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Estimating appendicular skeletal muscle mass of dual-energy X-ray absorptiometry using single-slice abdominal computed tomography imaging

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Recent advancements in imaging have improved the potential of computed tomography (CT) for body composition assessment. However, dual-energy X-ray absorptiometry (DXA) and CT are not clearly interchangeable for assessing appendicular skeletal muscle mass (ASM). This study aimed to predict ASM using a single abdominal CT slice in patients who underwent gastrectomy. This retrospective study included patients scheduled for or who underwent gastrectomy with an interval of 0–1 day between DXA and abdominal CT scans. Data on six variables were extracted: age, sex, weight, height, muscle area, and muscle density on abdominal CT. CT parameters were measured at the 3rd lumbar (L3) and upper thigh levels, respectively. A total of 221 datasets from 112 patients were included. The mean age was 62.0 years (range, 30–89 years) and the average body mass index was 21.3 ± 3.1 kg/m^2. More patients were male (58.8%), and 204 (92.3%) examinations were performed after gastrectomy. The variables that significantly affected the ASM were muscle area, weight, height, and sex. The predictive model for ASM revealed high R^2 values (0.915 and 0.918 for the L3 and upper thigh levels, respectively). The predictive model for ASM of DXA with clinical and CT parameters showed high performance, accordingly, CT scans can be used as a surrogate maker for ASM.

Keywords Skeletal muscle, Sarcopenia, Body composition, Tomography, Regression analysis

Abbreviations

ASM	Appendicular skeletal muscle mass
ASMI	Appendicular skeletal muscle mass index
BMI	Body mass index
CT	Computed tomography
DXA	Dual-energy X-ray absorptiometry
HU	Hounsfield unit
SD	Standard deviation
L3	Third lumbar vertebra
TAM	Total abdominal muscle
TTM	Total thigh muscle

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Preoperative sarcopenia in patients with gastric cancer is critical owing to its association with a higher risk of postoperative complications, including infections, prolonged hospital stays, and overall poor prognosis[1,2]. Moreover, sarcopenia after gastrectomy is notably high, ranging from 20% to 50% and is associated with an increased risk of death from cancer and other causes[3]. This highlights the need for early identification and management of sarcopenia.

Sarcopenia was defined based on criteria from leading organizations such as Asian Working Group for Sarcopenia criteria (AWGS) or European Working Group on Sarcopenia in Older People (EWGSOP)[4], incorporating assessments of both appendicular skeletal muscle mass (ASM) and muscle strength. The Dual-energy X-ray absorptiometry (DXA) is widely regarded as the reference standard for body composition analysis owing to its precision and ability to differentiate between fat mass, lean mass, and bone mineral content[5]. However, its limited accessibility and the need for specialized equipment can limit its use in routine clinical practice. Recent advances in imaging have improved the potential of computed tomography (CT) for body composition assessment[6,7]. CT imaging is routinely used in various clinical settings for diagnosis, offering a unique opportunity to repurpose these scans for comprehensive body composition analysis. This approach is more accessible than DXA, particularly in resource-limited environments and does not require additional DXA scans. However, unlike DXA, no definite criteria have been defined for diagnosing sarcopenia using CT[4].

Previous studies have indicated a strong correlation between DXA–derived ASM and the cross-sectional muscle area at the third lumbar vertebra (L3) level as measured by CT[8]. However, this correlation may be limited for estimating ASM using CT owing to the wide limits of agreement[9,10]. Only the area of muscle mass in the abdomen may not accurately reflect the ASM, but, if ASM can be accurately predicted using both clinical and CT parameters, it could also serve as a biomarker without additional DXA scans. While the L3 level on CT is commonly utilized for assessing muscle mass, upper thigh muscle measurements may better represent ASM and muscle quality with higher reproducibility[11,12]. A previous study reported that thigh muscle measurements were more strongly associated with all-cause mortality than trunk muscle measurements[13]. However, to our knowledge, no study has directly compared the predictive performance of L3 and upper thigh measurements for ASM estimation. Therefore, a novel aspect of this study is the direct evaluation and comparison of these two anatomical regions for predicting ASM.

Accordingly, this study aimed to directly compare the predictive performance of L3 and upper thigh measurements for ASM estimation and to develop and validate prediction models incorporating both clinical and CT-derived parameters.

Methods

Patients and clinical parameters

This retrospective study was approved by the Institutional Review Board of Hanyang University Hospital (IRB No. 2024-02-052), and all methods were performed in accordance with relevant guidelines and regulations. This study followed the transparent reporting of a multivariable prediction model for individual prognosis or diagnosis (TRIPOD) checklist (Supplementary Table 1). A total of 112 patients with gastric cancer who underwent both DXA and CT between January 2013 and December 2023 were consecutively enrolled. The inclusion criteria were as follows: (1) the interval between the DXA and CT scan of 0 or 1 day and (2) 18 years or older. The exclusion criteria were as follows: (1) not covered in upper thigh muscle area due to wrong position on CT ($n = 11$); (2) a history of hip arthroplasty or presence of metal artifacts ($n = 1$).

Anthropometric measurements including age, sex, height, weight, body mass index (BMI), gastrectomy status, and reason for gastrectomy were recorded. Height and weight were measured with a fixed stadiometer and digital scale using standard methods while wearing light clothing and no shoes. BMI was calculated as weight (kg) divided by height squared (m^2). Overall, 221 sets of DXA and CT images from 112 patients were analyzed. Except for one patient, all patients were Asian. The sample size was not formally calculated; all eligible patients meeting the inclusion criteria during the study period were consecutively enrolled.

DXA

DXA scan was used to measure ASM. Each patient underwent DXA (Discovery W DEXA; APEX software ver. 13.6.1.1; Hologic, Inc., Bedford, MA, United States) according to the manufacturer's protocols. DXA was performed under fasting conditions. The patients were positioned in the lateral hand position with both feet internally rotated by 15°. Whole body and regional lean mass values were measured by an experienced nuclear medicine technician. All scans were reviewed and confirmed by two clinicians in consensus.

ASM (kg) represents the sum of the lean masses in the legs and arms. It was normalized to height squared (kg/m^2) due to the strong association between height and lean mass, as recommended by the EWGSOP[13]. The ASM index (ASMI) was defined as ASM/height^2 (kg/m^2).

CT

Abdomen CT scans were performed with a contrast agent; therefore, they were performed after DXA or the day after DXA scan. The patients underwent abdominal CT using a 64-detector row CT system (Somatom Definition Edge and Somatom Definition FLASH; [64; Siemens Healthineers, Erlangen, Germany]; Brilliance 64 [GE Healthcare, Chicago, IL, United States]). The following CT parameters were used: a collimation of 0.6–0.625 mm, a pitch of 0.6 – 1.0, rotation time of 0.5 s, a peak voltage of 120 kVp, and tube current of 180 – 240 mAs. Arterial phase scans were initiated 20–40 s after injection of 2 mL/kg body weight of nonionic iodinated contrast agent at a rate of 4 mL/s using an automatic power injector. Axial images were reconstructed using a section thickness and reconstruction interval of 5 mm. Parameter measurements in abdominal CT in the arterial phase were performed at two levels: the inferior endplate of L3 and the lesser trochanter of the femur shaft at the upper thigh level[11] (Fig. 1). Two clinicians measured the muscle area and density (Hounsfield unit, HU) at each level

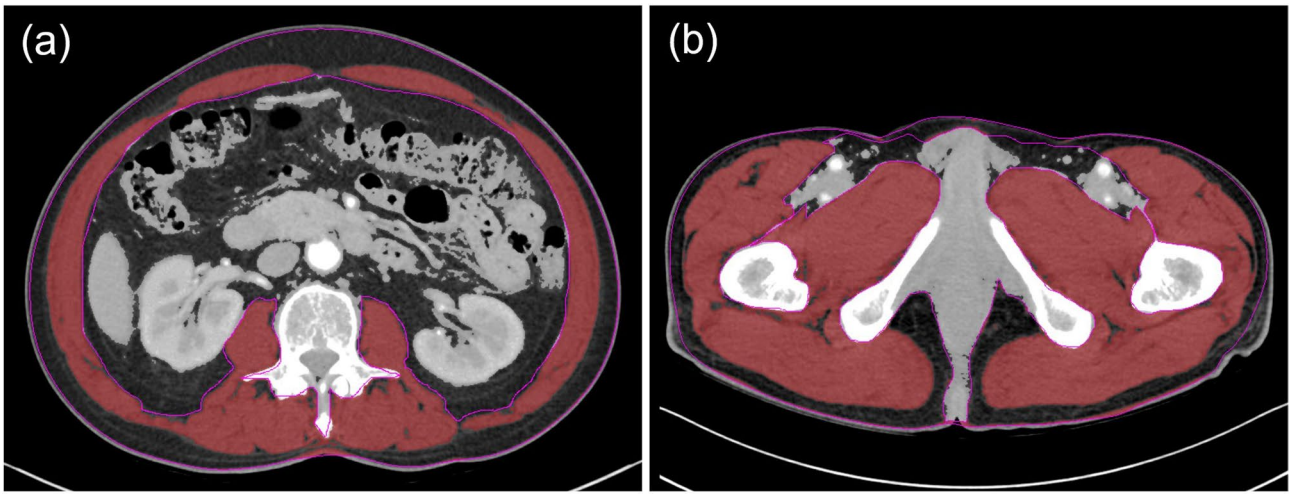

Fig. 1. Example of the semiautomated segmentation of skeletal muscle area at the L3 level (**a**) and upper thigh (**b**).

using commercial software (AquariusNet Server, TeraRecon, San Mateo, CA, United states). Before the study, two physicians underwent harmonization training to standardize their procedure for selecting and delineating CT regions of interest. This approach minimized interobserver variability and ensured data consistency. A HU threshold of − 29 to 150 HU was used to define skeletal muscle[14]. Manual adjustments were made to the selected areas. Muscle density (HU) was recorded to evaluate muscle quality. Overall, 221 abdominal CT scans, muscle area and density were measured in 221 abdominal and 209 thigh slices.

Statistical analysis

Data were analyzed using SPSS version 29.0 (IBM SPSS Statistics), Python 3.9 (Python Software Foundation) and MedCalc version 20.1 (MedCalc Software). Continuous data are presented mean ± standard deviation (SD). Categorical data are presented as numbers and percentages. The correlation of the area and density of total abdominal muscle (TAM), total thigh muscle (TTM), and ASM from DXA was evaluated using Pearson's correlation coefficient. We conducted a multiple linear regression analysis to determine the clinical and CT parameters to determine the significant associated parameters for ASM obtained using DXA. In the multiple regression analysis, age, weight, height, muscle area, and density were analyzed as continuous variables, and sex was coded as a binary variable. Using these variables, a predictive equation for ASM was constructed. To check for multicollinearity, we calculated tolerance and variance inflation factors (VIF). To evaluate the internal validity of the regression model, 5-fold cross-validation was performed at the patient level, ensuring that all scans from the same patient were assigned exclusively to either the training or the test set within each fold. Model performance was assessed using R^2, mean absolute error (MAE), and root mean square error (RMSE). A machine learning analysis was performed using multiple linear regression implemented via scikit-learn (Python 3.9), in which the dataset was randomly split into training ($n = 198$) and test ($n = 23$) sets at approximately a 9:1 ratio. To address the potential violation of the independence assumption arising from repeated measurements within patients, a linear mixed model (LMM) with a patient-level random intercept was additionally performed as a sensitivity analysis. Bland-Altman plots were constructed to visualize the agreement between the ASM of DXA and the predicted ASM. Statistical significance was set at a p-value of < 0.05.

Results

Baseline characteristics

A total of 221 sets of DXA and CT scans from 112 patients scheduled for or who underwent gastrectomy were included in the current analysis. At the time of the scans, most were performed after gastrectomy (92.3%) and the study included slightly more male patients (58.8%) with a mean age of 62.0 years (30–89 years) (Table 1). The mean BMI was 21.3 ± 3.1 kg/m^2.

The average number of scans per patient was 1.6 sets (Table 2). Overall, 171 sets were performed on the same day, and 50 sets were performed one day apart. When applying the AWGS criteria (ASMI < 7.0 kg/m^2 for male; < 5.4 kg/m^2 for female), the prevalence of sarcopenia was in 59.2% of men and 57.1% in women. However, using the CT cut-offs[15], the prevalence rates was 85.4% and 59.3%, respectively. Both modalities revealed a high prevalence of sarcopenia; however, the CT-based criteria identified a greater number of sarcopenia cases, particularly among men, than the DXA-based assessment.

The distribution of ASMI in men and women is presented in Fig. 2.

Characteristics	*n* = 221 (%)
Age (years, mean ± SD)	62.0 ± 10.6
< 50	29 (13.1)
50–59	68 (30.8)
60–69	68 (30.8)
≥ 70	56 (25.3)
Sex ratio (M: F)	130 (58.8): 91 (41.2)
Body weight (kg, mean ± SD)	58.3 ± 10.6
BMI (kg/m^2, mean ± SD)	21.3 ± 3.1
< 18.5	35 (15.8)
18.5 – 22.9	134 (60.6)
23 – 24.9	27 (12.2)
≥ 25	25 (11.3)
Diagnosis	
Gastric neoplasm	219 (99.1)
Non-tumorous condition	2 (0.90)
At the time of scans	
After gastrectomy: before gastrectomy	204 (92.3): 17 (7.7)

Table 1. Characteristics of data sets. BMI, body mass index; SD, standard deviation.

Characteristics	Total	Male	Female
Total number of participants	221	130	91
Average number of data set per patient	1.6	1.5	1.8
Interval between DXA and CT scan (days)			
0	171	101	70
1	50	29	21
Sarcopenia* using DXA		77 (59.2%) (< 7.0 kg/m^2)	52 (57.1%) (< 5.4 kg/m^2)
Sarcopenia using CT[§15]		111 (85.4%) (< 54.2 cm^2/m^2)	54 (59.3%) (< 38.5 cm^2/m^2)
DXA (mean ± SD)			
ASMI (kg/m^2)	6.23 ± 1.0 (4.12–10.10)	6.84 ± 0.8 (4.88–10.10)	5.35 ± 0.6 (4.12–6.91)
Abdomen CT (mean ± SD)			
TAM at L3 (cm^2)	116.9 ± 27.3 (65.2–188.0)	134.3 ± 19.8 (99.7–188.0)	92.2 ± 14.4 (65.2–130.0)
Density of TAM at L3 (HU)	37.3 ± 6.1 (17.3–48.8)	39.1 ± 5.3 (21.7–48.8)	34.9 ± 6.5 (17.3–47.3)
TTM at upper thigh (cm^2)	229.8 ± 41.1 (147.0–346.0)	256.3 ± 28.9 (198.0–346.0)	191.2 ± 21.5 (147.0–248.0)
Density of TTM at upper thigh (HU)	40.9 ± 5.5 (16.7–53.2)	42.7 ± 4.7 (30.1–53.2)	38.2 ± 5.6 (16.7–49.1)

Table 2. Details of data set of DXA and abdominal CT. SD, standard deviation; DXA, dual-energy X-ray absorptiometry; ASMI, appendicular skeletal muscle mass index; CT, computed tomography; TAM, total abdominal muscle; HU, Hounsfield unit; TTM, total thigh muscle. *Asian working group for sarcopenia 2019. [§]TAM at L3/height^2 (cm^2/m^2).

Correlation between ASM by DXA and muscle area on CT

The ASM measured by DXA was significantly correlated with the muscle area on CT at the L3 and thigh levels ($r = 0.910$ and 0.903, respectively; $p < 0.001$; Fig. 3). As presented in the scatter plots, muscle density at each level had a weak correlation ($r = 0.291$ for L3 and $r = 0.359$ for upper thigh, $p < 0.001$).

Regression model

The results of the multiple linear regression analyses are presented in Table 3. At both levels, sex, weight, height and muscle areas were significantly associated with the ASM. The ASM-estimated regression models for the L3 and upper thigh levels were as follows:

For L3 level,

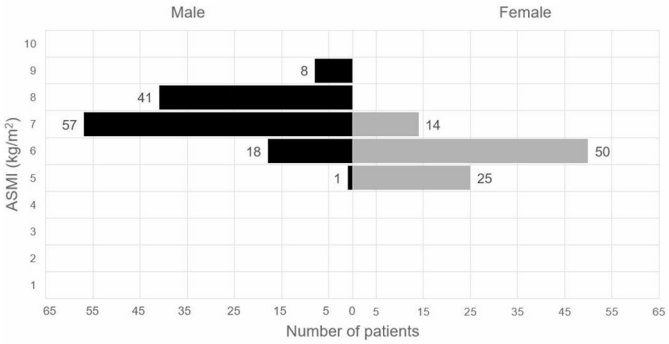

Fig. 2. Histogram of ASMI (kg/m^2) from DXA of male and female. ASMI appendicular skeletal muscle index; DXA dual-energy X-ray absorptiometry. *Number at the end of the bar represents the number of patients.

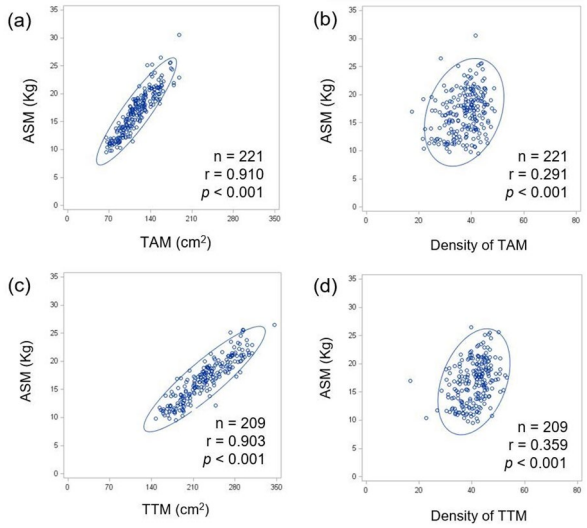

Fig. 3. Correlation between ASM (kg) and muscle area (cm^2) and density (HU) of L3 level and upper thigh. (**a**) TAM area vs. ASM; (**b**) TAM density vs. ASM; (**c**) TTM area vs. ASM; (**d**) TTM density vs. ASM. ASM, appendicular skeletal muscle mass; TAM, total abdominal muscle; TTM, total thigh muscle; HU, Hounsfield unit.

$$\begin{aligned}\text{ASM (kg)} &= -12.525 + 0.002\,(\text{age, years}) - 1.454\,(\text{if, female})\\ &\quad + 0.098\,(\text{weight, kg}) + 0.104\,(\text{height, cm}) + 0.060\,(\text{muscle area at L3 level, cm}^2)\\ &\quad + 0.006\,(\text{muscle density at L3}).\end{aligned}$$

For upper thigh level,

$$\begin{aligned}\text{ASM (kg)} &= -15.456 + 0.005\,(\text{age, years}) - 1.255\,(\text{if, female})\\ &\quad + 0.116\,(\text{weight, kg}) + 0.096\,(\text{height, cm}) + 0.038\,(\text{muscle area in the upper thigh, cm}^2)\\ &\quad + 0.035\,(\text{muscle density in the upper thigh}).\end{aligned}$$

The analysis estimating the ASM using six variables revealed good prediction, with R^2 values of 0.915 and 0.918 for the L3 and upper thigh levels, respectively. The muscle area showed the highest slope coefficient on ASM for both equations. The 5-fold cross-validation at the patient level yielded R^2 = 0.889, MAE = 0.882, and RMSE = 1.112 kg for the L3 model, and R^2 = 0.918, MAE = 0.829, and RMSE = 1.064 for the upper thigh model. The machine learning analysis and linear mixed model (LMM) with a patient-level random intercept are presented in Supplementary Tables 2 and 3.

The results for the agreement of ASM by DXA and the predicted ASMs at the L3 and the upper thigh level are presented as Bland-Altman plots in Fig. 4. Significant correlations were observed at L3 and upper thigh levels (r = 0.958 and r = 0.959, respectively, p < 0.001). The mean difference was 0 kg with 95% limits of agreement from − 2.2 to 2.2 kg for L3 level, and the mean difference was 0 kg with 95% limits of agreement from − 2.1 to 2.1 kg for upper thigh level.

Level	Variables	Coefficients				Collinearity Statistics		Adjusted		
		B	SE	T	*P*	Tolerance	VIF	R^2	MAE	RMSE
L3	Constant	− 12.525	2.996	− 4.181	< 0.001			0.915	0.882	1.112
	Age	0.002	0.011	0.191	0.849	0.427	2.341			
	Sex [men]	− 1.454	0.324	− 4.483	< 0.001	0.227	4.411			
	Weight	0.098	0.012	7.860	< 0.001	0.340	2.938			
	Height	0.104	0.015	7.174	< 0.001	0.389	2.572			
	TAM	0.060	0.006	9.455	< 0.001	0.194	5.142			
	TAM density	0.006	0.020	0.317	0.752	0.401	2.494			
Upper thigh	Constant	− 15.456	2.801	− 5.518	< 0.001			0.918	0.829	1.064
	Age	0.005	0.009	0.550	0.583	0.590	1.695			
	Sex [men]	− 1.255	0.299	− 4.204	< 0.001	0.260	3.850			
	Weight	0.116	0.012	9.584	< 0.001	0.411	2.435			
	Height	0.096	0.014	6.730	< 0.001	0.394	2.536			
	TTM	0.038	0.004	9.932	< 0.001	0.226	4.419			
	TTM density	0.035	0.020	1.714	0.088	0.453	2.206			

Table 3. Results of linear regression analysis. SE, standard error; VIF, variance inflation factor; MAE, mean absolute error; RMSE, root mean square error; TAM, total abdominal muscle; TTM, total thigh muscle; HU, Hounsfield units. Reference category is in square brackets.

Discussion

We analyzed the data to predict ASM measured by DXA using single-slice CT imaging at both L3 and upper thigh levels in 221 datasets of 112 patients. The preliminary calculation formula consisted of six variables; age, sex, weight, height, muscle area, and density on abdominal CT. Multiple linear regression analysis revealed high R^2 values of 0.915 and 0.918 for abdominal and thigh levels, respectively. Although the upper thigh muscle had a slightly higher proof power than the L3 level, the difference was not statistically significant.

According to the current consensus[4,15], sarcopenia is diagnosed using ASMI, which is defined as ASM/height^2 (kg/m^2). While DXA or bioelectrical impedance analysis are the reference standard modalities for this assessment, CT scans are routinely performed for the diagnosis and monitoring a variety of diseases, including cancer. Similar to ASMI obtained using DXA, the muscle area on CT alone has been used to predict low quality of life and poor mortality[16,17]. Many studies have been conducted to diagnose sarcopenia using psoas muscle or abdominal muscle areas obtained from CT slices[7,11,18]. Indeed, Dag et al. reported that psoas muscle area measured at L4/5 level on CT was associated with one-year survival after pediatric liver transplantation, suggesting that CT-based muscle measurements may serve as valuable prognostic biomarkers[17]. The cross-sectional area of the muscle at the level of the L3 is known to have a direct correlation with whole-body skeletal muscle mass[14]. Recent studies showed that the muscle area at the upper thigh level correlates well with those at the mid-thigh and L3 levels[11,19].

In previous studies, only the skeletal muscle area of L3 was used to predict the ASMI using DXA[9,10]. The formula was as follows: appendicular lean soft tissue (kg/m^2) = 0.11* (skeletal muscle at L3 (cm^2)/height^2) + 1.17. Although a strong correlation was observed between the skeletal muscle index on CT and the ASMI on DXA, the limits of agreement were significant. Our study also revealed a significant discrepancy of prevalence of sarcopenia using DXA and CT, most notably a 26.2% difference in prevalence among men (Table 2). Therefore, DXA and CT are not directly interchangeable. However, our ASM predictive model included four clinical variables—age, sex, weight, and height—as well as muscle area and density. Our ASM-estimating models showed high predictive value with narrow limits of agreement of approximately 2 kg for ASM.

Our multiple linear regression analysis (Table 3) revealed that the muscle area of the CT slice had the greatest effect on ASM, followed by weight, height, and sex. Female sex was negatively associated with ASM, while weight and height were positively associated. Age is the most well-known variable associated with muscle mass[20]. Muscle mass peaks at 30 s of age, gradually declines from 40 s, further decreases by 8% at 70 s of life and decreases by 15% every 10 years thereafter[21]. However, age was not a significant factor in the multiple linear regression analysis. It is presumed that age is pre-reflected in the muscle area of L3 or the upper thigh.

Although the L3 level on CT is commonly used to measure muscle mass area, previous studies have reported that the thigh muscles, particularly the quadriceps, reflect age-related sarcopenia[22]. DXA does not reflect atrophy in specific muscle. Therefore, it is advantageous to use thigh muscle of CT. The measurements of upper thigh muscle area revealed good inter-reader agreement than measurement of L3 inferior endplate level[10,11]. We measured the muscle mass area at the upper thigh level, and it performed slightly better than the abdominal muscles at the L3 level. However, no statistically significant difference was observed in the ASM prediction.

Muscle density indicates fat deposition in the muscles and represents muscle quality. High muscle mass does not necessarily equate to healthy muscle if the muscle fibers are interspersed with fat. In cancer patients receiving chemotherapy, low muscle density has been associated with poor overall survival as much as sarcopenia[23]. Also, it was an independent risk factor for overall complications and mortality in elderly patients with abdominal emergencies[24] Decreases in muscle density were detected earlier than decreases in ASM even when the muscle

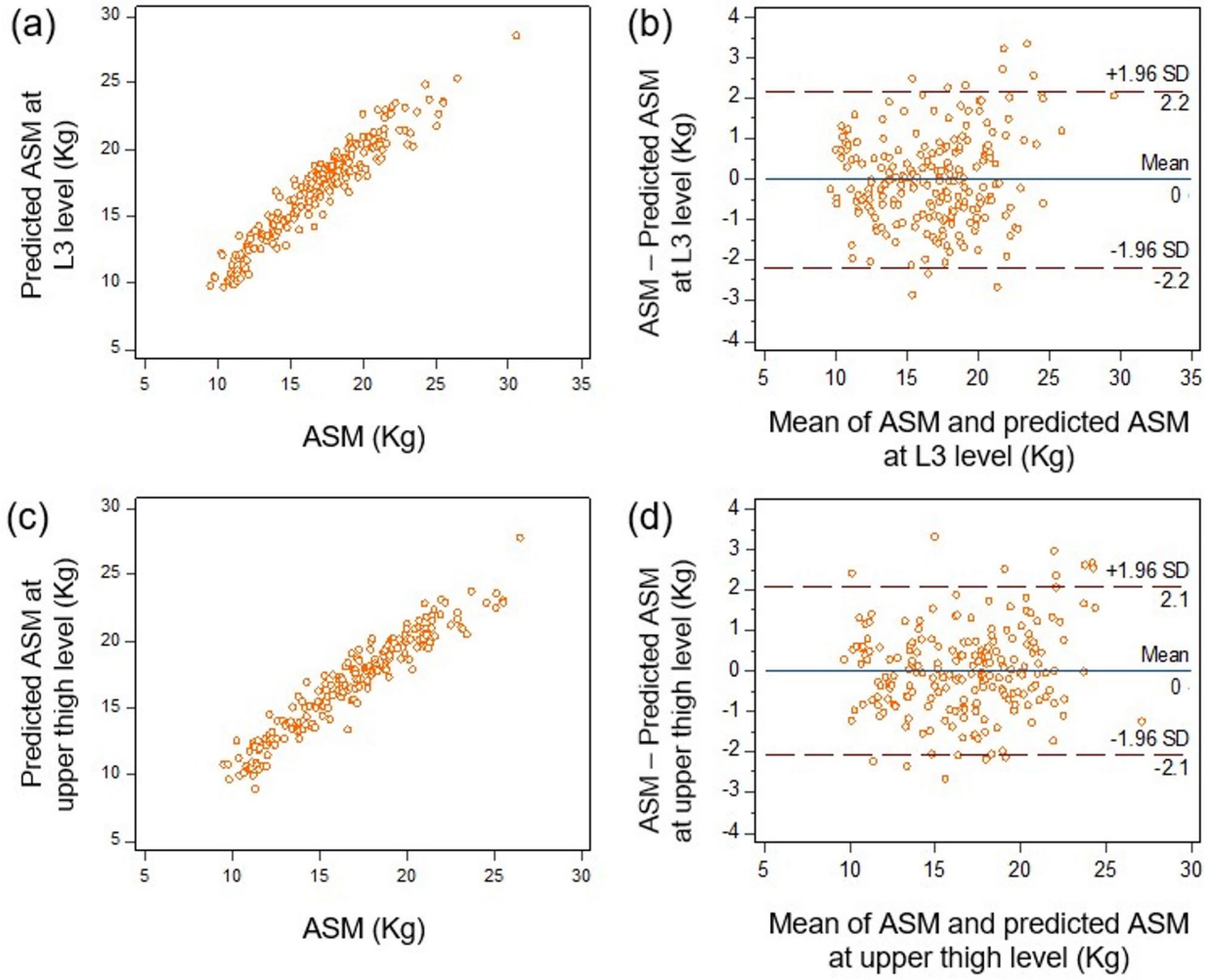

Fig. 4. Correlation and Bland-Altman plots between ASM and predicted ASM. (**a**) Correlation plot and (**b**) Bland-Altman plot between ASM and predicted ASM at L3 level; (**c**) Correlation plot and (**d**) Bland-Altman plot between ASM and predicted ASM at upper thigh level. ASM, appendicular skeletal muscle mass; TAM, total abdominal muscle; TTM, total thigh muscle.

area remained unchanged[25]. Although muscle density was not a relevant factor in linear regression analysis in our study, future research on its clinical relevance of muscle density is warranted.

Although there is a lot of literature to predict ASM measured by DXA using anthropometric variables[26], few studies have reported on single abdominal images (Table 4). Mouztzakis et al.[14] have proposed a simple equation to predict ASM measured by DXA using a single abdominal CT image. Subsequently, in addition to single cross-sectional images from L3 level CT or magnetic resonance imaging, a prediction equation for ASM or whole-body skeletal muscle mass had been developed with increasingly high prediction values (R^2) have been developed using variables such as age, gender, weight and height. Compared to the studies in the Table 4[14,27–29], our study has the strengths of including a group of cancer patients with lower BMI, who are vulnerable to sarcopenia, and a shorter interval between DXA and abdominal images (within 1 day). A machine learning regression model was implemented to predict ASM variables (Supplemental Table 2). Machine learning results revealed R^2 values of 0.919 and 0.942 at L3 and upper thigh levels, respectively.

In this study, we propose a preliminary formula for estimating the ASM using abdominal CT slices. Accumulating evidence suggests that CT-derived muscle measurements, similar to DXA-measured ASM, may serve as important prognostic imaging biomarkers associated with clinically relevant outcomes, including physical function, frailty, cancer prognosis, and mortality[13,30]. As part of sarcopenia assessment, these measurements may facilitate early risk stratification and guide preoperative interventions, such as targeted nutritional support or physical therapy, to improve clinical outcomes.

However, our study had several limitations owing to its retrospective design at a single tertiary medical center. First, most DXA and CT datasets were obtained from patients with specific diseases who underwent gastrectomy (92.3%). Gastrectomy reduces body weight and abdominal fat, and is also effective in reducing

Author, years	Cohort	*n* (Male,%)	Age, years	BMI, kg/m^2	Interval	Prediction	Parameters of CT/MRI	Other parameters	R^2
Mourtzakis et al. 2008[14]	Cancer + Caucasian	51 (58.8)	63 ± 10	26.9 ± 6.2	N/A	ASM	Skeletal muscle area at L3 level on CT	Height	–
Baker et al. 2012[27]	Obesity	49 (38)	48.8 ± 1.5	37.9 ± 0.9	0 day	ASMI[§]	Skeletal muscle area at L3 level on MRI	Age, height	0.757
Holt et al. 2016[28]	Crohn's disease	37 (40.5)	43.8 ± 2.6	23.9 ± 1.0	21 days	Whole body Skeletal muscle	Skeletal muscle area at L3 level on CT	Age, gender, height	0.930
Deyell et al. 2023[29]	Pediatric oncology patients; healthy children	80 (57); 73 (61)	13.6 (5.1–18.4)	19.2	14 days	Whole body Skeletal muscle	Skeletal muscle area at L3 level on CT (oncology), and MRI (healthy)	Height	0.953 for CT, 0.947 for MRI
This study	Gastric neoplasm	221[*] (58.8)	62.0 ± 10.6	21.3 ± 3.1	0–1 day	ASM	Skeletal muscle area and density at L3, and upper thigh level on CT	Age, gender, weight, height	0.915 for L3, 0.918 for upper thigh

Table 4. Studies predicting skeletal mass of DXA using single abdominal images. DXA, dual-energy X-ray absorptiometry; ASM, appendicular skeletal muscle mass; ASMI, appendicular skeletal muscle mass index; CT, computed tomography; MRI magnetic resonance imaging; L3, third lumbar vertebra; N/A not available. [§]ASM/height^2. [*]Number of data sets of 112 subjects.

intramuscular fat without significant changes in muscle density[31]. This formula may be less predictive in patients with other medical conditions. Second, the study population consisted of Asian participants with a low mean BMI (21.3 ± 3.1 kg/m^2). These results may be difficult to generalize to populations with different characteristics, such as Western populations or obese patients[32]. Third, contrast-enhanced CT scans were analyzed. Contrast media can significantly impact body composition and muscle density before and after contrast enhancement. The generalizability of the model to different CT protocols may be limited. The muscle density increases by approximately 20% on enhanced CT than that on unenhanced CT[33]. According to previous studies[33–35], the differences in average muscle attenuation values have been reported to be 4–8 HU. When applying these values to the formula and assuming the maximum difference of 8 HU, the L3 level shows an ASM of 0.08 kg and the thigh level shows a difference of 0.41 kg; however, further work is needed to assess the clinical relevance of these differences. Fourth, the clinical applicability of the calculated formula is somewhat complex due to the need for manual CT segmentation and in the absence of implementation tools. The further integration of this formula into existing muscle measurement software might reduce the need for manual work, potentially enabling its use in routine clinical settings. Finally, external validation of the regression model could not be performed due to the lack of datasets from other hospitals meeting our strict inclusion criteria (e.g., within 1 day between DXA and CT scans). Although a machine learning analysis was performed to support the results of the multiple linear regression, further prospective, multicenter studies are needed. Further research should incorporate diverse populations, including high-BMI groups and patients with sarcopenic obesity, to further validate and refine the clinical utility of our model.

In conclusion, CT-derived muscle measurements at the L3 and upper thigh levels showed strong predictive performance for DXA-measured ASM in the gastrectomy patients, and the machine learning analysis supports this finding. It appears that abdominal CT scans can not only identify potential abnormalities but also serve as a potential surrogate for ASM. A further study is to validate whether the predicted ASM values from our formula can serve as a robust predictor for clinical outcomes, such as postoperative complications or overall survival.

Data availability

The generated datasets available by request to the corresponding author.

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Author contributions

S.J.L. conceptualized and designed the study. M.K. and S.J.L. contributed to data acquisition and analysis. J.K. and S.J.L. assisted with the interpretation of findings and statistical analysis. M.K., J.K., and S.J.L. drafted the main manuscript text, while C.M.L., B.K.K., T.K.H., and Y.Y.C. provided critical revisions for important intellectual content. All authors reviewed and approved the final manuscript.

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Declarations

Ethics approval and consent to participate

Institutional Review Board approval was obtained, and informed consent was waived by the Institutional Review Board of Hanyang University Hospital (IRB No. 2024-02-052).

Competing interests

The authors declare no competing interests.

Additional information

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