Spinal Metastasis Surgery: A Proposal for a Predictive Model of Morbidity and Mortality

Cirurgia em metástase vertebral: Proposta de modelo preditivo de morbimortalidade

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Rev Bras Ortop 2019;54:665–672.

Abstract

Objective To develop a predictive model of early postoperative morbidity and mortality with the purpose of assisting in the selection of the candidates for spinal metastasis surgery.

Methods A retrospective analysis of consecutive patients operated for metastatic spinal disease. The possible prognostic preoperative characteristics were gender, age, comorbidities, tumor growth rate, and leukocyte and lymphocyte count in the peripheral blood. The postoperative outcomes were 30-day mortality, 90-day mortality and presence of complications. A predictive model was developed based on factors independently associated with these three outcomes. The final model was then tested for the tendency to predict adverse events, discrimination capacity and calibration.

Results A total of 205 patients were surgically treated between 2002 and 2015. The rates of the 30-day mortality, 90-day mortality and presence of complications were of 17%, 42% and 31% respectively. The factors independently associated with these three outcomes, which constituted the predictive model, were presence of comorbidities, no slow-growing primary tumor, and lymphocyte count below 1,000 cells/µL. Exposure to none, one, two or three factors was the criterion for the definition of the following categories of the predictive model: low, moderate, high and extreme risk respectively. Comparing the risk categories, there was a progressive increase in the occurrence of outcomes, following a linear trend. The discrimination capacity was of 72%, 73% and 70% for 30-day mortality, 90-day mortality and complications respectively. No lack of calibration occurred.

Keywords ► spine/surgery ► comorbidity ► lymphocytes ► morbidity ► mortality ► neoplasm metastasis ► postoperative complications

* Study developed at Hospital Erasto Gaertner by the Post-Graduate Program in Surgical Clinic of Universidade Federal do Paraná (UFPR), Curitiba, PR, Brazil.

Received June 7, 2018
Accepted August 6, 2018
DOI https://doi.org/10.1055/s-0039-1697018. ISSN 0102-3616. Copyright © 2019 by Sociedade Brasileira de Ortopedia e Traumatologia. Published by Thieme Revinter Publicações Ltda, Rio de Janeiro, Brazil.

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Introduction

The surgical treatment for vertebral metastasis is related to a high incidence of postoperative complications, therefore, it is controversial, and has been debated in the academic environment for decades. Other forms of treatment, such as radiotherapy, have fewer adverse effects, and are becoming increasingly attractive, especially because the patients often do not reach twelve months of survival. The patient with metastatic spinal disease (MSD) is on average 60 years old, and has a health condition weakened by comorbidities such as immunosuppression and malnutrition.

In cases of surgical treatment of MSD, postoperative complications occur in 17-51% of cases, and they often affect negatively the natural history of the disease, abbreviating the patient’s already short survival. On the other hand, when considering surgery, there is scientific evidence on the benefits of this treatment, even with better results than radiotherapy alone, because it enables the direct intracanal decompression of the structures (resection of the tumor mass), as well as the mechanical stabilization of the spine by surgical fixation. These procedures may lead to maintenance/recovery of urinary function, reduction in pain, and recovery, in some cases, of the ability to walk.

The anticipation of adverse events from surgery in cases of MSD and the prediction of the positive or negative evolution of the cases operated using predictive models (PMs) also resulted in many researches. Several PMs are available in the literature, some of which help in patient selection, but the majority has the primary function of estimating patient survival time. The authors did not find in the current literature any PM that would help estimate early morbidity and mortality after the surgical treatment of MSD. Thus, the objectives of the present study were to evaluate the clinical and laboratory parameters that influence early morbidity and mortality after the surgical treatment of MSD and determine, based on the multivariate analysis of these parameters, a PM that helps the attending physician estimate early postoperative morbidity and mortality in patients with vertebral metastatic lesions.

Materials and Methods

We conducted a retrospective analysis of a cohort of patients operated for MSD between January 2002 and December 31, 2015. The present study was approved by the Ethics Committee of the institution where it was performed. As this was a retrospective study, there was no need to apply the Informed Consent Form.

Inclusion Criteria

(1) Single and consecutive patients undergoing open surgery; and (2) presence of anatomopathological study confirming the diagnosis of metastatic vertebral malignant neoplasia.

Conclusion

The predictive model estimates morbidity and mortality after spinal metastasis surgery and hierarchizes risks as low, moderate, high and extreme.
Exclusion Criteria
(1) Primary surgery or revision in another institution; (2) incomplete medical record data; and (3) loss to follow-up.

Determination of possible prognostic risk factors
The authors considered the following preoperative characteristics as possible risk factors for the occurrence of negative outcomes in MSD:

1. male gender;
2. age ≥ 70 years;
3. presence of at least one comorbidity from the list in Box 1.

Possible Outcomes for the Predictive Model of the Treatment for Vertebral Metastatic Disease
In order to elaborate the PM, the following outcomes were considered:

1. mortality 30 days after surgery;
2. mortality 90 days after surgery;
3. incidence of at least one complication.

Postoperative complications were those occurring within 30 days of the procedure, based on the definition of the World Health Organization (WHO). They were characterized and classified by the method of Rampersaud et al only the major were included, and they were grouped into:

1. local/systemic;
2. infectious/non-infectious.

Box 1 Comorbidity index

- Diabetes
- Chronic lung disease
- Previous myocardial infarction
- Congestive heart failure
- Cardiac arrhythmia
- Pulmonary circulation disease
- Peripheral vascular disease
- Cerebrovascular disease
- Dementia
- Renal insufficiency
- Liver failure
- Connective tissue disease
- Coagulopathy
- Previous paralysis
- Peptic ulcer
- Acquired immunodeficiency syndrome

Predictive Model
Comparing the frequency of occurrence of outcomes in individuals exposed and not exposed to possible risk factors, the multivariate analysis determining the factors with statistical significance and the factors associated with all outcomes enabled the ranking of the risks as low, moderate, high and extreme. The PM was tested for trend of occurrence of events, capability of discrimination and calibration.

Statistical analysis
Continuous variables were dichotomized and treated as categorical variables. The Fisher and Chi-squared tests were applied for risk assessment. The analysis of mortality at 30 and 90 days postoperatively was performed separately for each point in time. The Kaplan-Meier method was used to elaborate survival curves. The final PM categories were compared for the trend of occurrence of events through the Chi-squared test. The discriminatory capacity and calibration of the final model were analyzed using the receiver operating characteristic (ROC) curve and the Hosmer-Lemeshow test respectively. Logistic regression models were applied to the groups of variables, provided that p < 0.05 in the bivariate analysis. The confidence interval was of 95% for all analyzes. The following software were used to perform the statistical tests: R (R Foundation for Statistical Computing, Vienna, Austria), version 3.3.1, and MedCalc (MedCalc Software, Oostend, Belgium), version 17.6.17-18

Results
Patients
A total of 306 patients were submitted to surgery, and after the adoption of the inclusion and exclusion criteria, 205 patients were included in the study. The general characteristics of the studied patients are presented in Table 1.

Possible Prognostic Risk Factors
A total of 114 patients (55%) were male; 48 patients (23%) were ≥ 70 years old; 65 patients (32%) had 1 or more comorbidities; 81 patients (40%) had tumors that were not slow-growing; 40 patients (20%) had leukocytes ≥ 13,000 cells/µL (mean of 9,700 cells/µL); and 51 patients (25%) had lymphocytes < 1,000 cells/µL (mean of 1,600 cells/µL).

Possible Outcomes of Metastatic Spinal Disease
Treatment in the Development of the Predictive Model
The mortality at 30 days was of 17% (n = 36), and at 90 days, it was of 43% (n = 88). The incidence of postoperative complications was of 31% (n = 64), and it is presented in Table 2.

Statistical Analysis
Tables 3 and 4 present a risk analytical study regarding the possible predictors of outcomes. We found that the characteristics that act as an independent risk factor for the occurrence of systemic complications are: age ≥ 70 years
old (odds ratio [OR]: 2.44, \( p < 0.05 \)); primary tumor that is not slow-growing (OR: 2.54; \( p < 0.05 \)), and total lymphocyte count < 1,000 cells/µL (OR: 3.19; \( p < 0.01 \)). Primary tumor that is not slow-growing is the only preoperative feature associated with surgical site infection (OR: 2.52; \( p < 0.05 \)).

Age/C\( \geq 70 \) years old and primary tumor that is not slow-growing are independent risk factors for infectious complication (OR: 2.82; \( p < 0.05 \); and OR: 3.22; \( p < 0.01 \) respectively). After the multivariate analysis, the complication-related mortality was associated with age/C\( \geq 70 \) years old (OR: 3.35; \( p < 0.01 \)), presence of comorbidities (OR: 2.74; \( p < 0.01 \), and total lymphocyte count < 1,000 cells/µL (OR: 3.61; \( p < 0.0001 \)). Death related to infectious complications, after the analysis of the multiple variables, correlates with age/C\( \geq 70 \) years (OR: 2.61; \( p < 0.05 \)), primary tumor that is not slow-growing (OR: 2.82; \( p < 0.05 \), and total lymphocyte count < 1,000 cells/µL (OR: 4.23; \( p < 0.01 \)).

**Predictive Model**

- Table 4 explains the independent risk factors for the outcomes of the present research. Those with statistical significance for the three outcomes were included in the PM, which is illustrated in Box 2.

- Figures 1, 2 and 3 show the survival curves at 90 days postoperatively according to the characteristics used to develop the final PM. Exposure to none, one, two or three factors was the criterion that defined the categories of low, moderate, high and extreme risk respectively. Figure 4 illustrates the incidence of early morbidity and mortality according to each risk category of the PM. Figure 5 shows survival at 90 days postoperatively according to the four risk categories.

**Box 2 Predictive model**

| Risk factors                                      | Present factors | Risk category |
|--------------------------------------------------|-----------------|---------------|
| Presence of at least one comorbidity             | 0               | Low           |
| Primary tumor that is not slow-growing            | 1               | Moderate      |
| Total peripheral blood lymphocyte count below 1,000 cells/µL | 2               | High          |
| Total                                             | 3               | Extreme       |

Note: According to Rampersaud et al., grade-III complication requires significant treatment (such as unexpected surgery or readmission, for example), increasing the hospital stay by more than 7 days and/or causing sequelae for more than 6 months. Grade-IV complication is one that results in death.

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**Table 1** General characteristics of the 205 patients who underwent surgery for vertebral metastasis

| Variables                        | \( n \) (%) |
|----------------------------------|-------------|
| Male gender                      | 114 (55%)   |
| Age (years), mean ± standard deviation | 58.9 ± 13.3 |
| Deaths before discharge          | 14 (7%)     |
| Alive during data collection     | 12 (6%)     |
| Approach                         |             |
| Cervical/cervicothoracic         | 11 (5%)     |
| Thoracic                         | 70 (34%)    |
| Thoracolumbar                    | 71 (35%)    |
| Lumbar/Lumbosacral               | 49 (24%)    |
| Multiple                         | 4 (2%)      |
| Posterior approach               | 201 (95%)   |
| Primary tumor                    |             |
| Prostate                         | 51 (24%)    |
| Breast                           | 43 (21%)    |
| Multiple myeloma                 | 26 (13%)    |
| Unknown                          | 20 (10%)    |
| Uterus                           | 12 (6%)     |
| Other                            | 53 (25%)    |
| Comorbidities                    |             |
| Diabetes                         | 25 (12%)    |
| Chronic lung disease             | 20 (10%)    |
| Cardiac insufficiency            | 7 (3%)      |
| Previous myocardial infarction   | 5 (2%)      |
| Cardiac arrhythmia               | 4 (2%)      |
| Other                            | 13 (6%)     |

**Table 2** Incidence of complications after surgical treatment for vertebral metastasis

| Variables                      | \( n \) (%) |
|-------------------------------|-------------|
| Systemic                      |             |
| Pneumonia                     | 14 (6.8%)   |
| Death by unknown cause        | 11 (5.4%)   |
| Gastrointestinal bleeding     | 4 (2.0%)    |
| Respiratory failure           | 3 (1.5%)    |
| Renal insufficiency           | 2 (1.0%)    |
| Sepsis with urinary focus     | 1 (0.5%)    |
| Sepsis with unknown focus     | 1 (0.5%)    |
| Other                         | 4 (2.0%)    |
| Subtotal                      | 40 (19.5%)  |

| Local Complications            |             |
|--------------------------------|-------------|
| Wound infection                | 20 (9.8%)   |
| Dehiscence                     | 2 (1.0%)    |
| Hematoma                       | 1 (0.5%)    |
| Neurological worsening         | 1 (0.5%)    |
| Subtotal                       | 24 (11.7%)  |
| Infectious                     | 36 (17.5%)  |
| Non-infectious                 | 28 (13.7%)  |
| Grade III                      | 19 (9.3%)   |
| Grade IV                       | 45 (21.9%)  |
| Total                          | 64 (31.2%)  |

Note: According to Rampersaud et al., grade-III complication requires significant treatment (such as unexpected surgery or readmission, for example), increasing the hospital stay by more than 7 days and/or causing sequelae for more than 6 months. Grade-IV complication is one that results in death.
Table 3  Bivariate analysis of preoperative characteristics as possible prognostic factors of early morbidity and mortality after surgical treatment for vertebral metastasis

| Characteristic                        | n (%) | Odds ratio for mortality at 30 days (CI) | Odds ratio for mortality at 90 days (CI) | Odds ratio for incidence of complications (CI) |
|---------------------------------------|-------|------------------------------------------|------------------------------------------|-----------------------------------------------|
| Sex                                   |       |                                          |                                          |                                               |
| Female                                | 91 Ref. | Ref.                                     | Ref.                                     | Ref.                                          |
| Male                                  | 114 1.00* (0.48–2.06) | 1.05* (0.60–1.83) | 1.15* (0.63–2.10) |                                               |
| Age (years)                           |       |                                          |                                          |                                               |
| < 70                                  | 157 Ref. | Ref.                                     | Ref.                                     | Ref.                                          |
| ≥ 70                                  | 48 2.94*** (1.37–6.31) | 2.08** (1.08–4.00) | 3.13**** (1.60–6.14) |                                               |
| Comorbidities                         |       |                                          |                                          |                                               |
| Absent                                | 140 Ref. | Ref.                                     | Ref.                                     | Ref.                                          |
| Present                               | 65 2.60*** (1.24–5.41) | 2.87**** (1.57–5.27) | 2.61*** (1.40–4.88) |                                               |
| Slow-growing primary tumor            |       |                                          |                                          |                                               |
| Yes                                   | 124 Ref. | Ref.                                     | Ref.                                     | Ref.                                          |
| No                                    | 81 2.21** (1.07–4.59) | 3.79**** (2.10–6.85) | 2.48*** (1.35–4.56) |                                               |
| Leukocytes (µL)                       |       |                                          |                                          |                                               |
| < 13,000                              | 165 Ref. | Ref.                                     | Ref.                                     | Ref.                                          |
| ≥ 13,000                              | 40 1.78* (0.77–4.08) | 3.17*** (1.54–6.52) | 1.81* (0.88–3.74) |                                               |
| Lymphocytes (µL)                      |       |                                          |                                          |                                               |
| ≥ 1,000                               | 154 Ref. | Ref.                                     | Ref.                                     | Ref.                                          |
| < 1,000                               | 51 3.06*** (1.44–6.52) | 1.96** (1.03–3.72) | 2.71*** (1.40–5.25) |                                               |

Abbreviations: CI, 95% confidence interval; Ref., reference variable.
Note: Values of p: * if p > 0.05; ** if p between 0.05 and 0.01; *** if p between 0.01 and 0.001; **** if p < 0.001.

Table 4  Multivariate analysis of preoperative characteristics as possible prognostic factors of early morbidity and mortality after surgical treatment for vertebral metastasis

| Characteristic                        | n (%) | Odds ratio for mortality at 30 days (CI) | Odds ratio for mortality at 90 days (CI) | Odds ratio for incidence of complications (CI) |
|---------------------------------------|-------|------------------------------------------|------------------------------------------|-----------------------------------------------|
| Age (years)                           |       |                                          |                                          |                                               |
| < 70                                  | 157 Ref. | Ref.                                     | Ref.                                     | Ref.                                          |
| ≥ 70                                  | 48 2.73*** (1.20–6.20) | 2.06* (0.98–4.36) | 3.15*** (1.51–6.59) |                                               |
| Comorbidities                         |       |                                          |                                          |                                               |
| Absent                                | 140 Ref. | Ref.                                     | Ref.                                     | Ref.                                          |
| Present†                              | 65 2.33*** (1.07–5.07) | 2.60*** (1.33–5.12) | 2.37** (1.21–4.65) |                                               |
| Slow-growing primary tumor            |       |                                          |                                          |                                               |
| Yes†                                  | 124 Ref. | Ref.                                     | Ref.                                     | Ref.                                          |
| No†                                   | 81 2.56*** (1.17–5.62) | 4.30**** (2.23–8.30) | 3.07*** (1.56–6.04) |                                               |
| Leukocytes (µL)                       |       |                                          |                                          |                                               |
| < 13,000                              | 165 Ref. | Ref.                                     | Ref.                                     | Ref.                                          |
| ≥ 13,000                              | 40 -- | 2.94** (1.29–6.70) | -- |                                               |
| Lymphocytes (µL)                      |       |                                          |                                          |                                               |
| ≥ 1,000†                              | 154 Ref. | Ref.                                     | Ref.                                     | Ref.                                          |
| < 1,000†                              | 51 3.07*** (1.37–6.87) | 2.19** (1.06–4.51) | 2.84*** (1.37–5.85) |                                               |

Abbreviations: CI, 95% confidence interval; Ref., reference variable.
Notes: † Characteristic included in the predictive model (PM) by the association with the three outcomes. Values of p: * if p > 0.05; ** if p between 0.05 and 0.01; *** if p between 0.01 and 0.001; **** if p < 0.001.
Comparing the categories from lowest to highest risk, there was a progressive increase in the occurrence of outcomes, following a linear trend (p < 0.0001). The same occurred when analyzing systemic complications (p < 0.0001), infectious complications (p < 0.0001), death from complication (p < 0.0001), death from infectious complication (p < 0.0001) and surgical wound infection (p < 0.05). The discriminatory capacity of the model, according to the ROC curve, was of 72% for the 30-day mortality, 73% for the 90-day mortality, and 70% for the incidence of complications. There was no evidence of lack of calibration by the Hosmer-Lemeshow test.

Discussion

The complications of MSD in relation to unfavorable surgical outcomes, including death, which is the worst of them, are in no way comparable to those obtained in the surgical treatment of most orthopedic diseases. In MSD surgery, 90-day mortality is important, and most authors agree that this time interval is the minimum expected to indicate a highly morbid and palliative procedure. However, there are few studies addressing this cutoff point in postoperative survival.

Preoperative clinical characteristics are supposed to exert greater influence on early surgical outcomes compared with long-term outcomes. Traditional PMs, such as the scoring system of Tokuhashi, focus more on features that are associated with mid- and long-term surgical outcomes, such as the presence of visceral metastases. Perhaps because of this, the Tokuhashi score only estimates events from 180 days after the procedure. More recently, Schoenfeld et al showed the serum level of albumin as a strong risk factor for mortality within 30 days, even surpassing the rate of tumor progression. The present study, hoping to identify more significant prognostic factors that could positively alter outcomes within three months of the procedure, evaluates some clinical features that are less valued in previous studies, such as comorbidities and peripheral blood cell count.

Comorbidity rates are rarely addressed in MSD research. Patil et al reported a 50% increased risk of complications from MSD surgery in patients with two comorbidities, as reported by Elixhauser et al. Arrigo et al noted an increased risk of up to five times in patients with two or more comorbidities mentioned by Charlson et al. The present work shows that the presence of at least one comorbidity among those obtained by the combination of those comorbidities mentioned by Charlson et al and Elixhauser et al represents an independent risk factor for early morbidity and mortality after metastatic spinal surgery. This is a risk factor not previously reported in the literature.

Secondary lymphocytopenia may have several etiologies, including malnutrition, infection, corticosteroid use, radiotherapy and chemotherapy. These conditions are common in MSD. Lymphocytopenia reduces the action of lymphocytes B, T and natural killers against bacteria, viruses and fungi, leaving the body susceptible to local or distant infections. Zinc and some vitamins play a role in cell maturation, and their deficiency may partly explain the lymphocytopenia presented by malnourished patients. Although low lymphocyte count is an old nutritional marker and a known factor of poor prognosis in cancer, surprisingly, the literature review does not show
Preoperative lymphocytopenia as a risk factor for MSD surgery. Revised studies use a different cutoff point for the cell count (1,500/µL), which may explain the conflicting findings. On the other hand, in the current research, the total lymphocyte count <1,000/µL proved to be a strong risk factor. The presence of these data represents a significant increase factor in the early occurrence of complications and death. It was related to a nearly five-fold increased risk of death from infectious complications. In this series, one patient with total preoperative total lymphocyte count of 245/µL died due to sepsis by *Candida* sp, a rare causative agent of systemic infection.

Previous studies have shown that older patients have worse MSD surgical outcomes. In the present study, we identified that individuals aged 70 years and older have a 2.73-fold increased risk of 30-day mortality; 3.15 times more total complications; 2.44 times more systemic complications; 2.82 times more infectious complications; 3.35 times more incidence of death by complications; and 2.61 times more incidence of death from infectious complications. However, because it failed to predict the 90-day mortality, this feature was excluded from the final PM.

The results about the influence of the aggressiveness of the primary tumor in the incidence of complications and mortality at 30 and 90 days after surgery are not surprising. Several previous studies report worse prognosis in groups of patients with tumors with more aggressive histological types.

In the present work, a PM was proposed to estimate early morbidity and mortality in MSD that considers not only the aggressiveness of the primary tumor, but also the patient’s systemic condition. In their management algorithm, state that the patient’s systemic condition is a decisive factor in the surgical decision-making. However, none of the many existing PMs in the literature consider the presence of comorbidities and the patient’s immune capacity. Only Ghori et al refer to the influence on nutritional status by analyzing serum albumin, and they suggest this factor as a possible tool to estimate complications.

The proposed PM estimates, by category, the occurrence of unfavorable events within 90 days of surgery. In the present study, low-risk patients had the lowest postoperative morbidity and mortality rates, while patients in the extreme-risk category had the worst outcomes (Figures 4 and 5). Future research could shed light on whether this PM is useful in guiding the therapeutic decision. It is believed that, due to its simplicity of application, this PM could be one of the first tools used to evaluate the patient with MSD.

The present research has several limitations, and undoubtedly needs future validation, especially in relation to the PM results. Due to the retrospective design, selection, measurement and susceptibility, bias may have occurred. The results may not be generalizable because the study was conducted in a single institution and on a typically heterogeneous sample.

**Conclusion**

Preoperative factors that enable the prediction of early morbidity and mortality for MSD are age ≥70 years, presence of at least one comorbidity of the specific index, primary tumor that is not slow-growing, leukocytes ≥13,000 cells/µL and total lymphocyte count <1,000 cells /µL. The proposed PM enables...
the estimate of the morbidity and mortality of surgery in cases of MSD, and the ranking of the surgical risks as low, moderate, high and extreme.

Conflicts of Interest
The authors have none to declare.

References
1. Patil CG, Lad SP, Santarelli J, Boakye M. National inpatient complications and outcomes after surgery for spinal metastasis from 1993-2002. Cancer 2007;110(03):625–630.
2. Cohen J, Alan N, Zhou J, Kojo Hamilton D. The 100 most cited articles in metastatic spine disease. Neurosurg Focus 2016;41(02):E10.
3. Rades D, Huttenlocher S, Dunst J, et al. Matched pair analysis comparing surgery followed by radiotherapy and radiotherapy alone for metastatic spinal cord compression. J Clin Oncol 2010;28(22):3597–3604.
4. Finkelstein JA, Zaveri G, Wai E, Vidmar M, Kreder H, Chow E. A population-based study of surgery for spinal metastases. Survival rates and complications. J Bone Joint Surg Br 2003;85(07):1045–1050.
5. Wise JJ, Fischgrund JS, Herkowitz HN, Montgomery D, Kurz LT. Complication, survival rates, and risk factors of surgery for metastatic disease of the spine. Spine 1999;24(18):1943–1951.
6. Schoenfeld AJ, Le HV, Marjoua Y, et al. Assessing the utility of a clinical prediction score regarding 30-day morbidity and mortality following metastatic spinal surgery: the New England Spinal Metastasis Score (NESMS). Spine J 2016;16(04):482–490.
7. Patchell RA, Tibbs PA, Regine WF, et al. Direct decompressive surgical resection in the treatment of spinal cord compression caused by metastatic cancer: a randomised trial. Lancet 2005;366(9486):643–648.
8. Choi D, Fox Z, Albert T, et al. Rapid improvements in pain and quality of life are sustained after surgery for spinal metastases in a large prospective cohort. Br J Neurosurg 2016;30(03):337–344.
9. Ibrahim A, Crockard A, Antonietti P, et al. Does spinal surgery improve the quality of life for those with extradural (spinal) osseous metastases? An international multicenter prospective observational study of 223 patients. Invited submission from the Joint Section Meeting on Disorders of the Spine and Peripheral Nerves, March 2007. J Neurosurg Spine 2008;8(03):271–278.
10. Quan GM, Vital JM, Aurouer N, et al. Surgery improves pain, function and quality of life in patients with spinal metastases: a prospective study on 118 patients. Eur Spine J 2011;20(11):1970–1978.
11. Tokuhashi Y, Uei H, Oshima M, Ajiro Y. Scoring system for prediction of metastatic spine tumor prognosis. World J Orthop 2014;5(03):262–271.
12. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis 1987;40(05):373–383.
13. Elixhauser A, Steiner C, Harris DR, Coffey RM. Comorbidity measures for use with administrative data. Med Care 1998;36(01):8–27.
14. Tomita K, Kawahara N, Kobayashi T, Yoshida A, Murakami H, Akamaru T. Surgical strategy for spinal metastases. Spine 2001;26(03):298–306.
15. Haynes AB, Weiser TG, Berry WR, et al; Safe Surgery Saves Lives Study Group. A surgical safety checklist to reduce morbidity and mortality in a global population. N Engl J Med 2009;360(05):491–499.
16. Rampersaud YR, Moro ER, Neary MA, et al. Intraoperative adverse events and related postoperative complications in spine surgery: implications for enhancing patient safety founded on evidence-based protocols. Spine 2006;31(13):1503–1510.
17. R Core Team. R: A language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing; 2016.
18. BVBA, MedCalc Software. Ostende, Belgium 2017.
19. George R, Jeja J, Ramkumar G, Chacko AG, Leng M, Thyran P. Interventions for the treatment of metastatic extradural spinal cord compression in adults. Cochrane Database Syst Rev 2008;(04):CD006716.
20. Schoenfeld AJ, Leonard DA, Saadat E, Bono CM, Harris MB, Ferrone ML. Predictors of 30- and 90-Day Survival Following Surgical Intervention for Spinal Metastases: A Prognostic Study Conducted at Four Academic Centers. Spine 2016;41(08):E503–E509.
21. Tokuhashi Y, Matsuzaki H, Oda H, Oshima M, Ryu J. A revised scoring system for preoperative evaluation of metastatic spine tumor prognosis. Spine 2005;30(19):2186–2191.
22. Arigo RT, Kalanithi P, Cheng I, et al. Charlson score is a robust predictor of 30-day complications following spinal metastasis surgery. Spine 2011;36(19):E1274–E1280.
23. Brass D, McKay P, Scott F. Investigating an incidental finding of lymphopenia. BMJ 2014;348:g1721.
24. Bharadwaj S, Ginoya S, Tandon P, et al. Malnutrition: laboratory markers vs nutritional assessment. Gastroenterol Rep (Oxf) 2016;4(04):272–280.
25. Trédan O, Ray-Coquard I, Chvetzoff G, et al. Validation of prognostic scores for survival in cancer patients beyond first-line therapy. BMC Cancer 2011;11:95.
26. Luksanaprucksa P, Buchowski JM, Hotchkiss W, Tongsaiz S, Wilarratsumi S, Chotivichit A. Prognostic factors in patients with spinal metastasis: a systematic review and meta-analysis. Spine J 2017;17(05):689–708.
27. Chi JH, Gokaslan Z, McCormick P, Tibbs PA, Krysco RJ, Patchell RA. Selecting treatment for patients with malignant epidural spinal cord compression—does age matter?: results from a randomized clinical trial Spine 2009;34(05):431–435.
28. Laufer I, Rubin DG, Lis E, et al. The NOMS framework: approach to the treatment of spinal metastatic tumors. Oncologist 2013;18(06):744–751.
29. Ghori AK, Leonard DA, Schoenfeld AJ, et al. Modeling 1-year survival after surgery on the metastatic spine. Spine J 2015;15(11):2345–2350.