

# Clinical impact of sarcopenia in patients with uterine cervical cancer treated with radiotherapy

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**Objective:** Though sarcopenia is known to be associated with worse prognosis in various tumors, studies regarding the significance of sarcopenia in uterine cervical cancer are uncommon. We investigated the clinical impact of sarcopenia in patients with uterine cervical cancer treated with radiotherapy (RT). **Methods:** Among 104 patients who received RT for uterine cervical cancer between 2011 and 2018, 58 patients treated with a definitive or adjuvant aim were included in this study. Sarcopenia was determined by measuring the skeletal muscle area using computed tomography that was performed for RT planning. **Results:** Among the 58 patients, 30 patients (51.7%) had sarcopenia and 20 patients (66.7%) with sarcopenia had a normal body mass index (BMI). The median age of patients was 55.5 years. There was no linear relationship between age and prevalence of sarcopenia. During the median follow-up period of 35 months, 3 patients died and 11 patients had disease recurrence or progression. Sarcopenia was associated with a worse progression-free survival (PFS; HR 12.301, 95% CI 2.243–67.450,  $p = 0.004$ ). The 2-year PFS rates of patients with and without sarcopenia were 66.3% and 92.3%, respectively ( $p = 0.008$ ). **Conclusions:** Sarcopenia was observed in approximately half of the patients who received RT for cervical cancer, including patients with a normal BMI. Sarcopenia was associated with a worse PFS, and treatment interruption or discontinuation was more frequent among patients with sarcopenia. Evaluation of skeletal muscle mass and support to reduce skeletal muscle loss could be useful to optimize treatment and achieve better PFS.

## Keywords

Sarcopenia; Cervical cancer; Radiotherapy; Survival

## 1. Introduction

Uterine cervical cancer is the fourth most common malignancy and fourth leading cause of cancer-related death in women [1]. Treatment strategies are determined by considering several factors including stage, histology type, comorbidity, and fertility preservation. Radiotherapy (RT) is administered as an adjuvant treatment after surgery for patients with adverse pathologic features or as a primary treatment combined with chemotherapy for patients with locally advanced disease. The chance of a cure can be increased by using an optimal combination of multimodal treatments. Nev-

ertheless, many cervical cancer patients continue to experience treatment failure and treatment-related toxicity. Therefore, an additional tool is needed to determine the optimal treatment strategy.

Historically, sarcopenia is referred to as the loss of skeletal muscle mass in the elderly. The European Working Group on Sarcopenia in Older People (EWGSOP) defined sarcopenia as a condition characterized by low muscle mass, low muscle strength, and low physical performance [2]. However, sarcopenia is related not only to aging but also to abnormal medical conditions, including advanced organ failure, inflammatory disease, endocrine disorder, and malignant disease. Studies on sarcopenia in cancer patients are increasing owing to the discovery of a surrogate indicator for low skeletal muscle mass. Computed tomography (CT)-defined skeletal muscle area at the level of the third lumbar spine correlates well with appendicular skeletal muscle mass [3]. As CT has been considered one of the standard diagnostic modalities for most cancers, measurement of skeletal muscle area using CT is easily attainable. In a systematic review including a total of 38 studies with 7843 patients, the prevalence of sarcopenia was 11–74% and sarcopenia was associated with worse overall survival (OS; hazard ratio [HR] 1.44, 95% confidence interval [CI] 1.32–1.56,  $p < 0.001$ ) and disease-free survival (HR 1.16, 95% CI 1.00–1.30,  $p = 0.014$ ) [4]. All studies used CT to determine sarcopenia. The most commonly studied malignancy was hepatocellular carcinoma followed by pancreaticobiliary cancer, gastroesophageal cancer, urothelial cancer, renal cell carcinoma, and colorectal cancer. Sarcopenia was also associated with an increased risk of treatment-related toxicity [5].

The prevalence and clinical impact of sarcopenia are not as well established in cervical cancer as in other malignancies. CT is not a mandatory for diagnosing cervical cancer. In patients who are candidates for RT, simulation CT for RT planning is a prerequisite for adequate treatment. In this study, we measured the skeletal muscle area using simulation CT and investigated the clinical impact of sarcopenia in cervical cancer patients treated with RT.

## 2. Materials and methods

### 2.1 Patient population

We retrospectively reviewed the medical records of 104 patients who received RT for uterine cervical cancer at Kangbuk Samsung Hospital between January 2011 and December 2018. After excluding 46 patients with distant metastasis or recurrent disease, 58 patients who received RT as definitive or adjuvant treatment were included in this study.

Cytology and human papilloma virus tests were conducted to screen patients, and the cancer diagnosis was established based on colposcopy-guided biopsy. Blood tests including complete blood count and biochemical analysis, urine test, chest radiography, and echocardiography were performed. Imaging tests, including CT, magnetic resonance imaging, and positron emission tomography, were selectively performed for cancer staging. We used the previous International Federation of Gynecology and Obstetrics (FIGO) staging system in this study even though the FIGO staging system was revised in 2019 [6].

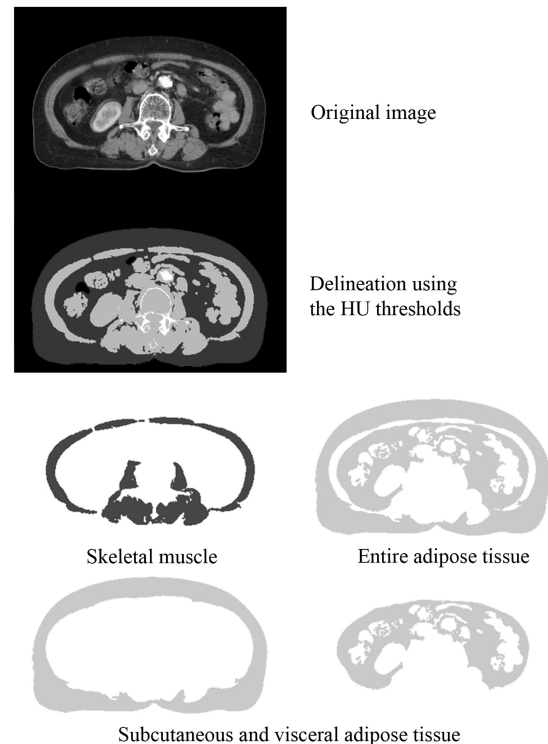
The primary treatment was determined according to the clinical stage. Patients with early stage disease underwent upfront surgery and those with adverse pathologic features, including large tumors, deep stromal invasion, and lymphovascular invasion, received adjuvant RT. Chemotherapy was combined with RT for patients with lymph node metastasis, parametrial invasion, or a positive resection margin [7–9]. Patients with locally advanced disease at the time of diagnosis underwent definitive concurrent chemoradiation therapy.

Three-dimensional simulation for RT planning was performed for all patients. According to our institutional protocol, CT images were obtained from the first lumbar vertebra to the lesser trochanter. All CT images were used for planning purposes, without extra irradiation for the present study. Contrast was used for patients receiving definitive RT to identify viable tumors. Patients received 44.0–50.4 Gy to the whole pelvis in 1.8–2.0 Gy per fraction once daily. The treatment field was extended to the level of the first lumbar spine if the para-aortic lymph node was involved. Pelvic RT was followed by brachytherapy or boost external beam RT for patients who underwent definitive RT or those with positive resection margins after surgery. After completion of the treatment, all patients were followed up every 3 to 4 months in the first 2 years, every 6 months for the next 3 years, and annually thereafter.

### 2.2 Body composition measurement

The areas of skeletal muscle and adipose tissue were measured using simulation CT. The skeletal muscle and subcutaneous and visceral adipose tissues were delineated on a single axial image at the level of the third lumbar spine using Pinnacle<sup>3</sup> ver. 16.0 (Philips Healthcare, Andover, MA, USA). The following Hounsfield unit (HU) thresholds were used: -190 to -30 HU for the entire adipose tissue and -29 to +150 HU for the skeletal muscle. This automated process was followed by manual segmentation of the subcutaneous and vis-

ceral adipose tissue (Fig. 1) [10]. A clinician confirmed all contours and made manual adjustments if needed. Based on the strong correlation between the appendicular skeletal muscle mass index (ASMI) and skeletal muscle index at the third lumbar spine (L3SMI), ASMI was calculated using the height and skeletal muscle area at the level of third lumbar spine [3]. Sarcopenia was defined as an ASMI <5.4 kg/m<sup>2</sup> based on the criteria of the Asian Working Group for Sarcopenia (AWGS) [11].



**Fig. 1. Delineation of the skeletal muscle, subcutaneous adipose tissue, and visceral adipose tissue.** The skeletal muscle and adipose tissue were delineated at the level of the third lumbar spine using Hounsfield unit (HU) thresholds. This automated process was followed by manual segmentation of the subcutaneous and visceral adipose tissue.

The body mass index (BMI, kg/m<sup>2</sup>) was calculated using parameters measured at the time of simulation for RT. A BMI of 18.5–25 kg/m<sup>2</sup> was considered normal.

### 2.3 Biochemical analysis

Complete blood count with differential within 2 weeks of treatment initiation was obtained. Moderate anemia was defined as a serum hemoglobin level <10 g/dL. The neutrophil-lymphocyte ratio (NLR) was calculated by dividing the neutrophil count by the lymphocyte count, and an NLR  $\geq 3$  was considered high.

### 2.4 Evaluation and statistical analysis

To compare the characteristics of patients with and without sarcopenia, the chi-square test, Fisher's exact test, and the independent *t*-test were used. OS was defined as the time

**Table 1. Characteristics of the study population.**

Characteristics	No. of patients (%)			<i>p</i> -value <sup>a</sup>
	All (n = 58)	Sarcopenia (-) (n = 28)	Sarcopenia (+) (n = 30)	
Mean age (years)	58.4 ± 13.9	56.0 ± 12.5	60.8 ± 14.9	0.191
Age				
>40 years	52 (89.7)	26 (92.9)	26 (86.7)	0.671
≤40 years	6 (10.3)	2 (7.1)	4 (13.3)	
Diabetes				
Non-diabetic	51 (87.9)	24 (85.7)	27 (90.0)	0.701
Diabetic	7 (12.1)	4 (14.3)	3 (10.0)	
Mean BMI (kg/m <sup>2</sup> )	23.8 ± 4.6	25.8 ± 4.2	21.9 ± 4.3	0.001
BMI (kg/m <sup>2</sup> )				
<18.5	6 (10.3)		6 (20.0)	0.003
18.5–25	35 (60.3)	15 (53.6)	20 (66.7)	
≥25	17 (29.3)	13 (46.4)	4 (13.3)	
Mean subcutaneous adipose tissue area (cm <sup>2</sup> )	150.1 ± 77.7	189.4 ± 72.9	113.4 ± 63.4	<0.001
Mean visceral adipose tissue area (cm <sup>2</sup> )	81.8 ± 59.2	103.2 ± 66.8	61.8 ± 43.5	0.008
ECOG performance status				
0–1	55 (94.8)	28 (100.0)	27 (90.0)	0.238
2–4	3 (5.2)		3 (10.0)	
Pathology				
Squamous cell carcinoma	49 (84.5)	23 (82.1)	26 (86.7)	0.726
Adenocarcinoma/Adenosquamous carcinoma	9 (15.5)	5 (17.9)	4 (13.3)	
FIGO stage				
I–IIA	24 (41.4)	13 (46.4)	11 (36.7)	0.451
IIB–IVA	34 (58.6)	15 (53.6)	19 (63.3)	
Lymph node metastasis				
No	22 (37.9)	13 (46.4)	9 (30.0)	0.198
Yes	36 (62.1)	15 (53.6)	21 (70.0)	
Hemoglobin				
≥10 g/dL	43 (74.1)	24 (85.7)	19 (63.3)	0.052
<10 g/dL	15 (25.9)	4 (14.3)	11 (36.7)	
Neutrophil-lymphocyte ratio				
<3	36 (62.1)	17 (60.7)	19 (63.3)	0.837
≥3	22 (37.9)	11 (39.3)	11 (36.7)	
Aim of radiotherapy				
Postoperative	29 (50.0)	17 (60.7)	12 (40.0)	0.115
Definitive	29 (50.0)	11 (39.3)	18 (60.0)	
Chemotherapy				
No	15 (25.9)	9 (32.1)	6 (20.0)	0.291
Yes	43 (74.1)	19 (67.9)	24 (80.0)	

BMI, body mass index; ECOG, Eastern Cooperative Oncology Group; FIGO, International Federation of Gynecology and Obstetrics.

<sup>a</sup> *p*-value < 0.05 is regarded significant.

from the initiation of treatment until death. Progression-free survival (PFS) was defined as the time from the initiation of treatment until disease progression, recurrence, or death. Kaplan-Meier survival curves were compared using the log-rank test. We performed Cox regression analysis for univariate and multivariate analyses. A *p*-value < 0.05 indicated significance. All statistical analyses were performed using SPSS Statistics ver. 24 (IBM Corp., Armonk, NY, USA).

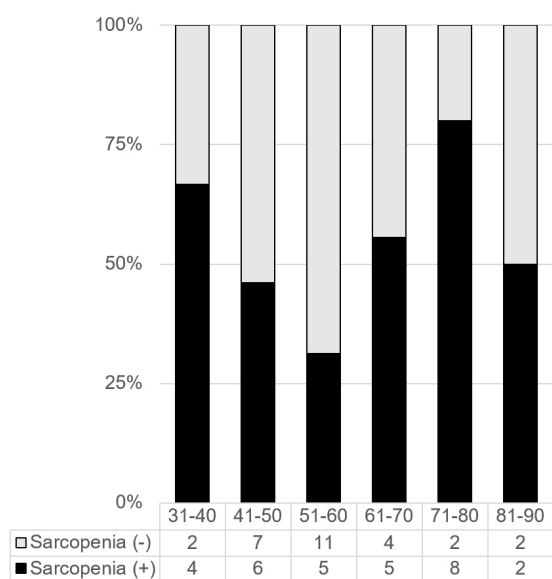
### 3. Results

#### 3.1 Patient characteristics

None of the patients had a history of RT, except one patient who received RT for breast cancer 15 years ago, with no evidence of breast cancer recurrence thereafter. Patient

characteristics are presented in Table 1. The median age was 55.5 years (range: 36–84 years). The median BMI was 22.8 kg/m<sup>2</sup> (range: 17.0–38.8 kg/m<sup>2</sup>), and 60.3% of patients had a normal BMI. The median subcutaneous and visceral adipose tissue areas were 124.1 cm<sup>2</sup> (range: 27.2–321.7 cm<sup>2</sup>) and 62.8 cm<sup>2</sup> (range: 11.2–299.2 cm<sup>2</sup>), respectively. The median ASMI was 5.3 kg/m<sup>2</sup> (range: 3.8–6.5 kg/m<sup>2</sup>). Twenty-nine patients received definitive RT, and the other 29 patients received adjuvant RT. Thirty patients (51.7%) underwent brachytherapy or boost external beam RT following whole pelvic RT. Forty-three patients (74.1%) underwent concurrent chemotherapy. Nine patients had more than 5 days of treatment interruption or did not finish the planned treatment.

A total of 30 patients (51.7%) had sarcopenia and 20 patients of them had a normal BMI (20/30, 66.7%). The mean BMI and subcutaneous and visceral adipose tissue areas were lower in patients with sarcopenia than in those without sarcopenia (21.9 kg/m<sup>2</sup> vs. 25.8 kg/m<sup>2</sup>,  $p = 0.001$ ; 113.4 cm<sup>2</sup> vs. 189.4 cm<sup>2</sup>,  $p < 0.001$ ; 61.8 cm<sup>2</sup> vs. 103.2 cm<sup>2</sup>,  $p = 0.008$ , respectively). Three patients had an Eastern Cooperative Oncology Group performance status  $\geq 2$ , and all of them had sarcopenia. Moderate anemia was more common in those with sarcopenia than in those without sarcopenia (36.7% vs. 14.3%,  $p = 0.052$ ). Treatment and other clinical characteristics including age, stage, pathology, and NLR were not significantly different between patients with and without sarcopenia. The prevalence of sarcopenia was the highest in patients aged 71–80 years (80.0%), but there was no linear relationship between age and prevalence (Fig. 2).



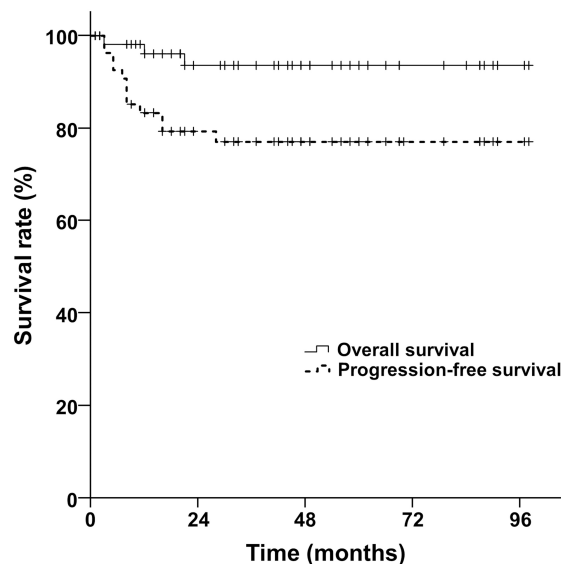
**Fig. 2. Prevalence of sarcopenia according to age.** The prevalence of sarcopenia was the highest among patients aged 71–80 (80.0%), but there was no linear relationship between age and prevalence.

### 3.2 Treatment results

During the median follow-up period of 35 months (range: 1–98 months), 3 patients died and 11 patients had recurrence or disease progression. The 2-year OS and PFS rates were 93.6% and 79.3%, respectively (Fig. 3).

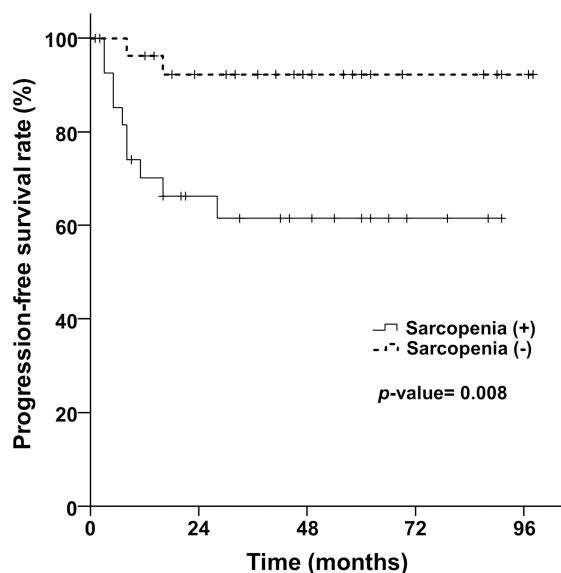
### 3.3 Analysis of prognostic factors

The results of univariate and multivariate analyses of PFS are presented in Table 2. In the univariate analysis, sarcopenia was associated with a worse PFS (HR 6.048, 95% CI 1.323–27.645,  $p = 0.020$ ), along with age  $\leq 40$  years (HR 3.906, 95% CI 1.049–14.542,  $p = 0.042$ ), diabetes (HR 4.550, 95% CI 1.357–15.251,  $p = 0.014$ ), an advanced FIGO stage (HR 11.291, 95% CI 1.452–87.820,  $p = 0.021$ ), and moderate anemia (HR 4.205, 95% CI 1.338–13.213,  $p = 0.014$ ). The 2-



**Fig. 3. Overall survival (OS) and progression-free survival (PFS) curves.** The 2-year OS and PFS rates were 93.6% and 79.3%, respectively.

year PFS rates of patients with and without sarcopenia were 66.3% and 92.3%, respectively ( $p = 0.008$ ) (Fig. 4). In the multivariate analysis, sarcopenia (HR 12.301, 95% CI 2.243–67.450,  $p = 0.004$ ), an advanced FIGO stage (HR 12.614, 95% CI 1.444–110.217,  $p = 0.022$ ), age  $\leq 40$  years (HR 10.169, 95% CI 1.913–54.042,  $p = 0.007$ ), and diabetes (HR 8.686, 95% CI 2.061–36.610,  $p = 0.003$ ) were independent prognostic factors for PFS.



**Fig. 4. Progression-free survival (PFS) according to the presence of sarcopenia.** The 2-year PFS rates of patients with and without sarcopenia were 66.3% and 92.3%, respectively ( $p = 0.008$ ).

The Cox regression analysis for OS was not available because there were only three deaths. Two patients with sar-

**Table 2. Prognostic factors for progression-free survival selected using the Cox proportional hazards model.**

	Univariate		Multivariate	
	HR (95% CI)	<i>p</i> -value <sup>a</sup>	HR (95% CI)	<i>p</i> -value <sup>a</sup>
Age ≤40 years	3.906 (1.049–14.542)	0.042	10.169 (1.913–54.042)	0.007
Diabetes	4.550 (1.357–15.251)	0.014	8.686 (2.061–36.610)	0.003
ECOG performance status 2–4	0.048 (0.000–1.93 × 10 <sup>6</sup> )	0.734		
Pathology (Adenocarcinoma and adenosquamous carcinoma)	1.871 (0.506–6.914)	0.348		
FIGO stage IIB–IVA	11.291 (1.452–87.820)	0.021	12.614 (1.444–110.217)	0.022
Lymph node metastasis	43.969 (0.342–5647.568)	0.127		
Hemoglobin <10 g/dL	4.205 (1.338–13.213)	0.014		
Neutrophil-lymphocyte ratio ≥3	0.972 (0.293–3.231)	0.963		
Sarcopenia	6.048 (1.323–27.645)	0.020	12.301 (2.243–67.450)	0.004

HR, hazard ratio; CI, confidence interval; ECOG, Eastern Cooperative Oncology Group; FIGO, International Federation of Gynecology and Obstetrics.

<sup>a</sup>*p*-value < 0.05 is regarded significant.

copenia died at 3 months and 12 months, respectively, and one patient without sarcopenia died at 22 months after the initiation of treatment.

#### 4. Discussion

While sarcopenia is generally considered to be the result of aging or weight loss, the current study showed different results. The prevalence of sarcopenia was 51.7% in all patients and 57.1% in patients with a normal BMI. Furthermore, among 17 patients with a BMI ≥25 kg/m<sup>2</sup>, 4 patients had sarcopenia. The prevalence of sarcopenia was the highest in patients aged 71–80 years (80.0%), but there was no linear relationship between age and prevalence. Sarcopenia should be considered as a characteristic independent of age and weight.

Three previous studies have investigated the clinical impact of sarcopenia in cervical cancer patients by measuring the skeletal muscle area at the level of the third lumbar spine using CT to determine sarcopenia (Table 3, Ref. [12–14]). All studies were conducted on patients who received RT with or without concurrent chemotherapy for cervical cancer, which represent a heterogeneous population with FIGO stage IB to IVA. However, sarcopenia was not associated with treatment outcomes in these studies. To our knowledge, this is the first report revealing the negative effect of pretreatment sarcopenia on the prognosis of cervical cancer. A Japanese study included the largest number of patients (*n* = 236) and defined sarcopenia as an L3SMI <36.55 cm<sup>2</sup>/m<sup>2</sup>, which can be converted to an ASMI of 5.2 kg/m<sup>2</sup>. The cut-off value was obtained from the receiver operating characteristic curve analysis. Sarcopenia was not associated with either OS (HR 1.126, 95% CI 0.697–1.818, *p* = 0.628) or PFS (HR 1.143, 95% CI 0.738–1.773, *p* = 0.549) [12]. Two other studies reported that skeletal muscle loss after cancer treatment, rather than pretreatment sarcopenia, was an independent prognostic factor [13, 14]. Sarcopenia was defined as the skeletal muscle area at the third lumbar spine level <90.29 cm<sup>2</sup>, which was the mean value for this study population, and as an L3SMI <41.0 cm<sup>2</sup>/m<sup>2</sup>, which can be converted to an ASMI of 5.7

kg/m<sup>2</sup>, respectively. Before comparing the results of our study with those of previous studies, some points need to be considered. First, skeletal muscle loss after cancer treatment is a retrospective observation that can be affected by multiple factors including disease burden, diet, and the cancer treatment itself. A large volume of evidence indicates that cancer treatment per se, mainly chemotherapy, can induce skeletal muscle loss [15–17]. Thus, pretreatment sarcopenia rather than treatment-related skeletal muscle loss should be considered as a prognostic factor. Second, each study used its own distinct criteria to define sarcopenia. Three international study groups, including the AWGS, EWGSOP, and International Working Group on Sarcopenia, proposed the cut-off point to define sarcopenia as follows: an ASMI of 5.4 kg/m<sup>2</sup>, 5.5 kg/m<sup>2</sup>, and 5.67 kg/m<sup>2</sup>, respectively [2, 11, 18]. The cut-off point proposed by the AWGS, which was used in our study, was slightly lower than that of others, and this difference was closely related to ethnic variations. In a study investigating the differences in skeletal muscle mass among ethnicities found that the skeletal muscle mass was the highest in African American women, followed by white, Hispanic, and Asian women [19]. Ethnic variation should be considered when determining the cut-off point.

The mechanism underlying sarcopenia and adverse outcomes remains uncertain. Studies have reported that patients with sarcopenia exhibit a higher incidence of chemotherapy-related toxicity and poor compliance to treatment [20]. RT interruption was also associated with sarcopenia in head and neck cancer [21, 22]. Prolongation of the overall treatment time of RT had a significant impact on pelvic tumor control and cancer-specific survival in uterine cervical cancer [23]. Two studies reported an approximate 1% loss of tumor control per day of prolongation [24, 25]. In our study, the number of patients who did not complete planned RT or had more than 5 days of RT interruption was higher in the sarcopenia group than in the non-sarcopenia group, though the difference was not significant (7 vs. 2, *p* = 0.147).

Besides sarcopenia, several patient-related factors, including anemia, diabetes, young age at diagnosis, and a high NLR,

**Table 3. Comparison of previous studies on sarcopenia among cervical cancer patients.**

Author	Patients	FIGO stage	Definition of sarcopenia	Sarcopenia	Results
Matsuoka <i>et al.</i> [12]	236	IB–IIA (n = 45) IIB–IVA (n = 191)	L3SMI <36.55 cm <sup>2</sup> /m <sup>2</sup> (ASMI <5.2 kg/m <sup>2</sup> )	NA	OS: Pretreatment sarcopenia (HR 1.126, 95% CI 0.697–1.818, <i>p</i> = 0.628) PFS: Pretreatment sarcopenia (HR 1.143, 95% CI 0.738–1.773, <i>p</i> = 0.549)
Lee <i>et al.</i> [13]	245	IB–II (n = 184) III–IVA (n = 61)	L3SMI <41.0 cm <sup>2</sup> /m <sup>2</sup> (ASMI <5.7 kg/m <sup>2</sup> )	51.8%	5-year OS: pretreatment sarcopenia (+) 82.6% versus sarcopenia (–) 83.0% ( <i>p</i> = 0.68) OS: skeletal muscle index loss >10% (HR 6.02, 95% CI 3.04–11.93, <i>p</i> < 0.001)
Kiyotoki <i>et al.</i> [14]	60	IB–IIA (n = 10) IIB–IVA (n = 50)	Skeletal muscle area <90.29 cm <sup>2</sup> Iliopsoas muscle area <10.07 cm <sup>2</sup>	55%	Pretreatment sarcopenia (skeletal muscle and iliopsoas muscle area) was not associated with OS ( <i>p</i> = 0.376 and <i>p</i> = 0.515) or PFS ( <i>p</i> = 0.738 and <i>p</i> = 0.958) OS: iliopsoas muscle loss ≥15% (HR 8.515, 95% CI 2.159–33.585, <i>p</i> = 0.002) PFS: iliopsoas muscle loss ≥15% (HR 6.001, 95% CI 1.908–18.871, <i>p</i> = 0.002)
Current study	58	IB–IIA (n = 24) IIB–IVA (n = 34)	L3SMI <38.45 cm <sup>2</sup> /m <sup>2</sup> (ASMI <5.4 kg/m <sup>2</sup> )	51.7%	PFS: pretreatment sarcopenia (HR 12.301, 95% CI 2.243–67.450, <i>p</i> = 0.004)

FIGO, International Federation of Gynecology and Obstetrics; L3SMI, height-adjusted skeletal muscle area at the level of third lumbar spine on CT scan image; ASMI, appendicular skeletal muscle mass index; NA, not available; OS, overall survival; HR, hazard ratio; CI, confidence interval; PFS, progression-free survival.

affect the prognosis of uterine cervical cancer [26–29]. Anemia is one of the most established negative prognostic factors. From a radiation oncologist’s perspective, anemia can cause tumor hypoxia, leading to the development of resistance and tumor growth [30]. Transfusion and administration of erythropoiesis-stimulating agents improved treatment outcomes in cervical cancer [31, 32]. For managing sarcopenia, multidisciplinary interventions, including nutritional support, resistance exercise, and pharmacologic therapies, are recommended [33–35]. However, as most available data were based on studies of aging-related sarcopenia or cancer cachexia, the impact of sarcopenia management on treatment outcomes of cervical cancer remains to be confirmed by further studies.

This study has some limitations. First, it was a retrospective study with a small sample size. As with previous studies, we determined sarcopenia based on the CT-defined skeletal muscle area. Information regarding muscle strength was not available because of the retrospective nature of this study. Considering the recent consensus on sarcopenia emphasizes the importance of evaluating muscle performance and strength, a prospective study evaluating skeletal muscle mass and strength is needed. Second, patients with early stage disease who are not candidates for RT were not included in this study, and our findings are not applicable to these patients.

In conclusion, sarcopenia was observed in approximately half of the patients who received RT for cervical cancer, including patients with a normal BMI. Sarcopenia was associated with a worse PFS, and treatment interruption or discontinuation was more frequent in patients with sarcopenia than in patients without sarcopenia. Evaluation of skeletal muscle mass and individualized support to reduce skeletal muscle loss

could be useful to optimize treatment and achieve better PFS, and this should be investigated in future research.

### Author contributions

HN, HL, and WYK conceived and designed the experiments; JSP performed the experiments; JSP analyzed the data; HN, HL, and WYK contributed materials; JSP, HN, and HL wrote the paper. All authors read and approved the final manuscript.

### Ethics approval and consent to participate

This study was approved by the Institutional Review Board of Kangbuk Samsung Hospital (IRB No. KBSMC 2019-08-015).

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### Conflict of interest

The authors declare no conflict of interest.

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