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ORIGINAL ARTICLE

Prognostic value of paravertebral muscle density in patients with spinal metastases from gastrointestinal cancer

Sho Dohzono[1] · Ryuichi Sasaoka[1] · Kiyohito Takamatsu[1] · Masatoshi Hoshino[2] · Hiroaki Nakamura[2]

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Abstract

Purpose Morphometric analyses have shown that trunk muscle mass and density are associated with mortality in cancer patients. Because of the low incidence of spinal metastasis from gastrointestinal cancer and the limited life expectancy of these patients, few studies have been reported in this population. We evaluated the prognostic value of trunk muscle area and density in predicting overall survival.

Methods The data from 78 patients with spinal metastases from gastrointestinal cancer, collected from February 2009 to July 2016, were evaluated. Psoas muscle and paravertebral muscle area and density were measured at the L3 level on CT scans taken at the time nearest to the diagnosis of spinal metastasis. Cox proportional hazards analysis was performed to evaluate the factors independently associated with overall survival.

Results The mean patient age was 68.3 years (range, 42–88 years). The overall median survival time was 4.8 months: 2.2 months in the extremely rapid growth group (stomach, biliary tract, and pancreas) and 7.6 months in the rapid growth group (esophagus, liver, and colorectum). Multivariate analyses showed that lower paravertebral muscle density (HR 2.23 [95% CI 1.24–3.99], $p = 0.007$), extremely rapid growth group, presence of abnormal laboratory data, poor performance status, and chemotherapy after spinal metastasis were independent prognostic factors.

Conclusions Median overall survival was poor among patients with spinal metastases from gastrointestinal carcinoma, especially among those with gastric, biliary tract, or pancreatic cancer. Lower paravertebral muscle density was an independent poor prognostic factor in patients with spinal metastases from gastrointestinal cancer.

Keywords Spinal metastasis · Gastrointestinal cancer · Muscle area · Psoas major · Sarcopenia · Prognosis

Introduction

Sarcopenia, which is defined as the presence of both low muscle mass and low muscle function, can be caused by age, low physical activity, disease (inflammatory or malignant), and reduced food intake [6]. Recent morphometric analyses of the psoas muscle have indicated associations between muscle status and surgical outcomes [10, 16, 20] and mortality [2, 3, 19, 32] in patients with colorectal cancer. Sarcopenic obesity, characterized by low muscle mass in combination with high body mass index (BMI), is a prognostic factor in patients with gastrointestinal cancer [21, 28].

Spinal metastases are found in 30 to 70% of cancer patients in autopsy studies [13]. However, the proportion of spinal metastases resulting from gastrointestinal cancer is low, with ranges between 2.4 and 14% [5, 11, 12, 27, 29]. The histology of the primary tumor is the single strongest predictor of postoperative survival in patients with spinal metastases; gastrointestinal cancers have been associated with the shortest life expectancy [29, 30]. Because of the low incidence of spinal metastases from gastrointestinal cancer and the limited life expectancy of these patients, few clinical studies have been conducted in this population.

Evaluation of prognosis in patients with spinal metastases is important in the decision to pursue surgical treatment. Several recent studies have used univariate analysis to

✉ Sho Dohzono
s.dohzono@med.osaka-cu.ac.jp

[1] Department of Orthopaedic Surgery, Yodogawa Christian Hospital, 1-7-50 Kunijima Higasiyodogawa-ku, Osaka, Osaka 533-0024, Japan

[2] Department of Orthopaedic Surgery, Osaka City University Graduate School of Medicine, 1-4-3 Asahimachi, Abeno-ku, Osaka, Osaka 545-8585, Japan

investigate the association between psoas muscle area and survival in patients with spinal metastases [8, 33]. However, many factors, such as histology, systemic status, extent of metastatic disease, and extent of previous treatment, affect survival in patients with spinal metastases. The aim of this study was to investigate overall survival in patients with spinal metastases from gastrointestinal cancer, and to use multivariate analysis to evaluate the prognostic value of trunk muscle area and density in predicting overall survival in these patients.

Materials and methods

Study population

The data from 85 patients who were diagnosed with spinal metastases from gastrointestinal cancer at Yodogawa Christian Hospital from February 2009 to July 2016 were retrospectively reviewed. Spinal metastases were diagnosed radiologically with computed tomography (CT), magnetic resonance imaging, or positron emission tomography. We excluded seven patients because of incomplete clinical or radiological data. Gastrointestinal cancer included cancer of the esophagus, stomach, liver, biliary system, pancreas, and colorectum. This study was approved by the Institutional Review Board of Yodogawa Christian Hospital.

Measurements

Trunk muscle area and density were measured on CT images. The bilateral psoas major muscles and paravertebral muscles (PVM) (multifidus and erector muscles) were measured by aggregating the cross-sectional area (mm^2) at the L3 level on CT images taken at the time closest to the diagnosis of spinal metastasis (Fig. 1). The L3 level was used as a standard landmark, because this correlates best with whole-body muscle mass [18, 25]. Muscle density was measured according to the muscle radiation attenuation rate in Hounsfield units (HU). Adipose tissue and skeletal tissue areas were defined according to standard HU ranges (− 190 to − 30 HU for adipose tissue and − 29 to 150 HU for skeletal muscle) [17]. Muscle area was normalized for patient height (m^2) to calculate the muscle index for the psoas major muscle and PVM in mm^2/m^2. Because measurements of the psoas muscle and PVM were dependent on sex, muscle area, and density were evaluated for male and female cohorts separately with different median cutoff points.

Prognostic factors

The following variables were analyzed as covariates, and each variable was categorized into two groups: sex, age (≥ 70 or < 70 years), BMI (≥ 20 or < 20 kg/m^2), primary site (extremely rapid growth or rapid growth), presence/absence of abnormal laboratory data, presence/absence of visceral or cerebral metastasis, Eastern Cooperative Oncology Group performance status (0–2 or 3–4), history of previous chemotherapy, presence/absence of multiple skeletal metastases, and chemotherapy after spinal metastasis. Abnormal laboratory data were defined as C-reactive protein ≥ 0.4 mg/dL, lactate dehydrogenase ≥ 250 IU/L, serum albumin < 3.7 g/dL, platelet count < 100,000/μL, serum calcium ≥ 10.3 mg/dL, or total bilirubin ≥ 1.4 mg/dL [14].

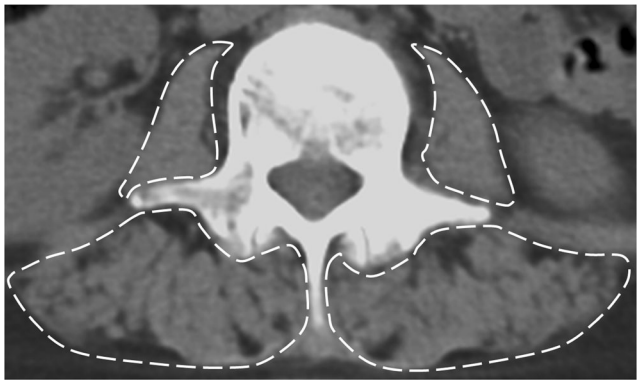

Fig. 1 Axial CT at L3 level showing measurement of the cross-sectional area of the psoas major and paravertebral muscles

Statistical analysis

We used a *t* test to compare the average muscle area and density between men and women. Survival was estimated with the Kaplan–Meier method; survival estimates were compared with the log-rank test. Any variable with $p < 0.10$ was selected as a candidate for Cox proportional hazards analyses to evaluate the factors independently associated with overall survival after spinal metastasis. Data were censored on July 30, 2017. Patients who were lost to follow-up were censored at the date of last contact/follow-up. Patients who were alive on July 30, 2017 were censored for overall survival analysis. Overall survival was calculated from the date of spinal metastasis diagnosis to the date of death. IBM SPSS Statistics, version 19 (IBM Corp.) was used for all statistical analyses; $p < 0.05$ was considered statistically significant.

Results

A total of 78 patients were included in this study. Patients' demographic and clinical data are shown in Table 1. The mean patient age was 68.3 years (range, 42–88 years); 56% of patients were male. The primary site was the esophagus in six patients (8%), stomach in 19 (24%), liver in 14 (18%), biliary tract in five (6%), pancreas in seven (9%), colorectum in 25

Table 1 Demographic and clinical data

	n (%)
Sex	
Male	44 (56)
Female	34 (44)
Age	
≥ 70 years	38 (49)
< 70 years	40 (51)
Primary site	
Esophageal cancer	6 (8)
Gastric cancer	19 (24)
Hepatocellular carcinoma	14 (18)
Biliary tract cancer	5 (6)
Pancreatic cancer	7 (9)
Colorectal cancer	25 (32)
Others	2 (3)
Location of metastasis*	
Cervical spine	33 (42)
Thoracic spine	63 (81)
Lumbar spine	40 (51)
Bone lesion	
Lytic	49 (63)
Blastic	22 (28)
Intertrabecular	7 (9)
SINS	
≥ 13	13 (17)
7–12	48 (62)
< 6	17 (22)
Surgery for spinal metastasis	10 (13)
Use of antiresorptive agent**	46 (59)
Radiation therapy for spinal metastasis	39 (50)

SINS, Spinal Instability Neoplastic Score

*Including multiple lesions

**Zoledronic acid or denosumab

Table 2 Baseline prognostic factors

	n (%)
BMI	
≥ 20 kg/m^2	48 (62)
20 kg/m^2	30 (38)
Primary site	
Extremely rapid growth*	31 (41)
Rapid growth**	45 (59)
Abnormal laboratory data***	
Yes	70 (90)
No	8 (10)
Visceral or cerebral metastasis	
Yes	53 (68)
No	25 (32)
ECOG performance status	
0–2	40 (51)
3–4	38 (49)
Previous chemotherapy	
Yes	38 (49)
No	40 (51)
Multiple skeletal metastases	
Yes	68 (87)
No	10 (13)
Chemotherapy after spinal metastasis	
Yes	48 (62)
No	30 (38)

BMI, body mass index; *ECOG*, Eastern Cooperative Oncology Group

*Stomach, biliary tract, pancreas

**Esophagus, liver, colorectum

***C-reactive protein ≥ 0.4 mg/dL, lactate dehydrogenase ≥ 250 IU/L, serum albumin < 3.7 g/dL, platelet count < 100,000/μL, serum calcium ≥ 10.3 mg/dL, or total bilirubin ≥ 1.4

(32%), and others in two (3%). The most frequent site of metastasis was the thoracic spine (63 patients, 81%), followed by the lumbar spine in 40 (51%), and the cervical spine in 33 (42%). Ten patients (13%) underwent surgery for spinal metastasis. Ten patients (13%) had a solitary site of spinal metastasis; 68 patients (87%) had multiple sites. Table 2 shows baseline characteristics and the distribution of prognostic factors.

Muscle area and density

Both the area and the density of the trunk muscles were significantly or tended to be greater in men than in women (Table 3). Univariate analysis showed that overall survival in patients with high PVM density was significantly longer than in those with low muscle density. However, the area of the psoas major and PVM were not significant prognostic factors (Table 4).

Survival

The overall median survival time for all patients was 4.8 months (range, 0.6–52.3 months). Median survival was 5.3 months (range, 4.8–18.9 months) for esophageal cancer, 2.2 months (range, 0.7–25.2 months) for gastric cancer, 7.1 months (range, 1.6–4.3 months) for hepatocellular carcinoma, 2.4 months (range, 1.1–2.7 months) for gall bladder cancer, 3.3 months (range, 1.1–10.0 months) for pancreatic cancer, and 7.6 months (range, 0.6–52.3 months) for colorectal cancer. We divided the primary site into two groups according to overall median survival time: the extremely rapid growth group (stomach, biliary tract, and pancreas) and the rapid growth group (esophagus, liver, and colorectum).

Table 3 Muscle area and density according to sex

	Psoas major		PVM	
	Mean (SD)	*p* value	Mean (SD)	*p* value
Muscle area, mm^2/m^2				
Male	482.8 (118.3)	< 0.001	1506.6 (279.9)	0.052
Female	326.3 (93.2)		1380.7 (258.2)	
Muscle density, HU				
Male	40.3 (5.7)	0.016	33.0 (11.0)	< 0.001
Female	37.1 (7.3)		18.2 (22.2)	

PVM, paravertebral muscles; *SD*, standard deviation; *HU*, Hounsfield units

Table 4 shows the univariate and multivariate analyses of overall survival period. Multivariate analyses showed that lower PVM density (HR 2.23 [95% CI 1.24–3.99], $p = 0.007$), extremely rapid growth group (HR 3.23 [95% CI 1.84–5.65], $p < 0.001$), presence of abnormal laboratory data (HR 4.84 [95% CI 1.63–14.4], $p = 0.005$), Eastern Cooperative Oncology Group performance status 3 or 4 (HR 3.12 [95% CI 1.5–56.31], $p = 0.001$), and treatment with chemotherapy after spinal metastasis (HR 0.43 [95% CI 0.21–0.91], $p = 0.027$) were independent prognostic factors.

Discussion

This study investigated the overall survival in patients with spinal metastases from gastrointestinal cancer and the prognostic value of psoas major and PVM area and density. Muscle area and density were categorized with sex-specific median cutoff points. The results showed that median overall survival was poor, especially in patients with gastric, biliary tract, or pancreatic cancer. Low PVM density was an independent prognostic risk factor.

A previous prospective study revealed that low trunk muscle density was predictive for poor overall survival in patients with metastatic colorectal cancer [2]. Similarly, our study showed an association between low PVM density and poor overall survival. However, in contrast with several studies in patients with gastrointestinal cancer [15, 21, 24, 26, 32], our study showed that the muscle area of the psoas and PVM was not associated with overall survival. Possible explanation for this include the following: (1) low muscle density (poor quality due to fatty infiltration) is a stronger factor of poor survival than reduced muscle mass, (2) we could not validate sarcopenia as a prognostic factor due to a small number of patients.

Previous studies have described an association between psoas muscle area and survival among patients with metastatic spinal tumors, according to univariate analysis [8, 33]. Many prognostic factors have been reported in patients with spinal metastasis: histology, systemic status, extent of metastatic disease, and extent of previous treatment. Therefore, several prognosis-evaluation systems have been developed [1, 14, 22, 29–31]. Our sex-adjusted multivariate analysis showed that low PVM density was associated with poor overall survival, independent of other prognostic factors. Lower muscle density indicates a higher amount of fatty infiltration in the muscle. This raises the question of whether interventions aimed at preserving muscle affect outcomes. A retrospective study of patients with metastatic spinal cord compression showed that rehabilitation improved functional outcomes and that those who achieved high functional gains after rehabilitation had longer survival [28]. In contrast, a randomized controlled trial revealed that PVM training did not improve overall survival in patients with spinal metastases who received radiation therapy [23].

The histology of the primary tumor is the single strongest predictor of postoperative survival in patients undergoing surgery for spinal metastases; gastrointestinal cancers are associated with the poorest life expectancy [29, 30]. The median overall survival in the present study was 4.8 months for all patients and 2.2 months for those with extremely rapid-growth cancers (gastric, biliary tract, and pancreatic cancer). Previous studies have reported median survival times of 2.8 months for gastric cancer [29], 1.5 to 5.5 months for pancreatic cancer [4, 29], and 1.5 to 4.0 months for biliary tract cancer [7, 9]. When deciding on treatment for spinal metastases, general condition and life expectancy should be considered. Our study revealed that the presence of abnormal laboratory data and poor performance status were associated with poor overall survival, as previously reported [14, 29, 30]. Furthermore, we also found that low PVM density was associated with poor overall survival, independent of prognostic covariates, in patients with spinal metastasis from gastrointestinal cancer. This information can help surgical decision-making in conjunction with other classification criteria or prognostic scoring systems.

There are several limitations to the present study. First, its retrospective nature is a limitation; the treatment of spinal metastases and the systemic treatments for primary cancer were not uniform. Multivariate analysis can reduce bias in prognostic estimates, but the analyses remain subject to biases

Table 4 Univariate and multivariate analyses of overall survival periods

	Univariate analysis		Multivariate analysis	
	Mean (median) survival, months	*p* value	HR (95% CI)	*p* value
Sex				
Male	8.8 (5.3)	0.838	Reference	0.309
Female	10.4 (4.5)		1.35 (0.76–2.42)	
Age				
≥ 70 years	8.5 (4.1)	0.418	Reference	0137
< 70 years	9.3 (4.8)		0.65 (0.37–1.15)	
Muscle area				
Psoas major				
Greater than median	8.4 (4.8)	0.797		
Less than median	10.3 (4.1)			
PVM				
Greater than median	10.9 (4.8)	0.738		
Less than median	8.0 (6.1)			
Muscle density				
Psoas major				
Greater than median	11.9 (6.1)	0.166		
Less than median	7.0 (3.6)			
PVM				
Greater than median	12.7 (7.3)	0.024	Reference	0.007
Less than median	6.2 (2.7)		2.23 (1.24–3.99)	
BMI				
≥ 20 kg/m^2	8.2 (5.3)	0.764		
< 20 kg/m^2	10.4 (4.8)			
Primary site				
Extremely rapid growth*	4.9 (2.2)	0.002	3.23 (1.84–5.65)	< 0.001
Rapid growth**	12.6 (7.6)		Reference	
Abnormal laboratory data***				
Yes	8.3 (4.1)	0.022	4.84 (1.63–14.4)	0.005
No	18.1 (10.7)		Reference	
Visceral or cerebral metastasis				
Yes	8.5 (3.8)	0.176		
No	10.9 (7.6)			
ECOG performance status				
0–2	13.8 (8.7)	< 0.001	Reference	0.001
3–4	4.4 (2.2)		3.12 (1.55–6.31)	
Previous chemotherapy				
Yes	7.8 (3.8)	0.423		
No	10.5 (6.2)			
Multiple skeletal metastases				
Yes	7.8 (4.8)	0.137		
No	18.4 (3.3)			
Chemotherapy after spinal metastasis				
Yes	16.4 (10.9)	< 0.001	0.43 (0.21–0.91)	0.027
No	5.1 (2.4)		Reference	

HR, hazard ratio; *PVM*, paravertebral muscles; *BMI*, body mass index; *ECOG-PS*, Eastern Cooperative Oncology Group performance status

*Stomach, biliary tract, pancreas

**Esophagus, liver, colorectum

***C-reactive protein ≥ 0.4 mg/dL, lactate dehydrogenase ≥ 250 IU/L, serum albumin < 3.7 g/dL, platelet count < 100,000/μL, serum calcium ≥ 10.3 mg/dL, or total bilirubin ≥ 1.4

resulting from unobserved confounding factors. Second, this is a relatively small study in which a small number of patients (13%) underwent surgery. Further studies with a larger sample size should be performed to confirm the present results.

In conclusion, median overall survival was poor among patients with spinal metastases from gastrointestinal carcinoma, especially among those with gastric, biliary tract, or pancreatic cancer. Lower PVM density was independently associated with poorer overall survival. These findings in conjunction with other prognostic scoring systems should be useful in determining appropriate treatments.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Bauer H, Tomita K, Kawahara N, Abdel-Wanis ME, Murakami H (2002) Surgical strategy for spinal metastases. Spine 27:1124–1126
2. Blauwhoff-Buskermolen S, Versteeg KS, de van der Schueren MA, den Braver NR, Berkhof J, Langius JA, Verheul HM (2016) Loss of muscle mass during chemotherapy is predictive for poor survival of patients with metastatic colorectal cancer. J Clin Oncol 34:1339–1344
3. Boer BC, de Graaff F, Brusse-Keizer M, Bouman DE, Slump CH, Slee-Valentijn M, Klaase JM (2016) Skeletal muscle mass and quality as risk factors for postoperative outcome after open colon resection for cancer. Int J Color Dis 31:1117–1124
4. Borad MJ, Saadati H, Lakshmipathy A, Campbell E, Hopper P, Jameson G, Von Hoff DD, Saif MW (2009) Skeletal metastases in pancreatic cancer: a retrospective study and review of the literature. Yale J Biol Med 82:1–6
5. Constans JP, de Divitiis E, Donzelli R, Spaziante R, Meder JF, Haye C (1983) Spinal metastases with neurological manifestations. Review of 600 cases. J Neurosurg 59: 111–118
6. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, Martin FC, Michel JP, Rolland Y, Schneider SM, Topinkova E, Vandewoude M, Zamboni M (2010) Sarcopenia: European consensus on definition and diagnosis: report of the European working group on sarcopenia in older people. Age Ageing 39:412–423
7. Dowsiriroj P, Paholpak P, Sirichativapee W, Wisanuyotin T, Laupattarakasem P, Sukhonthamarn K, Kosuwon W, Jeeravipoolvarn P (2017) Cholangiocarcinoma with spinal metastasis: single center survival analysis. J Clin Neurosci 38:43–48
8. Gakhar H, Dhillon A, Blackwell J, Hussain K, Bommireddy R, Klezl Z, Williams J (2015) Study investigating the role of skeletal muscle mass estimation in metastatic spinal cord compression European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society 24: 2150–2155
9. Goodwin CR, Abu-Bonsrah N, Boone C, Ruiz-Valls A, Sankey EW, Sarabia-Estrada R, Elder BD, Kosztowski T, Sciubba DM (2016) Non-hepatocellular carcinoma spinal metastases. J Clin Neurosci 27:22–27
10. Hanaoka M, Yasuno M, Ishiguro M, Yamauchi S, Kikuchi A, Tokura M, Ishikawa T, Nakatani E, Uetake H (2017) Morphologic change of the psoas muscle as a surrogate marker of sarcopenia and predictor of complications after colorectal cancer surgery. Int J Color Dis 32:847–856
11. Hatrick NC, Lucas JD, Timothy AR, Smith MA (2000) The surgical treatment of metastatic disease of the spine. Radiother Oncol 56: 335–339
12. Ibrahim A, Crockard A, Antonietti P, Boriani S, Bunger C, Gasbarrini A, Grejs A, Harms J, Kawahara N, Mazel C, Melcher R, Tomita K (2008) 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 8: 271–278
13. Jacobs WB, Perrin RG (2001) Evaluation and treatment of spinal metastases: an overview. Neurosurg Focus 11:e10
14. Katagiri H, Okada R, Takagi T, Takahashi M, Murata H, Harada H, Nishimura T, Asakura H, Ogawa H (2014) New prognostic factors and scoring system for patients with skeletal metastasis. Cancer Med 3:1359–1367
15. Kudou K, Saeki H, Nakashima Y, Sasaki S, Jogo T, Hirose K, Hu Q, Tsuda Y, Kimura K, Nakanishi R, Kubo N, Ando K, Oki E, Ikeda T, Maehara Y (2018) Postoperative development of sarcopenia is a strong predictor of a poor prognosis in patients with adenocarcinoma of the esophagogastric junction and upper gastric cancer. Am J Surg
16. Margadant CC, Bruns ER, Sloothaak DA, van Duijvendijk P, van Raamt AF, van der Zaag HJ, Buskens CJ, van Munster BC, van der Zaag ES (2016) Lower muscle density is associated with major postoperative complications in older patients after surgery for colorectal cancer. Eur J Surg Oncol 42:1654–1659
17. Mitsiopoulos N, Baumgartner RN, Heymsfield SB, Lyons W, Gallagher D, Ross R (1998) Cadaver validation of skeletal muscle measurement by magnetic resonance imaging and computerized tomography. J Appl Physiol (1985) 85: 115–122
18. Mourtzakis M, Prado CM, Lieffers JR, Reiman T, McCargar LJ, Baracos VE (2008) A practical and precise approach to quantification of body composition in cancer patients using computed tomography images acquired during routine care. Appl Physiol Nutr Metab 33:997–1006
19. Nagata T, Nakase Y, Nakamura K, Sougawa A, Mochiduki S, Kitai S, Inaba S (2016) Prognostic impact of a nutritional index including muscle volume in stage 4 colorectal cancer. In Vivo 30:885–891
20. Nakanishi R, Oki E, Sasaki S, Hirose K, Jogo T, Edahiro K, Korehisa S, Taniguchi D, Kudo K, Kurashige J, Sugiyama M, Nakashima Y, Ohgaki K, Saeki H, Maehara Y (2017) Sarcopenia is an independent predictor of complications after colorectal cancer surgery. Surg Today
21. Prado CM, Lieffers JR, McCargar LJ, Reiman T, Sawyer MB, Martin L, Baracos VE (2008) Prevalence and clinical implications of sarcopenic obesity in patients with solid tumours of the respiratory and gastrointestinal tracts: a population-based study. Lancet Oncol 9:629–635
22. Rades D, Dunst J, Schild SE (2008) The first score predicting overall survival in patients with metastatic spinal cord compression. Cancer 112:157–161
23. Rief H, Omlor G, Akbar M, Welzel T, Bruckner T, Rieken S, Haefner MF, Schlampp I, Gioules A, Habermehl D, von Nettelbladt F, Debus J (2014) Feasibility of isometric spinal muscle training in patients with bone metastases under radiation therapy - first results of a randomized pilot trial. BMC Cancer 14:67

24. Saeki H, Nakashima Y, Kudou K, Sasaki S, Jogo T, Hirose K, Edahiro K, Korehisa S, Taniguchi D, Nakanishi R, Kubo N, Ando K, Kabashima A, Oki E, Maehara Y (2018) Neoadjuvant chemoradiotherapy for patients with cT3/nearly T4 esophageal cancer: is sarcopenia correlated with postoperative complications and prognosis? World J Surg 42:2894–2901
25. Shen W, Punyanitya M, Wang Z, Gallagher D, St-Onge MP, Albu J, Heymsfield SB, Heshka S (2004) Total body skeletal muscle and adipose tissue volumes: estimation from a single abdominal cross-sectional image. J Appl Physiol 97(1985):2333–2338
26. Sun G, Li Y, Peng Y, Lu D, Zhang F, Cui X, Zhang Q, Li Z (2018) Can sarcopenia be a predictor of prognosis for patients with non-metastatic colorectal cancer? A systematic review and meta-analysis. Int J Color Dis 33:1419–1427
27. Tancioni F, Navarria P, Pessina F, Attuati L, Mancosu P, Alloisio M, Scorsetti M, Santoro A, Baena RR (2012) Assessment of prognostic factors in patients with metastatic epidural spinal cord compression (MESCC) from solid tumor after surgery plus radiotherapy: a single institution experience European spine journal : official publication of the European spine society, the European spinal deformity society, and the European section of the Cervical Spine Research Society 21. Suppl 1: S146–S148
28. Tang V, Harvey D, Park Dorsay J, Jiang S, Rathbone MP (2007) Prognostic indicators in metastatic spinal cord compression: using functional independence measure and Tokuhashi scale to optimize rehabilitation planning. Spinal Cord 45:671–677
29. Tokuhashi Y, Matsuzaki H, Oda H, Oshima M, Ryu J (2005) A revised scoring system for preoperative evaluation of metastatic spine tumor prognosis. Spine 30:2186–2191
30. Tomita K, Kawahara N, Kobayashi T, Yoshida A, Murakami H, Akamaru T (2001) Surgical strategy for spinal metastases. Spine 26:298–306
31. van der Linden YM, Dijkstra SP, Vonk EJ, Marijnen CA, Leer JW (2005) Prediction of survival in patients with metastases in the spinal column: results based on a randomized trial of radiotherapy. Cancer 103:320–328
32. van Vledder MG, Levolger S, Ayez N, Verhoef C, Tran TC, Ijzermans JN (2012) Body composition and outcome in patients undergoing resection of colorectal liver metastases. Br J Surg 99: 550–557
33. Zakaria HM, Basheer A, Boyce-Fappiano D, Elibe E, Schultz L, Lee I, Siddiqui F, Griffith B, Chang V (2016) Application of morphometric analysis to patients with lung cancer metastasis to the spine: a clinical study. Neurosurg Focus 41:E12