■ SPINE

Modified Frailty Index as a novel predictor for the incidence and severity of postoperative complications after spinal metastases surgery

A PROSPECTIVE COHORT STUDY

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Aims

Frailty has been gathering attention as a factor to predict surgical outcomes. However, the association of frailty with postoperative complications remains controversial in spinal metastases surgery. We therefore designed a prospective study to elucidate risk factors for postoperative complications with a focus on frailty.

Methods

We prospectively analyzed 241 patients with spinal metastasis who underwent palliative surgery from June 2015 to December 2021. Postoperative complications were assessed by the Clavien-Dindo classification; scores of ≥ Grade II were defined as complications. Data were collected regarding demographics (age, sex, BMI, and primary cancer) and preoperative clinical factors (new Katagiri score, Frankel grade, performance status, radiotherapy, chemotherapy, spinal instability neoplastic score, modified Frailty Index-11 (mFI), diabetes, and serum albumin levels). Univariate and multivariate analyses were developed to identify risk factors for postoperative complications ($p < 0.05$).

Results

Overall, 57 postoperative complications occurred in 47 of 241 (19.5%) patients. The most common complications were wound infection/dehiscence, urinary tract infection, and pneumonia. Univariate analysis identified preoperative radiotherapy ($p = 0.028$), mFI ($p < 0.001$), blood loss ≥ 500 ml ($p = 0.016$), and preoperative molecular targeted drugs ($p = 0.030$) as potential risk factors. From the receiver operating characteristic curve, the clinically optimal cut-off value of mFI was 0.27 (sensitivity, 46.8%; specificity, 79.9%). Multivariate analysis identified mFI ≥ 0.27 (odds ratio (OR) 2.94 (95% CI 1.44 to 5.98); $p = 0.003$) and preoperative radiotherapy (OR 2.11 (95% CI 1.00 to 4.46); $p = 0.049$) as significant risk factors. In particular, urinary tract infection ($p = 0.012$) and pneumonia ($p = 0.037$) were associated with mFI ≥ 0.27. Furthermore, the severity of postoperative complications was positively correlated with mFI ($p < 0.001$).

Conclusion

The mFI is a useful tool to predict the incidence and the severity of postoperative complications in spinal metastases surgery.

Cite this article: *Bone Joint J* 2024;106-B(12):1469–1476.

Introduction

In recent years, because of advances in cancer treatment, the number of cancer survivors with spinal metastases has increased rapidly.[1] Approximately 10% to 20% of patients with spinal metastases develop severe pain and/or neurological dysfunction because of pathological fractures or spinal cord compression.[2,3] These symptoms severely impair patients' performance status (PS) and quality of life (QoL), which can result in a poor prognosis.[4,5]

Current evidence shows that spinal surgery improves patients' ambulatory status, PS, QoL, and survival, which are the goals of cancer treatment.[2,4–8] Historically, surgical decision-making has been based on a prognosis prediction system,

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doi:10.1302/0301-620X.106B12.BJJ-2024-0100.R1 $2.00

Bone Joint J 2024;106-B(12):1469–1476.

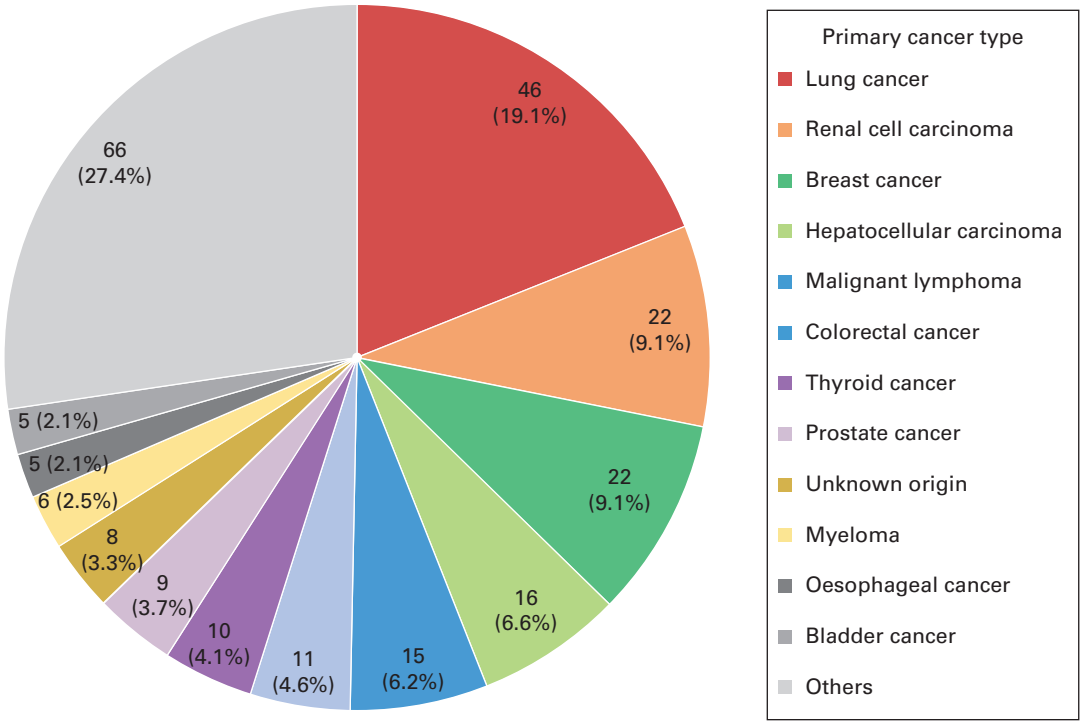

Fig. 1

Primary cancer types of 241 patients with spinal metastases.

such as the new Katagiri score.[9] However, postoperative complications may hamper or decelerate achievement of the potential benefits of surgery. Therefore, risk factors for postoperative complications should also be considered before surgical decision-making. Many studies have reported the complication rate of spinal metastasis surgery to range from 5.3% to 76.2%.[8,10–13] However, most of these studies are vague in their definition of complications, and the risk factors for postoperative complications of spinal metastasis surgery remain unclear.

A recent retrospective study with a clear definition of complications – the Clavien-Dindo classification[14] – identified lower albumin levels, additional comorbidities, three or more spine levels operated upon, and combined surgical approach as the independent risk factors for 30-day complications after spinal metastases surgery.[11] In the last decade, frailty – ageing-related decrease in physiological reserves and increase in vulnerability to physiological stressors – has attracted much attention in predicting surgical outcomes.[15] The Modified Frailty Index-11 (mFI)[16] is the most common tool to assess the degree of frailty; it has been reported to be useful in predicting postoperative complications in spinal and cancer surgery.[17–19] The items included in the mFI are listed in Supplementary Table i.[20] However, whether mFI can be a risk predictor for complications after spinal metastasis surgery is controversial,[21,22] and a clinically optimal cut-off value of mFI is still unclear. We therefore designed a prospective study to identify risk factors for postoperative complications using the Clavien-Dindo classification with a focus on mFI.

Methods

This study was approved by the ethics committee and institutional review board of our hospital. Written informed consent was obtained from each patient. The study was conducted in accordance with the principles of the Declaration of Helsinki[23] and with the laws and regulations of our country.

Patients and procedures. We prospectively enrolled 289 consecutive patients with spinal metastases diagnosed by plain radiography, CT, MRI, bone scintigraphy, positron emission tomography, and/or needle biopsy who had an indication for surgery in our hospital from June 2015 to December 2021. The indications for surgery were progressive neurological deficits, mechanical instability (Spinal Instability Neoplastic Score (SINS)[24] of ≥ 7), or intractable pain refractory to conservative care. The indication for surgery was determined by consensus among multiple spinal surgeons (YK, TY, YT, KK), except for emergency surgery performed within 48 hours of diagnosis of surgical indication due to rapidly progressive neurological dysfunction or advanced neuropathy. The exclusion criteria were: impaired consciousness due to cerebral metastasis; total en bloc spondylectomy for oligometastases; complete paraplegia for > 48 hours; and refusal of surgery after sufficient explanation. Demographic details (age, sex, BMI), and clinical characteristics except for the primary tumour type, were recorded just before surgery. The surgeon chose the surgical procedure based on the patient's estimated survival, neurological function, degree of spinal cord compression, and SINS. The surgical procedure was generally posterior decompression and instrumentation, while

Table I. Number of postoperative complications according to the Clavien-Dindo classification.

Variable	Wound dehiscence/ infection	Urinary tract infection	Pneumonia	Implant failure, adjacent fracture	VTE	Others	Total
Complications, n (%)							
Grade II*	9 (15.8)	5 (8.8)	6 (10.5)		6 (10.5)	6 (10.5)	32 (56.1)
Grade III†	10 (17.5)	1 (1.8)	1 (1.8)	5 (8.8)		3 (5.3)	20 (35.1)
Grade IV‡		1 (1.8)				1 (1.8)	2 (3.5)
Grade V§	1 (1.8)	1 (1.8)	1 (1.8)				3 (5.3)
Total	20 (35.1)	8 (14.0)	8 (14.0)	5 (8.8)	6 (10.5)	10 (17.5)	57 (100.0)
Patients with complications, n (%)¶							
Grade II*	6 (12.8)	4 (8.5)	4 (8.5)		5 (10.6)	3 (6.4)	22 (46.8)
Grade III†	10 (21.3)	1 (2.1)	1 (2.1)	5 (10.6)		3 (6.4)	20 (42.6)
Grade IV‡		1 (2.1)				1 (2.1)	2 (4.3)
Grade V§	1 (2.1)	1 (2.1)	1 (2.1)				3 (6.4)
Total	17 (36.2)	7 (14.9)	6 (12.8)	5 (10.6)	5 (10.6)	7 (14.9)	47 (100.0)

*Requiring pharmacological treatment with drugs other than those allowed for Grade I.
†Requiring surgery/endoscopy.
‡Life-threatening complication.
§Death due to complication.
¶Patients with multiple complications were classified into the one with the highest grade.
VTE, venous thromboembolism.

instrumentation alone was performed for patients without neurological deficits and severe spinal cord compression. Because we focused on symptom relief by stabilization with or without decompression and local control by adjuvant therapies rather than direct debulking, neither corpectomy nor an anterior approach was performed. The primary tumour type was confirmed by the postoperative pathological diagnoses of samples collected during surgery, and an unknown primary tumour was defined as a tumour with no identifiable primary site.[25] Postoperative treatments including radiotherapy and chemotherapy was determined by a multidisciplinary tumour board focused on bone metastases. Postoperative radiotherapy and/or chemotherapy were commenced two weeks or more postoperatively. Patients were followed up one, three, and six months postoperatively, and subsequently every three months until death.

Patient characteristics. In total, 241 patients were enrolled. We excluded five patients with solitary spinal metastasis who underwent total en bloc spondylectomy and 43 who did not undergo surgery because of impaired consciousness (n = 4), complete paraplegia for > 48 hours and little hope for improvement (n = 3), and refusal of surgical treatment (n = 36). The mean age was 67.3 years (SD 11.6; 24 to 92), and 149 (61.8%) of 241 patients were male. The most common primary cancer was lung cancer (n = 46; 19.1%), followed by renal cell carcinoma (n = 22; 9.1%) and breast cancer (n = 22; 9.1%) (Figure 1). The median postoperative survival time was 10.8 months (IQR 3.5 to 65.8).

Primary outcome. The primary outcome was postoperative complications assessed as Clavien-Dindo Grade ≥ II within three months postoperatively. Given the nature of surgery for spinal metastases, a Grade II blood transfusion was not included as a complication. A patient with multiple complications was classified as having the one with the highest grade.

Explanatory variables. Regarding demographic details, patients aged ≥ 70 years reportedly have a higher risk of complications.[25] Additionally, recent studies have demonstrated that patients aged ≥ 80 years are at higher risk than those aged 70 to 79 years.[26,27] Therefore, age was stratified into < 70, 70 to 79, and ≥ 80 years. BMI ≥ 30 kg/m^2 was considered as a candidate variable because it is a risk factor for venous thromboembolism[28,29] and ≥ 500 ml blood loss.[29]

Of the clinical factors, primary cancer type, visceral metastasis, serum albumin level (< 3.5 g/dL), multiple bone metastases, Eastern Cooperative Oncology Group Performance Status, preoperative Frankel grade, and preoperative chemotherapy were considered as explanatory variables. These variables consist of prognosis scoring systems such as the revised Tokuhashi score,[30] new Katagiri score,[9] and New England Metastasis Score,[31] which is associated with 30-day major complications as well as prognosis.[32] The part of the new Katagiri score pertaining to the primary lesion was used to evaluate primary cancer malignancy. Preoperative radiotherapy and molecular targeted drugs were also included because of their association with wound dehiscence and/or infection.[33,34] HbA1c ≥ 6.5% was also included as a potential risk factor for postoperative infection.[35] As an indicator of severity of frailty, the mFI-11 was used as an explanatory variable after calculating the cut-off value.[16] The total SINS was used to assess spinal instability.[24] If a patient had multiple lesions, the lesion with the highest score was included. The tumour location was categorized based on the section of the lesion in the SINS.

Surgery-related factors including operating time, blood loss, number of fused vertebrae, screw technique (open or percutaneous), and surgical method (decompression with instrumentation or instrumentation alone) can affect the postoperative course. Based on a prior report,[29] blood loss ≥ 500 ml was considered as a potential risk factor. Because the degree of invasiveness depends on the number of fused vertebrae, screw technique, and surgical method, these variables were also included.

Statistical analysis. Statistical analyses were performed using SPSS Statistics v. 28.0 (IBM, USA). Data are presented as means and SDs, or medians with IQRs. Continuous variables were analyzed by the independent-samples *t*-test or Mann-Whitney U test, and categorical variables were analyzed by the

Table II. Demographics, clinical factors, and surgery-related factors of patients with and without complications.

Variable	Total	Without complications	With complications	p-value
Patients, n	241	194	47	
Demographics				
Mean age, yrs (SD)	67.3 (11.6)	66.4 (11.8)	70.9 (9.9)	0.013*
≥ 80 yrs, n (%)	28 (11.6)	20 (10.3)	8 (17.0)	0.198‡
≥ 70 yrs, n (%)	115 (47.7)	88 (45.5)	27 (57.4)	0.137‡
Male sex, n (%)	149 (61.8)	115 (59.3)	34 (72.3)	0.098‡
Mean BMI, kg/m^2 (SD)	21.0 (3.9)	20.9 (4.0)	21.4 (3.4)	0.213*
BMI ≥ 30 kg/m^2, n (%)	6 (2.5)	5 (2.6)	1 (2.1)	> 0.999§
Clinical factors				
Median new Katagiri score, points (IQR)	5.0 (4.0 to 7.0)	5.5 (4.0 to 6.3)	5.0 (4.0 to 7.0)	0.831†
Primary tumour type, n (%)				0.133‡
Slow growth	70 (29.1)	61 (31.4)	9 (19.2)	
Moderate growth	76 (31.5)	62 (32.0)	14 (29.8)	
Rapid growth	95 (39.4)	71 (36.6)	24 (51.1)	
Visceral metastasis	133 (55.2)	106 (54.6)	27 (57.5)	0.766‡
Multiple bone metastasis	167 (69.3)	138 (71.1)	29 (61.7)	0.208‡
Frankel classification, n (%)				0.051‡
Grade A, B, and C	98 (40.7)	73 (37.6)	25 (53.2)	
Grade D and E	143 (59.3)	121 (62.4)	22 (46.8)	
ECOGPS grade, n (%)				0.824‡
PS 1	24 (10.0)	18 (9.3)	6 (12.8)	
PS 2	38 (15.8)	31 (16.0)	7 (14.9)	
PS 3	79 (32.8)	66 (34.0)	13 (27.7)	
PS 4	100 (41.5)	79 (40.7)	21 (44.7)	
Median SINS (IQR)	11 (9.0 to 13.0)	11 (9.0 to 13.0)	11 (9.0 to 12.0)	0.778†
SINS ≥ 7, n (%)	226 (93.8)	183 (94.3)	43 (91.5)	0.470‡
SINS ≥ 13, n (%)	64 (26.6)	53 (27.3)	11 (23.4)	0.586‡
Lesion location, n (%)				0.241‡
Junctional spine (occiput–C2, C7–T2, T11–L1, L5–S1)	98 (40.7)	78 (40.2)	20 (42.6)	
Mobile spine (C3–6, L2–4)	60 (24.9)	45 (23.2)	15 (31.9)	
Semi-rigid spine (T3–10)	81 (33.6)	70 (36.1)	11 (23.4)	
Rigid spine (S2–5)	2 (0.83)	1 (0.52)	1 (2.13)	
Mean mFI (SD)	0.18 (0.09)	0.17 (0.08)	0.23 (0.10)	< 0.001*
mFI ≥ 0.27, n (%)	61 (25.3)	39 (20.1)	22 (46.8)	< 0.001‡
HbA1c ≥ 6.5%, n (%)	30 (12.5)	21 (10.8)	9 (19.2)	0.124‡
Serum albumin levels < 3.5g/dl, n (%)	104 (43.2)	80 (41.2)	24 (51.1)	0.178‡
Preoperative radiotherapy, n (%)	62 (25.7)	44 (22.7)	18 (38.3)	0.028‡
Preoperative chemotherapy, n (%)	108 (44.8)	82 (42.3)	26 (55.3)	0.106‡
Preoperative use of molecular targeted drugs, n (%)	39 (16.2)	26 (13.4)	13 (27.7)	0.030‡
Surgery-related factors				
Median operating time, mins (IQR)	196 (148 to 238)	193 (144 to 227)	216 (165 to 254)	0.535*
Median blood loss, ml (IQR)	200 (100 to 450)	180 (87 to 398)	345 (150 to 600)	0.026†
Blood loss ≥ 500 ml, n (%)	51 (21.2)	35 (18.0)	16 (34.0)	0.016‡
Median number of fused vertebrae (IQR)	7.0 (5.0 to 7.0)	7.0 (5.0 to 7.0)	7.0 (6.0 to 8.0)	0.144*
Screw technique, n (%)				0.134‡
Open technique	168 (69.7)	131 (67.5)	37 (78.7)	
Percutaneous technique	73 (30.3)	63 (32.5)	10 (21.3)	
Surgical method, n (%)				0.418‡
Decompression and instrumentation	184 (76.4)	146 (75.3)	38 (80.9)	
Instrumentation alone	57 (23.7)	48 (24.7)	9 (19.2)	

*Independent-samples *t*-test.
†Mann-Whitney U test.
‡Chi-squared test.
§Fisher's exact test.
ECOG, Eastern Cooperative Oncology Group; mFI, modified Frailty Index; PS, performance status; SINS, Spinal Instability Neoplastic Score.

Table III. Multivariate logistic regression analysis to identify risk factors for postoperative complications in spinal metastases surgery.

Variable	Multivariable analysis		Stepwise multivariable analysis	
	OR (95% CI)	p-value	OR (95% CI)	p-value
Male sex	1.42 (0.67 to 2.99)	0.356		
Frankel classification	0.61 (0.30 to 1.26)	0.185		
mFI ≥ 0.27	2.94 (1.44 to 5.98)	0.003	3.48 (1.74 to 6.94)	< 0.001
Preoperative radiotherapy	2.11 (1.00 to 4.46)	0.049	2.16 (1.06 to 4.41)	0.026
Molecular targeted drugs	1.83 (0.80 to 4.22)	0.155		
Blood loss ≥ 500 ml	1.96 (0.91 to 4.22)	0.086	2.18 (1.04 to 4.56)	0.040

mFI, modified Frailty Index; OR, odds ratio.

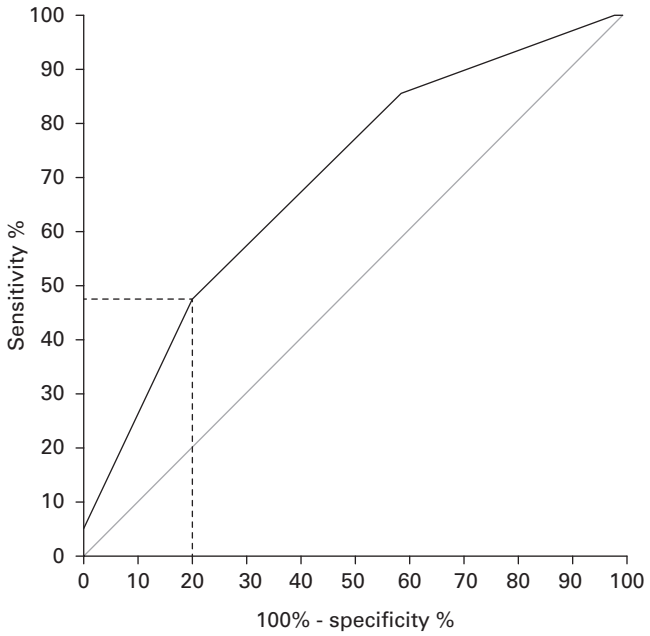

Fig. 2

The receiver operating characteristic curve for prediction of postoperative complications based on the modified Frailty Index. Sensitivity 46.8%; specificity 79.9%; cut-off value 0.23.

chi-squared test or Fisher's exact test between patients with and without complications. For continuous variables whose appropriate threshold has not been identified, the clinically optimal cut-off value was determined based on the receiver operating characteristic (ROC) curve using Youden's index. All variables with $p < 0.10$ in the comparison between patients with and without complications were eligible for inclusion as potential predictors in the multivariable logistic forced entry and stepwise regression models to identify independent risk factors for postoperative complications. Additionally, the chi-squared or Fisher's exact test was used to compare the occurrence of complications between patients with and without the identified risk factors. Spearman's rank correlation coefficient was used to evaluate the correlation between the significant risk factors and the severity of complications. Statistical significance was set at $p < 0.05$.

Results

Postoperative complications. In total, 57 complications occurred within three months postoperatively, and 47 (19.5%) patients had at least one complication. The numbers of Grade II, III, and IV complications were 32, 20, and two, respectively. One patient had one Grade III complication with two Grade II complications; eight had Grade II complications with Grade III, IV, or V complications. Consequently, there were 22 patients (46.8%) whose highest grade of complications was Grade II. The most common complication was wound dehiscence/infection (n = 20; 35.1%), followed by urinary tract infection (n = 8; 14.0%) and pneumonia (n = 8; 14.0%). More than half of the patients with wound dehiscence/infection (n = 11) required revision surgery (i.e. ≥ Grade III). Three patients (1.2%) died within three months postoperatively from the following complications (i.e. Grade V): one from sepsis after wound infection, one from sepsis after urinary tract infection, and one from respiratory failure after pneumonia (Table I).

Risk factors for postoperative complications. In the comparison of demographic details, clinical factors, and surgery-related factors between patients with and without complications, patients with complications tended to be male ($p = 0.098$), have Frankel Grade A, B, or C ($p = 0.051$), had undergone preoperative radiotherapy ($p = 0.028$), been administered preoperative molecular targeted drugs ($p = 0.016$), and had intraoperative blood loss ≥ 500 ml ($p = 0.026$, all chi-squared test) and have a higher mFI ($p < 0.001$, independent-samples *t*-test) (Table II). From the ROC curve and Youden's index, the cut-off value of mFI was 0.23 (sensitivity, 46.8%; specificity, 79.9%) (Figure 2). As a mFI ≥ 0.23 means three or more variables present, and three divided by 11 is 0.27, the cut-off value was determined to be 0.27 as a practical threshold.

A multivariable logistic regression model including these variables, with an adequate predictive ability by the Hosmer-Lemeshow goodness-of-fit chi-squared test ($p = 0.856$, seven degrees of freedom) and a model c-statistic of 0.725, recognized preoperative radiotherapy (OR 2.11 (95% CI 1.00 to 4.46); $p = 0.049$), and mFI (OR 2.94 (95% CI 1.44 to 5.98); $p = 0.003$) as significant risk factors (Table III). A backward stepwise multivariable logistic regression model, also with sufficient predictive ability by the Hosmer-Lemeshow goodness-of-fit chi-squared test ($p = 0.445$, four degrees of freedom) and a model c-statistic of 0.701, identified blood loss ≥ 500 ml (OR 2.18 (95% CI 1.04 to 4.56); $p = 0.040$), preoperative radiotherapy (OR 2.16 (95% CI 1.06 to 4.41); $p = 0.026$), and mFI ≥ 0.27 (OR 3.48 (95% CI 1.74 to 6.94); $p < 0.001$) as significant risk factors (Table III). Preoperative radiotherapy and mFI were significant risk factors for complications by both methods.

Association of risk factors with severity of complications and common complications. A mFI ≥ 0.27 was significantly

Table IV. Association of modified Frailty Index (mFI) ≥ 0.27 with postoperative complications.

Complication	mFI, n (%)		p-value
	≥ 0.27 (n = 61)	< 0.27 (n = 180)	
Wound dehiscence/ infection	7 (11.5)	10 (5.6)	0.326*
Urinary tract infection	5 (8.2)	2 (1.1)	0.012†
Pneumonia	4 (6.6)	2 (1.1)	0.037†
Implant failure, adjacent fracture	2 (3.3)	3 (1.7)	0.603†
VTE	1 (1.6)	4 (2.2)	> 0.999†
Others	3 (4.9)	4 (2.2)	0.374†

*Chi-squared test.
†Fisher's exact test.
VTE, venous thromboembolism.

Table V. Association of preoperative radiotherapy with postoperative complications.

Complication	Preoperative radiotherapy, n (%)		p-value
	Yes (n = 62)	No (n = 179)	
Wound dehiscence/ infection	9 (14.5)	8 (4.5)	0.008*
Urinary tract infection	2 (3.2)	5 (2.8)	> 0.999†
Pneumonia	1 (1.6)	5 (2.8)	> 0.999†
Implant failure, adjacent fracture	0 (0)	5 (2.8)	0.332†
VTE	2 (3.2)	3 (1.7)	0.605†
Others	3 (4.8)	4 (2.2)	0.378†

*Chi-squared test.
†Fisher's exact test.
VTE, venous thromboembolism.

associated with urinary tract infection (OR 7.95, 95% CI 1.50 to 42.1; p = 0.012, Fisher's exact test) and pneumonia (OR 6.25, 95% CI 1.13 to 35.6; p = 0.037, Fisher's exact test), whereas wound dehiscence/infection did not show a significant association (Table IV). Additionally, the severity of complications by the Clavien-Dindo classification was significantly correlated with mFI (p < 0.001, Pearson correlation coefficient). Preoperative radiotherapy was a risk factor for wound dehiscence/infection (OR 3.63, 95% CI 1.33 to 9.88; p = 0.008) (Table V), but not urinary tract infection or pneumonia (both p > 0.999, Fisher's exact test). Patients treated with preoperative radiotherapy and molecular targeted drugs tended to have wound problems requiring surgery (i.e. Grade III) (OR 5.38, 95% CI 0.74 to 8.60; p = 0.040).

Discussion

The current study prospectively examined 241 patients who underwent surgery for spinal metastasis and identified mFI ≥ 0.27 and preoperative radiotherapy as independent risk factors for complications. Specifically, mFI ≥ 0.27 was associated with postoperative urinary tract infection and pneumonia, and preoperative radiotherapy was associated with postoperative wound dehiscence/infection. In addition, mFI was correlated with the severity of postoperative complications, indicating that patients with higher severity of frailty are at higher risk of severe complications.

Although previous studies reported complications after spinal metastases surgery, most of them had vague definitions of complications and their severity.[11,13,25,26,32] Therefore, we used the Clavien-Dindo classification,[14] which has been widely used in recent years as a systematic evaluation for postoperative complications. A retrospective study of 647 patients with spinal metastases using the Clavien-Dindo classification reported that the rate of complications ≥ Grade II was 30.4%.[11] The lower complication rate in the current study (19.5%) may be attributable to differences in surgical method, as the previous study included patients with anterior and combined surgery,[11] whereas we included only patients with posterior surgery. Although the combined approach is advantageous in terms of anterior reconstruction and debulking the volume of the metastatic lesion, this highly invasive approach is an independent risk factor for 30-day complications after spinal metastases surgery.[11]

A recent systematic review of surgical spinal literature demonstrated that various frailty tools are associated with postoperative outcomes, and the most common tool is the mFI.[18] The impact of frailty and sarcopenia – age-related loss of skeletal muscle mass and strength – on adverse events in patients with spinal metastases has been gaining attention. Several studies recently highlighted the mFI-5, a simplified version of mFI, and the Metastatic Spinal Tumour Frailty Index (MSTFI) as predictors of postoperative adverse events,[21,36] while Massaad et al[15] demonstrated that the MSTFI had poor discrimination for predicting complications. A retrospective study of 108 patients demonstrated sarcopenia, but not frailty, as a predictor of adverse events after emergency surgery for spinal metastases.[22] Another recent study demonstrated that sarcopenia is associated with higher mortality in patients with spinal metastasis.[37] Taken together, the association of mFI with postoperative complications is controversial, and the cut-off value of mFI is unclear. Importantly, the current study showed that mFI with a cut-off value of 0.27 was associated with the risk of complications after spinal metastasis surgery and correlated with the severity of complications. These findings would be valuable in predicting the postoperative course of patients with spinal metastases who have limited expectancy. Because mFI ≥ 0.27 has been significantly associated with postoperative complications of spinal surgery in the elderly,[17] we considered this cut-off value to be similar and reasonable based on the invasiveness of surgery.

One common postoperative complication in spinal metastases surgery is pneumonia.[10] A mFI ≥ 0.27 was associated with postoperative pneumonia, and two of the six patients with postoperative pneumonia had aspiration pneumonia and a mFI of ≥ 0.27. Early intervention by a speech therapist, including the assessment of swallowing disorders, instruction in safe eating methods, and rehabilitation to improve swallowing, can aid in preventing frailty and aspiration pneumonia.[38]

Preoperative radiotherapy is a risk factor for complications after spinal metastasis surgery. Demura et al[33] demonstrated the association of radiotherapy with postoperative wound infection and/or dehiscence, as was found in the present study. Because the dose and frequency of radiotherapy and the use of chemotherapy and molecular targeted drugs can affect wound healing, early intervention by a multidisciplinary team may be crucial in patients who have received preoperative radiation therapy.

Our study has limitations. First, we did not consider the effect of the surgeon's skill. However, all operations were conducted by a senior surgeon or a spinal specialist in conjunction with a senior surgeon. Additionally, we did not adjust for the indications and the surgical procedures, as these variables did not reach statistical significance in univariate analysis. As we only used the posterior approach, this resulted in procedural homogeneity, therefore we did not evaluate complications specific to the anterior approach. Furthermore, the impact of complications on adjuvant therapies, cost, QoL, and survival remains unknown. Further studies are warranted to analyze these issues.

In conclusion, we identified a mFI $\geq$ 0.27 and preoperative radiotherapy as risk factors for complications after spinal metastasis surgery. Moreover, as a high mFI is associated with severe complications, the surgical indication should be carefully and comprehensively determined in patients with severe frailty. However, as Western societies continue ageing, the number of patients with frailty will continue to increase, as will the number of patients with frailty and spinal metastases combined. Prophylactic approaches to prevent frailty, such as exercise promotion in cancer survivors, may be helpful in reducing complications and improving clinical outcomes following spinal metastases surgery.

Take home message

- A modified frailty index (mFI) ≥ 0.27 and preoperative radiotherapy were independent risk factors for postoperative complications in spinal metastases surgery.
- The mFI was associated with the severity of postoperative complications.
- The mFI helps clinicians estimate the risk of complications in patients with spinal metastases.

Supplementary material

The 11 items of the modified Frailty Index-11.

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Funding statement:
The authors disclose receipt of the following financial or material support for the research, authorship, and/or publication of this article: the publication fee was provided by Teijin Nakashima Medical Co. Ltd (Okayama, Japan). K. Kakutani and Y. Takeoka report institutional payments from Surgical Spine Inc, SMI, HOYA Technosurgical, Johnson & Johnson, and Medtronic, towards this study.

ICMJE COI statement:
K. Kakutani and Y. Takeoka report institutional payments from Surgical Spine Inc, SMI, HOYA Technosurgical, Johnson & Johnson, and Medtronic, towards this study. K. Kakutani and Y. Takeoka also report institutional payments from Teijin Nakashima Medical, unrelated to this study. R. Kuroda reports institutional payments from Smith & Nephew, Stryker Japan, B Braun Aesculap Japan, Japan Medical Dynamic Marketing, and Kyocera Corp, consulting fees from Medacta International, speaker payments or honoraria from Medacta International, Smith & Nephew, and Johnson & Johnson, and payment for expert testimony and support for attending meetings and/or travel from Smith & Nephew and Johnson & Johnson, all unrelated to this study.

Data sharing:
The data that support the findings for this study are available to other researchers from the corresponding author upon reasonable request.

Acknowledgements:
The authors thank John Daniel from Edanz for editing a draft of this manuscript. They would also like to thank Yuji Kakiuchi, Masaaki Ito, Shingo Miyazaki, Zhongying Zhang, Koichiro Maeno, and Kotraro Nishida for determing the indications for surgery.

Ethical review statement:
This study was approved by the ethics committee and institutional review board of our hospital (IRB approval No. 1733). Written informed consent was obtained from each patient. The study was conducted in accordance with the principles of the Declaration of Helsinki and with the laws and regulations of our country.

Open access funding:
The open access fee for this article was provided by the scholarship fund from Teijin Nakashima Medical Co. Ltd.

This article was primary edited by S. P. F. Hughes.