >65 yrs, 11/25 (44%) were able to mobilize independently before surgery, while 14 (56%) achieved independent mobility at 6 wks postsurgery.
Park et al., 2011	Retrospective review	3	103	54.6	Decompression & fixation	Breast (7); colon (6); hepatobiliary (8); kidney (11); liver (15); lung (23); lymphoma (1); multiple myeloma (12); prostate (1); stomach (2); thyroid (2); uterus (1); bladder (1); unknown origin (7)	Surgical complications requiring 2nd surgery, such as wound infections, extensive bleeding, & symptomatic recurrence 9.7% (10)	Significant predictors of postop ambulation based on multivariate logistic regression: Postop ambulation w/ or w/o aid: OR 5.35, 95% CI, 1.57–18.17; p = 0.007 Hip flexion greater than Grade III: OR 6.23, 95% CI 1.29–7.35; p = 0.039

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TABLE 2. Predictors of ambulatory status or motor function

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Histology	Complications	Ambulation Outcomes
Park et al., 2015	Longitudinal observational study	2	50	58	Wide decompression surgery + fixation procedure	Non–small cell lung cancer	Major complications: (sepsis, pneumonia, lung abscess, neurological deterioration, inoperable wound dehiscence, disseminated intravascular coagulation, thromboembolism, total atelectasis, pleural effusion) 34.0% (17/50) Surgical complications: paraplegia (1); inoperable wound dehiscence (1); deep infection (1) Medical complications: (14) 28%, 9 (18%) of whom died 30-day mortality rate 10.0% (5/50)	Significant factors associated w/ postop nonambulatory status: >72 vs ≤72 hrs: OR 8.69, 95% CI 1.64–46.17; $p = 0.011$ Nonambulatory preop vs ambulatory: OR 17.7, 95% CI 1.55–203.10; $p = 0.021$
Park et al., 2013	Retrospective review	3	102	55	Decompression w/ pedicle screws	GI tract (10); hepatobiliary system (7); breast (19); lung (34); multiple myeloma (5); kidney (15); other (12)	Reexploration (7); symptomatic tumor recurrences (3); wound infections (2); postop hematoma (1); instrumentation failure (0); intraop bleeding (1)	Significant predictors of postop ambulation (multivariate logistic regression test): Preop ambulation: OR 21.1, 95% CI 8.71–72.5; $p < 0.001$ Preop motor power: OR 49.2, 95% CI 18.43–167.78; $p < 0.001$
Putz et al., 2014	Retrospective review from a prospectively gathered database	3	43	63.7	Decompression & additional posterior or posteroanterior stabilization	Lung (17); kidney (9); breast (10); prostate (7)	Wound infection 9%; gluteal pressures sores 5%; pulmonary embolism, thrombosis, dural leakage, subileus, gastritis, & hemorrhagic pleural effusion 14%	Significant preop factors influencing change in ambulation: Preop mobility: $p < 0.001$ Preop neurological status: $p < 0.001$ Type of operation: $p = 0.02$ Significant preop factors influencing change in mobility: Primary tumor: $p < 0.001$ Preop mobility: $p < 0.001$
Rades et al., 2012	Retrospective review	3	126		Surgery+RT (42); RT alone (84)	Breast cancer (15); prostate cancer (30); myeloma/lymphoma (18); lung cancer (24); other tumors (39)	Wound infections, extensive bleeding, postop pneumonia, & pulmonary embolism occurred in 7 patients (14%) of the surgery+RT group	Impact of potential prognostic factors on motor function: Time developing motor deficits before RT was significant (estimate 1.81, 95% CI 0.64–2.98; $p = 0.002$). The radiotherapy treatment regimen was not associated w/ functional outcome (estimate -0.12; 95% CI −0.97 to +0.74; $p = 0.79$).

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TABLE 2. Predictors of ambulatory status or motor function

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Histology	Complications	Ambulation Outcomes
Schoeggl et al., 2002	Retrospective outcome measurement study	3	84	60	Decompressive laminectomy w/ total or subtotal tumor resection	Lung (19); breast (18); prostate (17); hematopoietic tumors (10); hypernephroma (7); melanoma (4); colorectal carcinoma (3); liver (2); ovarian cancer (1); esophagus (1); unknown (2)	Intraop complications 4.7%; operative complications 5.9%: superficial wound infection 4.7 epidural abscess w/ repeat surgery 1.2%	Degree of mobility in the immediate postop phase Grade I paraplegia vs Grade II knee bending/toe wiggling vs Grade III straight-leg lifting vs Grade IV ambulatory w/ walker vs Grade V ambulatory w/o assistance Postop: 2/5 vs 2/38 vs — vs —vs — 2/5 vs 10/38 vs — vs — vs — 1/5 vs 18/38 vs 11/23 vs — vs — — vs 8/38 vs 9/23 vs 10/14 vs 1/4 — vs — vs 3/23 vs 4/14 vs 3/4 2 mos: 1/3 vs 2/23 vs — vs — vs — 2/3 vs 6/23 vs 5/17 vs 2/14 vs — — vs 12/23 vs 6/17 vs 5/14 vs— — vs 3/23 vs 4/17 vs 5/14 vs 1/4 — vs — vs 2/17 vs 2/14 vs 3/4 4 mos: 1/2 vs 2/11 vs — vs — vs — 1/2 vs 2/11 vs 4/11 vs 3/10 vs — — vs 6/11 vs 4/11 vs 3/10 vs — — vs 1/11 vs 3/11 vs 3/10 vs — — vs — vs — vs 1/10 vs 1/1

Sx = symptoms; — = blank entry in original study.
* Presented as the mean, unless indicated otherwise.

TABLE 3. Description of surgical techniques

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Outcome Scale	Outcomes
Abel et al., 2008	Retrospective review	3	34	60	Posterior decompression & stabilization	Prostate gland carcinoma (7); renal carcinoma (4); lung carcinoma (6); plasmacytoma (5); breast carcinoma (3); other (8); unknown (1)	Deep vein thrombosis (2); lung embolism (1); upper GI bleeding (1); pneumonia associated w/ lung atelectasis (1); deep wound infection necessitating revision surgery (1)	ASIA	Average ASIA grade for light touch (max value 112) at admission was 73.32 (SD 20.67) & improved to 82.82 (SD 21.30) at discharge (p = 0.07, t-test). Average ASIA grade for sensation of pinprick at admission was 71.93 (SD 23.11) & 79.90 (SD 24.32) at discharge. This difference was not significant either (t-test). There was no significant difference btwn the mean ASIA motor score (max 100) at admission & discharge (72.1 vs 73.5, p > 0.7; t-test).
Fürstenberg et al., 2009	Retrospective clinical trial	3	35	Group 1: 60; Group 2: 63	Decompression w/ & w/o stabilization	Unknown (1); esophagus (1); colon (2); liver (2); plasmacytoma (2); kidney (3); prostate (4); chondrosarcoma (2); testicular carcinoma (1); non-Hodgkin lymphoma (1); breast (6); lung (10)	Wound infection 14.3%; embolus 2.9%; sepsis 2.9%; thrombosis 2.9%	ASIA	Group 1 (n = 21) operated on w/in 48 hrs of the development of symptoms vs Group 2 (n = 14) operated on >48 hrs after the development of Sx: Decompression w/o stabilization: 19.0% vs 21.4% Decompression w/ dorsal stabilization: 71.4% vs 78.6% Decompression w/ dorsoventral: 4.8% vs 0.0% Ventral stabilization: 4.8% vs 0.0% Improvement in T01 score: 38.1% vs 7.1% p = 0.021, chi-square test) Improvement in T02 score: 71.4% vs 28.6% (p = 0.010 chi-square test)

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TABLE 3. Description of surgical techniques

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Outcome Scale	Outcomes
Miscusi et al., 2015	Prospective group and retrospective study	1	42	Prospective (58); retrospective (52)	Minimally invasive laminotomy/laminectomy & percutaneous stabilization in prospective group vs posterior spinal cord decompression & stabilization through traditional open surgery in retrospective group	Lung cancer (15); breast cancer (12); myeloma (4); clear cell renal carcinoma (3); melanoma (3); prostate cancer (3); ovarian cancer (1); thyroid cancer (1)	UTI in minimally invasive group (1)	ASIA, VAS, EORTC QLQ-C30, EORTC-QLQ-BM22	Open surgery vs minimally invasive surgery group: Postop improvement 63% vs 65% (p = 0.574) QLQ-C30 QOL postop 25.8 vs 30.8 (p = 0.009) QLQ-C30 functional scale postop 72.6 vs 70 (p = 0.03) QLQ-C30 symptom scales postop. 15.8 vs 14.8 (p = 0.006) QLQ-BM22 functional scale postop. 79.8 vs 54.93 (p = 0.025) QLQ-BM22 symptom scale 8.2 vs. 6.1 (p = 0.0007); Operation time 3.2 vs 2.2 hrs (p < 0.01); Blood loss 900 vs 240 ml (p < 0.01) No. of red blood cell transfusions 12 vs 0 (p < 0.01) No. of complications 0 vs 1 (p < 0.01) Postop bed rest days 4 vs 2 (p < 0.01) Time to discharge 9.25 vs 7.2 (p < 0.01) No. of deaths (open surgery vs minimally invasive) 1 vs 0 Postop VAS scores improved 53% vs 74% (p = 0.007)
Schoeggl et al., 2002	Retrospective outcome measurement study	3	84	60	Decompressive laminectomy w/ total or subtotal tumor resection	Lung (19); breast (18); prostate (17); hematopoietic tumors (10); hypernephroma (7); melanoma (4); colorectal carcinoma (3); liver (2); ovarian cancer (1); esophagus (1); unknown (2)	Intraop complications 4.7%; operative complications 5.9%; superficial wound infection 4.7%; epidural abscess w/ repeat surgery 1.2%		Continence disorders pre- vs postop vs after 2 mos vs after 4 mos (%): Mild: 21 vs 10 vs 12 vs 17 Moderate: 19 vs 16 vs 19 vs 13 Urinary catheter: 16 vs 12 vs 15 vs 21 Total: 56 vs 38 vs 46 vs 51 Postop analgesic consumption postop decreased vs analgesic idem vs consumption increased (%): Postop: 55 vs 38 vs 7 After 2 mos: 33 vs 49 vs 18 After 4 mos: 21 vs 37 vs 42 Overall median survival (wks): 34

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TABLE 3. Description of surgical techniques

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Outcome Scale	Outcomes
Wang et al., 2004	Prospective case series	4	140	Median 60.3	Single-stage PTA decompression	Renal cell (29); lung (non–small cell) (25); colon (15); sarcoma (14); breast (12); prostate (9); multiple myeloma (7); hepatocellular (3); lymphoma (3); melanoma (3); thyroid (3); undifferentiated carcinoma (3); adenoid cystic carcinoma of palate (2); esophageal (2); pancreatic (2); cervical (2); chordoma (1); primitive neuroectodermal tumor (1); malignant peripheral nerve sheath tumor (1); mixed germ cell tumor (1); paraganglioma (1); salivary (1)	Major complications occurring <30 days postop: Wound infection/dehiscence 2.9%; pneumonia 2.1%; pulmonary embolism 2.1%; postop hematoma 0.7%; radiculopathy 0.7%; stroke 0.7%; GI bleed 0.7%; death 4.3%; total 14.3% Instrumentation failure 5% (median time to failure 17 mos)	ASIA, ECOG	Pain improvement after surgery 96% 1-mo ASIA grades: E 40%; D 50%; Grade B or C 9.2%; A 0% ECOG grades 0 to 2 at presentation and remained stable: 62% ECOG grades 3 to 4 at presentation: (51 patients), of these 51, 75% improved & became ambulatory

PTA = posterolateral transpedicular approach; T01 = ASIA score compared pre- with postoperatively; T02 = ASIA score compared preoperatively with follow-up; VAS = visual analog scale.
* Presented as the mean, unless indicated otherwise.

ambulatory status (OR 2.8 [95% CI 1.2–6.7], $p = 0.02$), and increased time to developing motor deficit (OR 5.8 [95% CI 2.2–14.9], $p < 0.01$) were significant predictors of postoperative improvement in motor function. Utilizing a multivariable logistic regression analysis, Park et al.[30] found that preoperative ambulation (OR 5.4 [95% CI 1.6–18.2], $p < 0.01$]) and preoperative hip flexion power greater than Grade III (OR 6.2 [95% CI 1.3–7.4], $p = 0.04$) were predictive of improved postoperative ambulation. Park et al.[29] found that preoperative lower-extremity power classification ($p < 0.001$) and preoperative ambulation ($p < 0.001$) significantly predicted postoperative ambulation. Finally, Chaichana et al.[3] found that the primary lung histology was associated with increased odds of postoperative ambulation relative to all other primary tumor histologies.

Description of Surgical Techniques

Five studies compared outcomes following different surgical techniques for decompression surgery (Table 3).[1,12,23,39,45] Three of the studies were retrospective and 2 were prospective. All 5 studies reported primary tumor sites of lung, prostate, and breast, and 4 studies reported primary renal cancers. The techniques reported on were posterior decompression and stabilization, posterior decompression without stabilization, and posterior decompression with total or subtotal tumor resection.[1,12,23,39,45] The outcomes measures used to compare surgical technique varied across the 7 included studies. Four studies used the American Spinal Injury Association (ASIA) Impairment Scale to assess neurological function.[1,12,23,45]

Two studies reported outcomes after decompression without stabilization. Schoeggl et al.[39] reported results of decompressive laminectomy with total or partial tumor removal. The authors found that patients undergoing this technique experienced an improvement in their quality of life based on a reduction in analgesic consumption postoperatively and a decrease in the total percentage of patients experiencing continence disorders following surgery (Table 3).[39] However, the technique did not improve quality of life outcomes for patients with preoperative paraplegia.[39] Wang et al.[45] prospectively studied a consecutive series of 140 patients receiving single-stage posterolateral transpedicular decompression and reported a 96% improvement in pain as measured through the visual analog scale score.

Two studies reported outcomes after minimally invasive decompressive surgery. Miscusi et al.[23] prospectively studied 42 patients and compared minimally invasive surgery with standard open surgery for vertebral thoracic metastases and reported that there were no significant differences in postoperative ASIA score and complication rates between the 2 cohorts. However, the authors did note that the minimally invasive group had significantly less blood loss (240 ml vs 900 ml, $p < 0.01$), shorter operation time (2.2 hours vs 3.2 hours, $p < 0.01$), and shorter bed rest length (2 days vs 4 days, $p < 0.01$) compared with the open surgery group. Furthermore, the authors also found that patients treated with minimally invasive surgery experienced a greater improvement in quality of life at 30-day follow-up based on the European Organisation for Research and Treatment of Cancer Quality of Life questionnaire (EORTC QLQ-30) ($p < 0.01$) and EORTC Bone Me-

TABLE 4. Neurological function

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Functional Scale	Outcomes
Landmann et al., 1992	Retrospective review	3	127	Median 63	Decompressive laminectomy + postop irradiation (127 cases); RT alone (26 patients) 17%	Prostate (39); breast (34); lung (18); lymphoma (9); unknown (8); kidney (7); myeloma (7); bladder (3); thyroid (3); miscellaneous (12)	Recurrence in original treatment field 6% (8); recurrences w/in the original treatment field after irradiation alone 8% (2); rapid progression of pain & neurological deficit 27% (7/26) in patients who started therapy w/ irradiation		Improvement in sphincter function: laminectomy & irradiation 68% vs irradiation alone 33% Improvement in pain relief: laminectomy & irradiation: 88% vs irradiation alone 72%
Fürstenberg et al, 2009	Retrospective clinical trial	3	35	Group 1, 60; Group 2, 63	Decompression w/ & w/o stabilization	Unknown (1); esophagus (1); colon (2); liver (2); plasmacytoma (2); kidney (3); prostate (4); chondrosarcoma (2); testicular carcinoma (1); non-Hodgkin lymphoma (1); breast (6); lung (10)	Wound infection 14.3%; embolus 2.9%; sepsis 2.9%; thrombosis 2.9%	ASIA	Group 1 (n = 21) operated on w/in 48 hrs of the development of Sx vs Group 2 (n = 14) operated on >48 hrs after the development of Sx: Improvement in T01 score: 38.1% vs 7.1% (p = 0.021, chi-square test) Improvement in T02 score: 71.4% vs. 28.6% (p = 0.010 chi-square test)
Tancioni et al., 2012	Nonrandomized, prospective study	2	25	Median 68	Minimally invasive percutaneous approach	Lung (15); GI (5); breast (2); hepatocarcinoma cancer (2); ovarian (1)	None related to surgery; no major morbidity or perioperative mortality noted; no revision surgeries Asymptomatic leakage of cement 1 (4%); wound complication 1 (4%); pneumonia, deep vein thrombosis & UTI 2 (8%); local recurrence 2 (8%)	Frankel scale	Improvement in neurological deficit in 22 (88%); median survival 10 mos (range 6–24 mos); no patient survived >30 mos
Crnalic et al., 2013	Retrospective review	3	68	Hormone naive: median 77; hormone refractory: median 71	Posterior decompression w/ or w/o stabilization	Prostate		Frankel scale; KPS	Significant factors associated w/ regaining ambulation in patients w/ hormone-refractory disease who were unable to walk before surgery: Duration of paresis <48 hrs: p = 0.005 KPS 80–100%: p = 0.036 Preoperative PSA serum level <200 ng/ml: (p = 0.033) Surgery w/ posterior decompression & stabilization: p = 0.034

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TABLE 4. Neurological function

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Functional Scale	Outcomes
Quraishi et al, 2013[36]	Retrospective review	3	121	61	Decompression surgery	Breast (20); lung (12); prostate (18); renal (18); myeloma (18); GI (9); other (21); unknown (5)	Patients were divided into 3 groups: those who underwent surgery w/in 24 hrs (Group 1, n = 45); btwn 24 & 48 hrs (Group 2, n = 23); & after 48 hrs (Group 3, n = 53) from acute presentation of neurological symptoms. Overall complication rate: 41% (50); overall postop surgical site infection: 15% (18/121); complication rate Group 1: 40% (18/45); complication rate Group 2: 43% (10/23); complication rate Group 3: 42% (22/53)	Correlation w/ LOS, Frankel grade, survival, & complications	Histology of primary tumor & correlation w/: LOS: p = 0.54 Change in Frankel grade: p = 0.14 Survival: p = 0.22 Complications: p = 0.07 Levels of spinal metastases & correlation w/: LOS: p = 0.40 Change in Frankel grade: p = 0.73 Survival: p = 0.40 Complications: p = 0.68 Revised Tokuhashi score and correlation w/: LOS: p = 0.37 Change in Frankel grade: p = 0.39 Survival: p = 0.01 Complications: p = 0.26 No. of metastases in the spine & correlation w/: LOS: p = 0.53 Change in Frankel grade: p = 0.84 Survival: p = 0.96 Complications: p = 0.05
Chong et al., 2012	Retrospective observational study	3	105	58.3	Single-stage PDS, corpectomy	Lung cancer (43%); hepatobiliary cancer (25%); CRC (6.7%); breast cancer (3.8%); stomach cancer (3.8%); cervical cancer (2.9%); esophageal cancer (2.9%); kidney (1.9%); thyroid cancer (1.9%); gingival cancer (1); melanoma(1); mesothelioma (1); mixed germ cell tumor (1); osteosarcoma (1); prostate cancer (1); sarcoma (1); thymic cancer (1); undifferentiated carcinoma (1)	Mechanical failure of spinal instrumentation (0) Surgical complications 11 patients (10%): CSF leakage (4); postop epidural hematoma (4); wound dehiscence (2); pneumothorax (1)	KPS; Frankel score; VAS	Significant preoperative factors affecting functional outcome (p < 0.01): KPS ≥70 vs <70: p < 0.01) Ambulatory vs nonambulatory: p < 0.01) Significant factors affecting pain control measured by VAS Restoration of anatomy (corpectomy and cage vs. others): 3.3 vs. 1.8, p = 0.02 No. of fixated segments (<4 vs ≥4): 2.7 vs 3.7 (p < 0.01)

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TABLE 4. Neurological function

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Primary Tumor Site	Complications	Functional Scale	Outcomes
Lei et al., 2015[21]	Retrospective review	3	73	Median 57	Posterior decompression & spine stabilization	Lung cancer	Postop wound infections (2); death w/in 4 wks (1)	Frankel scale	Multivariate analysis of preop factors for survival: Preop ambulatory status: RR 4.51, 95% CI 1.757–11.578; p = 0.0017 Visceral metastasis: RR 7.913, 95% CI 2.678–23.382; p = 0.0002 Time to motor deficits: RR 4.828, 95% CI 2.005–11.628; p = 0.0004 Ambulatory vs nonambulatory: Test Group A: 4 vs 11 Test Group B: 17 vs 5 (p = 0.0023) Validation Group A: 10 vs 6 Validation Group B: 19 vs 1 (p = 0.0298)
Quraishi et al, 2015	Retrospective cohort review	3	101	64.7	Decompression w/ & w/o stabilization	Breast (14); lung (10) prostate (21); renal (11); myeloma (1); GI (8); other (25); unknown (11)	Group 1 (low-grade compression) vs Group 2 (high grade) overall complication rate Group 1: 25% vs overall complication rate Group 2: 42.6% (p = 0.12); postop wound infection Group 1: 2.5%; postop wound infection Group 2: 16%	Frankel score; Tokuhashi Score	Mean revised Tokuhashi score Group 1 vs Group 2 10 vs 9.1 (p = 0.1) Changes in Frankel scores were not statistically significant (p = 0.22). Mean Frankel scores were not reported btwn Group 1 vs Group 2

LOS = length of stay; — = blank entry in original study.
* Presented as the mean, unless indicated otherwise.

TABLE 5. Primary tumor site

Authors & Year	Classification	Evidence Level	No. of Patients	Age* (yrs)	Surgery Type	Primary Tumor Site	Complications	Type of Outcome	Outcomes
Bakker et al., 2014	Retrospective review	3	21		Decompression surgery	RCC (21)		Survival	Univariate analysis: Cervical localization: HR 43.7, 95% CI 2.2–866; p = 0.01 Curative intent: HR 0.3, 95% CI 0.09–0.90; p = 0.03) Frankel Grade C/D vs E: HR 3.2, 95% CI 1.05–9.49; p = 0.04 Motzer intermediate: HR 13.5, 95% CI 1.6–111; p = 0.01 (reference group Motzer favorable risk) High risk: HR 38.4, 95% CI 3.4–431; p = 0.003 (reference group Motzer favorable risk) Multivariable analysis: Motzer intermediate: HR 17.4, 95% CI 1.8–166; p = 0.01; High risk: HR 39.3, 95% CI 3.1–499; p = 0.005
Chaichana et al., 2009	Retrospective review	3	114	58	Decompression surgery	Lung (27); breast (26); prostate (20); kidney (21); GI (13); melanoma (7)	Wound dehiscence 10%; postop CSF leaks requiring operative intervention 3%; epidural hematoma requiring operative intervention 1%; perioperative death 3%	Long-term surgical outcomes	Summary of long-term surgical outcomes in 114 patients w/ MESCC: Lung (17) vs breast (26) vs prostate (20) vs kidney (21) vs GI (13) vs melanoma (7) (% based on no. in each category) Periop mortality: 0 vs 4 vs 0 vs 5 vs 8 vs 0 Wound dehiscence: 4 vs 8 vs 10 vs 14 vs 23 vs 0 CSF leak: 11 vs 0 vs 0 vs 0 vs 0 vs 0 Epidural hematoma: 0 vs 4 vs 0 vs 0 vs 0 vs 0 Spinal recurrence: 7 vs 4 vs 20 vs 14 vs 8 vs 29 Postop additional surgery: 0 vs 4 vs 20 vs 29 vs 8 vs 29 Additional RT: 19 vs 46 vs 30 vs 19 vs 23 vs 14 Chemo: 19 vs 42 vs 25 vs 24 vs 8 vs 14 % of patients who underwent additional surgery was lower in lung cancer group than prostate (p = 0.02), melanoma (p = 0.04), or kidney cancer (p = 0.004) groups. % of patients who underwent postop RT was higher in the group w/ breast cancer than in the patients w/ lung (p = 0.04) or kidney (p = 0.05) cancer. % of patients treated w/ chemo postop was lower in the group of patients w/ GI cancers than in those w/ breast cancer (p = 0.03).
Enkaoua et al., 1997	Retrospective review	3	71	61	Excisional & palliative surgery	Thyroid (34); renal cancer (28); unknown (9)		Histology	Significant characteristics of patients according to primary cancer site: Sex ratio (M/F): p <0.0001 No. (%) w/ total vertebral body involvement: p = 0.03

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TABLE 5. Primary tumor site

Authors & Year	Classification	Evidence Level	No. of Patients	Age* (yrs)	Surgery Type	Primary Tumor Site	Complications	Type of Outcome	Outcomes
Laufer et al., 2010	Retrospective review	3	39	Median 61	Decompression surgery	Renal (12); prostate (7); neuroendocrine (4); head & neck (4); GI (4); sarcoma (2); thyroid (2); breast (1); cervical SCC (1); lymphoma (1); melanoma (1)	Major surgical complication rate: 5%	Reoperations	No. of reoperations, No. of patients (%): 1, 29 (75) 2, 6 (15); 3, 2 (5); 4, 2 (5)
Quraishi et al., 2013[36]	Retrospective review	3	121	61	Decompression surgery	Breast (20); lung (12); prostate (18); renal (18); myeloma (18); GI (9); other (21); unknown (5)	Overall complication rate 41% (50 patients); Overall postop surgical site infection 15% (18/121); Complication rate Group 1: 40% (18/45) Complication rate Group 2: 43% (10/23); Complication rate Group 3: 42% (22/53) Patients were divided into 3 groups: those who underwent surgery w/in 24 hrs (Group 1, n = 45), btwn 24 & 48 hrs (Group 2, n = 23), & after 48 hrs (Group 3, n = 53) from acute presentation of neurological symptoms	Correlation w/ LOS, Frankel grade, survival, & complications	Histology of primary tumor & correlation w/: LOS: p = 0.54 Change in Frankel grade: p = 0.14 Survival: p = 0.22 Complications: p = 0.07 Levels of spinal metastases & correlation w/: LOS: p = 0.40 Change in Frankel grade: p = 0.73 Survival: p = 0.40 Complications: p = 0.68 Revised Tokuhashi score & correlation w/: LOS: p = 0.37 Change in Frankel grade: p = 0.39 Survival: p = 0.01 Complications: p = 0.26 No. of metastases in the spine & correlation w/: LOS: p = 0.53; Change in Frankel grade: p = 0.84 Survival: p = 0.96 Complications: p = 0.05

* Presented as the mean, unless indicated otherwise.

TABLE 6. Miscellaneous outcomes

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Tumor Histology	Complications (no.) or %	Type of Outcome	Outcomes
Ju et al., 2013	Retrospective review	3	27	Median 65	Decompression surgery	Prostate (27)	16 complications occurred in 35% (11/31 procedures); death w/in 30 days of surgery of an unreported cause (1); acute inpatient rehabilitation after surgery (14) 52% Major complications: Instrumentation failure requiring reop; pneumothorax; spinal hematoma; small-bowel obstruction; deep wound infection; GI bleeding necessitating nasogastric tube placement; pulmonary embolism Minor complications: Durotomy status after intraop closure; wound infection responsive to treatment w/ antibiotics; UTI; pleural effusion; thrombocytopenia & anemia requiring multiple postop transfusions; transient left recurrent laryngeal nerve dysfunction; instrumentation failure	Predictors of complications	Significant factors associated w/ increased incidence of complications: Age <65 yrs: OR 0.3, 95% CI 0.003-0.4; p = 0.005 Instrumentation spanning ≥7 spinal levels: OR 7.0, 95% CI 1.2–41.4; p = 0.03 Median length of stay after surgery: 9 days
Landmann et al., 1992	Retrospective review	3	127	Median 63	Decompressive laminectomy + postop RT (127); RT alone (26)	Prostate (39); breast (34); lung (18); lymphoma (9); unknown (8); kidney (7); myeloma (7); bladder (3); thyroid (3); miscellaneous (12)	Recurrence in original treatment 6% (8); recurrences w/in the original treatment field after irradiation alone 8% (2); rapid progression of pain & neurological deficit 27% (7/26) in patients who started therapy w/ irradiation	Sphincter function & pain relief	Improvement of sphincter function: Laminectomy & RT: 68% vs RT alone: 33% Improvement in pain relief: Laminectomy & RT: 88% vs RT alone 72%

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TABLE 6. Miscellaneous outcomes

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Tumor Histology	Complications (no.) or %	Type of Outcome	Outcomes
Patchell et al., 2005	Randomized, multiinstitutional, nonblinded trial	1	101	Median 60 for both groups	Surgery followed by RT (50); RT alone (51)	RT group, surgery group: lung (13), (13); breast (6), (7); prostate (10), (9); other genitourinary (6), (5); GI (4), (2); melanoma (3), (3); head & neck (2), (1); unknown (3), (5); other (4), (5)	Wound infection (3); failure of fixation requiring additional surgery (1) Extended hospital stay (>20 days) occurred in 7 patients in the surgery group & 11 in the RT group.	Surgery vs RT	Surgical treatment resulted in significant differences in: Maintenance of continence RR 0.47, 95% CI 0.25–0.87; p = 0.016) Maintenance of ASIA score RR 0.28, 95% CI 0.13–0.61; p = 0.001 Maintenance of Frankel score RR 0.24, 95% CI 0.11–0.54; p = 0.0006; Survival time RR 0.6, 95% CI 0.38–0.96; p = 0.033 The 30-day mortality rates were 6% in the surgery group and 14% in the RT group (p = 0.32). At Day 30 after treatment, the % of patients with Frankel scores at or above study entry level was significantly (p = 0.0008) higher in the surgery group than in the RT group (91% vs 61%).
Rades et al., 2012	Retrospective review	3	126		Surgery+RT (42); RT alone (84)	Breast cancer (15); prostate cancer (30); myeloma/lymphoma (18); lung cancer (24); other tumors (39)	Wound infections, extensive bleeding, postoperative pneumonia, & pulmonary embolism occurred in 7 patients (14%) in the surgery+RT group.	Local control	The local control rates for the entire cohort were 96% at 6 mos & 91% at 12 mos. Local control was defined as absence of neurological progression w/in the irradiated spine. Treatment regimen was not significantly associated w/ local control (p = 0.44) Univariate analysis of local control: Surgery+RT vs RT alone: p = 0.44) Age >70 vs <70 yrs: p = 0.19 Male vs female: p = 0.21 ECOG 3–4 vs 1–2: p = 0.99 Primary tumor types: p = 0.14 ≥3 vertebrae: p = 0.57 Other bone metastases at the time of RT: p = 0.33 Visceral metastases at the time of RT: p = 0.048 Ambulatory status before RT vs not: p = 0.23 >7 days developing motor deficits before RT vs 1–7 days: p = 0.39

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TABLE 6. Miscellaneous outcomes

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Tumor Histology	Complications (no.) or %	Type of Outcome	Outcomes
Rades et al., 2011	Retrospective review	3	67		Surgery+RT	Non–small cell lung cancer (36); CUP (13); RCC (9); CRC (9)	Surgical complications such as wound infections requiring a 2nd surgery, extensive bleeding, postop pneumonia, & pulmonary embolism occurred in 9 patients (13%) in the surgery+RT group.	Local control	The local control rates for the entire cohort were 93% at 6 mos and 86% at 12 mos. The treatment regimen was not significantly associated w/ local control (p = 0.87). Univariate analysis of local control: surgery+RT vs RT at 6 mos: 93 vs 93; at 12 mos 85 vs 89, p = 0.87 ≤60 vs >60 yrs at 6 mos: 94 vs 93; at 12 mos: 91 vs 82; p = 0.58 Female vs male at 6 mos: 86 vs 94; at 12 mos 86 vs 86; p = 0.98 ECOG Grade 1–2 vs 3–4 at 6 mos: 96 vs 89; at 12 mos: 87 vs 89; p = 0.7 NSCLC vs CUP vs RCC vs CRC at 6 mos: 95 vs 94 vs 88 vs 92; at 12 mos: 92 vs 94 vs 60 vs 92; p = 0.30 No. of involved vertebrae 1–2 vs ≥3 at 6 mos: 95 vs 91; at 12 mos: 85 vs 91; p = 0.88 Other bone metastases no vs yes at 6 mos: 95 vs 87; at 12 mos 86 vs 89; p = 0.34 Visceral metastases no vs yes at 6 mos: 95 vs 87; at 12 mos: 88 vs 87; p = 0.49 Not ambulatory vs ambulatory at 6 mos: 86 vs 94; at 12 mos: 86 vs 87; p = 0.97 Time to development of motor symptoms 1–7 vs >7 days at 6 mos: 80 vs 96; at 12 mos: 80 vs 88; (p = 0.12). Interval btwn surgery & RT ≤2 vs >2 wks at 6 mos: 91 vs 100; 81 vs 100; p = 0.31

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TABLE 6. Miscellaneous outcomes

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Tumor Histology	Complications (no.) or %	Type of Outcome	Outcomes
Wang et al., 2004	Prospective case series	4	140	Median 60.3	Single-stage PTA decompression	Renal cell (29); lung (non–small cell) (25); colon (15); sarcoma (14); breast (12); prostate (9); multiple myeloma (7); hepatocellular (3); lymphoma (3); melanoma (3); thyroid (3); undifferentiated carcinoma (3); adenoid cystic carcinoma of palate (2); esophageal (2); pancreatic (2); cervical (2); chordoma (1); primitive neuroectodermal tumor (1); malignant peripheral nerve sheath tumor (1); mixed germ cell tumor (1); paraganglioma (1); salivary (1)	Major complications occurring <30 days postop: Wound infection/dehiscence 2.9%; pneumonia 2.1%; pulmonary embolism 2.1%; postop hematoma 0.7%; radiculopathy 0.7%; stroke 0.7%; GI bleed 0.7%; death 4.3%; total 14.3%; instrumentation failure 5% The median time to failure was 17 mos.	ASIA, ECOG	Pain improvement after surgery 96%. 1-mo ASIA outcomes: Grade E 40% Grade D 50% Grade B or C 9.2% Grade A 0% ECOG grades 0–2 at presentation & remained stable 62% ECOG grades 3–4 at presentation: (51 patients); of these 51, 75% improved & became ambulatory

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TABLE 6. Miscellaneous outcomes

Authors & Year	Classification	Evidence Level	No. of Patients	Age (yrs)*	Surgery Type	Tumor Histology	Complications (no.) or %	Type of Outcome	Outcomes
Quraishi et al., 2013[36]	Retrospective review	3	121	61	Decompression surgery	Breast (20); lung (12); prostate (18); RCC (18); myeloma (18); GI (9); other (21); unknown (5)	Overall complication rate 41% (50 patients) Overall postop surgical site infection 15% (18/121) Complication rate Group 1: 40% (18/45) Complication rate Group 2: 43% (10/23) Complication rate Group 3: 42% (22/53)	Frankel, effect of surgical timing	Group 1 vs 2 vs 3 outcomes: Postop Frankel grade Group 1 vs 2, p = 0.09; Group 1 vs 2 vs 3, p = 0.048 Grade A: 4 vs 1 vs 1 Grade B: 4 vs 0 vs 0 Grade C: 8 vs 3 vs 11 Grade D: 20 vs 10 vs 27 Grade E 9 vs 9 vs 14 Mean length of stay (days): 20 vs 22 vs 20, p = 0.67 Complications: 40% vs 43% vs 42%, p = 0.97 Infection: 16% vs 9% vs 17%, p = 0.64 Mean survival (days) 573 vs 820 vs 643, p = 0.99 Outcome comparison for patients undergoing surgery w/in 48 hrs vs after 48 hrs: Frankel grade (postop) Grade A: 3 vs 1, p =0 .048 Grade B: 4 vs 0 Grade C: 11 vs 11 Grade D: 30 vs 27 Grade E: 18 vs 14 Mean length of stay (days): 21 vs 20, p = 0.4 Complications: 41% vs 42%, p = 0.97 Infection 13% vs 17%, p = 0.37 Mean survival (days): 657 vs 643, p = 0.79

* Presented as the mean, unless indicated otherwise.

tastases module (EORTC QLQ-BM22) ($p = 0.03$) relative to patients who underwent laminectomy and stabilization via traditional open surgery.[23] Similarly Tancioni et al.[41] reported outcomes in 25 consecutive patients treated with minimally invasive surgery and noted clinical remission of pain in 96% of patients and improvement of neurological deficit in 88% of patients.

Abel et al.[1] retrospectively studied 34 patients who underwent posterior decompression and stabilization for metastatic compression of the thoracic spinal cord and found that there was no significant difference between the mean ASIA motor score at admission and discharge (72.1 vs 73.5, respectively; $p = 0.7$). Furthermore, the authors found no evidence that anterior approaches were superior to posterior approaches for MESCC in the thoracic spine.

Neurological Function

Eight studies reported outcomes on neurological function (Table 4).[5,6,12,17,21,34,36,41] Seven studies were retrospective and one was a nonrandomized, prospective study. The 7 retrospective studies used different decompression techniques, and the prospective study used a minimally invasive approach. Four studies reported functional status using the following methods: Frankel score, visual analog scale (VAS), Tokuhashi Score, and the KPS.[5,6,21,34] The most prevalent primary tumors reported were lung (7 studies), prostate (6 studies), and breast (6 studies).

Three studies reported improvement in neurological function following decompression surgery.[12,17,41] Landmann et al.[17] found that sphincter function recovered in 68% of patients who underwent decompressive laminectomy and received postoperative radiation therapy compared with only 33% of patients treated by radiotherapy alone. The authors also reported that pain relief was achieved in 88% of cases after combined treatment compared with 72% of patients after radiation only.[17] Furthermore, Landmann et al.[17] found that 91% (127/140) of patients that underwent laminectomy followed by adjuvant radiotherapy had improved postoperative neurological outcomes. In their study, 82% of paraparetic patients regained ambulatory ability, 68% showed an improvement in sphincter function, and 88% achieved pain relief. Conversely, in patients treated with radiation therapy alone, only 64% of paraparetic patients became ambulatory, while 33% showed an improvement in sphincter function, and 72% became pain free.

Quraishi et al.[36] studied the effect of the timing of surgery on neurological outcome and survival in patients with MESCC. The authors found that surgery should be performed earlier rather than later relative to the onset of compression symptoms, as the Frankel grade improvement was significantly better ($p = 0.05$) in patients that underwent surgery within 48 hours of acute neurological deterioration relative to patients who underwent surgery 48 hours or more following presentation.[36]

In a separate study, Quraishi et al.[34] were the first to use the Bilsky 6-point scale to group patients according to the degree of preoperative cord compression prior to undergoing decompression with and without stabilization. The authors found that increased preoperative compression grade was associated with greater improvement in postoperative Frankel scores.[34] Additionally, there were no significant differences between complication rates or median survival times across patient groups ($p = 0.6$).[34]

Radiation Therapy and Local Control

Four studies reported the effects of radiation therapy and local disease control for spinal metastases.[13,25,37,38] Rades et al.[37] studied local control rates among patients receiving surgery and radiotherapy versus radiotherapy alone. The authors found that for 67 patients who underwent surgery with radiotherapy, the local control rate was 93% at 6 months and 86% at 12 months.[37] Rades et al.[37] included a matched-pair analysis and found that patients with MESCC from an unfavorable primary tumor (i.e., radioresistant tumors such as renal cell carcinoma and colorectal cancer) had improved functional outcome following decompressive surgery and stabilization in addition to radiotherapy, but not after laminectomy with radiotherapy. The authors suggested that laminectomy should not be considered a viable treatment option before radiotherapy in patients with MESCC.[37] Rades et al.[37] found that the type of treatment was not significantly associated with the rate of local control ($p = 0.9$). In another study, Rades et al.[38] analyzed data from 42 elderly (age > 65 years) patients with MESCC who underwent surgery and received radiotherapy and found that 96% of patients had local control at 6 months and 91% at 12 months. Rades et al.[38] also found that the type of treatment was not significantly associated with the rate of local control ($p = 0.4$).

One study found that spinal radiation before surgical decompression can have a negative impact on surgical outcomes for MESCC. Ghogawala et al.[13] reported that the major wound complication rate for patients who received radiation before surgical decompression and stabilization was 32%, significantly higher than the 12% seen in patients who had surgery first ($p < 0.05$).

Complications

Complications reported among the included studies were varied. However, the most commonly cited complication was wound infection or dehiscence (22 studies), which occurred in 2.5% to 16% of patients.[1,3–5,12,13,15,21,22,29–35,37–39,41,43,45] Chaichana et al.[3] did not find a statistically significant difference in the incidence rate of complications among spinal metastases based on primary tumor site. However, Ju et al.[15] reported that younger age ($p < 0.01$) and instrumentation greater than 7 spinal levels ($p = 0.03$) were associated with increased odds of complication in patients with MESCC stemming from prostate cancer. Quraishi et al.[36] compared complication rates based on timing of surgery and determined that the incidence of complications was similar among those treated with surgery within 24 hours (40% complication rate), between 24 and 48 hours (43%), and over 48 hours (42%) following acute presentation of neurological symptoms ($p = 1.0$).

Primary Tumor Site

Five studies reported outcomes based on site of primary tumor (Table 5).[2,3,11,18,36] All 5 studies were retrospective. The most common primary tumor site included renal cancer (4 studies), breast cancer (3 studies), prostate cancer (3 studies), gastrointestinal cancer (3 studies), and lung cancer (2 studies).

Laufer et al.[18] found that 29/39 (75%) patients who underwent decompression surgery required at least 1 reoperation regardless of tumor histology (Table 6). In contrast, Chaichana et al.[3] compared long-term surgical outcomes based on primary tumor histology and found that patients with primary prostate cancers had the shortest mean duration of spinal cord compression symptoms prior to surgery ($p < 0.05$), but they presented with motor deficits more frequently compared with all other histology types ($p < 0.05$). The authors also found that patients with primary breast cancer histology were more likely to present with cervical MESCC than patients with primary lung cancer histology ($p = 0.04$) and were more likely to present with compression fractures relative to patients with primary prostate cancers ($p = 0.04$).[3]

Miscellaneous

Seven studies reported outcomes not related to the previous topics (Table 6).[15,17,32,36–38,45] The most common primary tumor sites included prostate cancer (6 studies), lung cancer (6 studies), breast cancer (5 studies), and renal cancer (3 studies). Five of the studies were retrospective and 2 were prospective.

Laufer et al.[18] analyzed the functional outcomes and complications associated with reoperation for MESCC and found that reoperation can improve outcomes among patients with high-grade epidural spinal cord compression with persistent metastatic tumors at previously treated spinal levels. Specifically, the authors found that 97% of patients maintained or had an improvement in functional status by one ECOG grade.

Discussion

The present study comprehensively reviews the literature on decompression surgery for spinal metastases. Included studies were classified according to the outcomes reported. Specifically, studies were categorized as reporting survival outcomes, ambulation outcomes, surgical technique, neurological function outcomes, primary tumor histology outcomes, and miscellaneous outcomes. Table 1 reported a wide range of predictors of survival, including Motzer score, Tokuhashi score, Frankel grade, KPS, and ECOG performance status. Table 2 reported several predictors of ambulatory status or motor function including Frankel grade, ECOG score, ASIA grade, and KPS. Table 3 reported different surgical techniques for decompression surgery and mostly focused on ASIA grade outcomes. Table 4 reported neurological functional outcomes and mostly reported outcomes using ASIA grade, Frankel grade, and KPS. Table 5 reported outcomes based on primary tumor site and reported a variety of long-term surgical outcomes including survival outcomes, reoperation rates, and correlations of primary tumor site with length of stay, change in Frankel grade, survival, and complications. Lastly, Table 6 reported miscellaneous outcomes including predictors of complications, sphincter function and pain relief, local control rates, stereotactic radiosurgery dosage, and the effect of surgical timing on Frankel grades. A review of these clinical parameters can improve preoperative risk counseling and help surgeons optimize their choice of surgical technique to decrease the occurrence of postoperative complications and improve patient quality of life.

Predictors of Survival

Survival was the most commonly reported outcome. Different scoring algorithms have been proposed to improve survival prediction among patients with spinal metastases who undergo decompression surgery. Three studies found that KPS was associated with survival following decompression surgery.[7,15,28] Ju et al.[15] found that a better preoperative KPS (defined as KPS ≥ 80%) was the only significant predictor of survival in a multivariable study of patients with prostate cancer metastatic to the spine (HR 6.1 [95% CI 1.3–28.5], $p = 0.02$). Padalkar et al.[28] also found that increased KPS was significantly associated with greater median survival times in patients treated with decompression with instrumentation for spinal metastases. Crnalic et al.[7] reported that a KPS of 80%–100% was significantly associated with prolonged survival, with a median survival of 5 months.

Predictors of Ambulatory Status/Motor Function

A prior study found that ambulatory ability is the single most important factor for surgeons when deciding if surgical intervention is an appropriate treatment for patients with metastatic spinal cord compression.[22] We found that 8 studies reported that preoperative ambulatory or preoperative motor status was a significant predictor of postoperative ambulatory status.[4,13,16,20,29–31,33] However, we did not find any evidence of a surgical decision-making tool that uses postoperative ambulation as an outcome following decompression surgery for spinal metastases. Future studies are warranted to develop evidence-based decision-making tools that use postoperative ambulatory status as an outcome. These decision tools may significantly improve preoperative patient risk counseling and patient selection for decompression surgery for spinal metastases.

Description of Surgical Techniques

We found 5 studies that identified outcomes following different surgical techniques for decompression surgery among patients with spinal metastases.[1,12,23,39,45] In reviewing the aforementioned studies on surgical technique, the only prospective studies were those by Miscusi et al.[23] and Wang et al.[45] Furthermore, no studies reported using matching techniques, such as propensity matching, which help mitigate bias in observational studies. Therefore, despite promising evidence of the benefits of the innovative surgical techniques described above, larger prospective, randomized trials or rigorously designed observational studies are needed to appropriately evaluate the effectiveness of different surgical approaches for decompression surgery among patients with spinal metastases.

Neurological Function

Two studies found that neurological outcomes may improve if decompression surgery is performed within 48 hours of MESCC symptom presentation. Fürstenberg et al.[12] studied 35 patients who underwent early surgical treatment for MESCC and found that early surgical treatment was associated with improved neurological outcomes as measured by the ASIA grade ($p = 0.02$). Similarly, Quraishi et al.[36] found that surgery should be performed earlier rather than later among patients with MESCC, as the Frankel grade improvement was significantly greater ($p = 0.05$) among patients who received surgery within 48 hours of presenting with symptoms relative to patients who received surgery after 48 hours.[36]

Conclusions

This work presents a comprehensive systematic review of outcomes following decompression surgery for metastatic spinal tumors of varied primary tumor sites. The present study highlights significant predictors of survival, ambulation, and functional status following decompression surgery for metastatic spine disease. The results of the data presented herein also identify significant gaps in the literature, which may help spur additional investigation of the optimal surgical management of patients with MESCC.

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Disclosures

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