Original Article

Clinical usefulness of psoas muscle thickness for the diagnosis of sarcopenia in patients with liver cirrhosis

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Background/Aims: The most widely used method for diagnosing sarcopenia is the skeletal muscle index (SMI). Several studies have suggested that psoas muscle thickness per height (PMTH) is also effective for detecting sarcopenia and predicting prognosis in patients with cirrhosis. The aim of this study was to evaluate the optimal cutoff values of PMTH for detecting sarcopenia in cirrhotic patients.

Methods: All cirrhotic patients who underwent abdominal computed tomography (CT) scan including L3 and umbilical levels for measuring SMI and transverse psoas muscle thickness, respectively, were included. Two definitions of sarcopenia were used: (1) sex-specific cutoffs of SMI ($\leq$52.4 cm^2/m^2 in men and $\leq$38.5 cm^2/m^2 in women) for SMI-sarcopenia and (2) cutoff of PMTH (<16.8 mm/m) for PMTH-sarcopenia.

Results: Six hundred fifty-three patients were included. The average age was 53.6±10.2 years, and 499 patients (76.4%) were men. PMTH correlated well with SMI in both men and women (P<0.001). Two hundred forty-one (36.9%) patients met the criteria for SMI-sarcopenia. The best PMTH cutoff values for predicting SMI-sarcopenia were 17.3 mm/m in men and 10.4 mm/m in women, and these were defined as sex-specific cutoffs of PMTH (SsPMTH). The previously published cutoff of PMTH was defined as sex-nonspecific cutoff of PMTH (SnPMTH). Two hundred thirty (35.2%) patients were diagnosed with SsPMTH-sarcopenia, and 280 (44.4%) patients were diagnosed with SnPMTH-sarcopenia. On a multivariate Cox regression analysis, SsPMTH-sarcopenia (hazard ratio [HR], 1.944; 95% confidence interval [CI], 1.144–3.304; P=0.014) was significantly associated with mortality, while SnPMTH-sarcopenia was not (HR, 1.446; 95% CI, 0.861–2.431; P=0.164).

Conclusions: PMTH was well correlated with SMI in cirrhotic patients. SsPMTH-sarcopenia was an independent predictor of mortality in these patients and more accurately predicted mortality compared to SnPMTH-sarcopenia. **(Clin Mol Hepatol 2018;24:319-330)**

Keywords: Sarcopenia; Cirrhosis; Prognosis; Psoas muscle

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Study Highlights

Sarcopenia is a common complication in patients with liver cirrhosis. Although the smooth muscle index (SMI) is the most widely used technique for the diagnosis of sarcopenia, delineating the surface of muscles is relatively complex, and specific software is need for computation. Previous studies suggested that psoas muscle thickness represents muscle mass and psoas muscle thickness/height (PMTH) is associated with prognosis of patients with liver cirrhosis. In this study, PMTH was a good substitute for SMI and an independent prognostic factor for mortality in cirrhotic patients. In addition, applying different cutoff values based on sex improves its prognostic value.

INTRODUCTION

Sarcopenia is characterized by a decline in muscle mass, muscle strength, and physical activity.[1] In the past, sarcopenia was only considered part of the aging process.[2] However, recent studies have shown that sarcopenia is associated with impaired physical capability,[3-5] poor quality of life, adverse metabolic effects, falls,[6] disability, mortality,[7,8] and high healthcare expenditures.[9] Therefore, sarcopenia is increasingly recognized as a progressive disease frequently associated with various comorbidities and mortality.[10]

Malnutrition is common in patients with advanced liver diseases, and malnutrition and sarcopenia frequently occur in patients with liver cirrhosis.[11-15] A number of studies have reported that, in cases of cirrhosis, sarcopenia is an independent prognostic factor of prognosis.[13-21] However, objective assessment of muscle mass in cirrhotic patients remains challenging. Various definitions and measurement methods have been used to quantify and diagnose sarcopenia. However, there is still no consensus on measurement and cutoff values.[22]

Radiological image analysis is being increasingly utilized to diagnose sarcopenia in patients with cirrhosis.[10] The skeletal muscle index (SMI), assessed by the cross-sectional area of several muscles on computed tomography (CT) at the L3 vertebral level, is the most widely used technique. SMI has been shown to be an independent predictor of mortality in cirrhotic patients.[23-26] Abdominal muscles, including the psoas muscle, are appropriate to use for the assessment of skeletal muscle mass, because abdominal muscle mass, unlike appendicular muscle mass, is relatively independent of activity level.[10] However, delineating the surface of different groups of muscles is relatively complex, takes time and specific software is needed for computation. Therefore, SMI is hardly generalizable to outpatients.

A recent study used psoas muscle thickness measured on CT to diagnose sarcopenia.[27] They measured transverse psoas muscle thickness, defined as diameter of the psoas muscle perpendicular to the longest axial diameter of the muscle at the umbilical level, and then normalized the value to the patient's height by dividing transverse psoas muscle thickness by height. This psoas muscle thickness/height (PMTH) was easily calculated as muscle mass and was determined to be associated with mortality in patients with cirrhosis. This method does not require specific software and can be calculated quickly. However, the study did not correlate PMTH with other measurements, such as psoas muscle area or SMI. Also, sex differences in muscle mass were not considered, and 16.8 mm/m was suggested as a cutoff value for the definition of sarcopenia in all patients. Our study was performed to measure how well PMTH predicts outcomes in cirrhotic patients and to establish optimal PMTH cutoff values for detecting sarcopenia by sex.

MATERIALS AND METHODS

Patients

We included all patients with liver cirrhosis who underwent an abdominal CT and laboratory tests at the Korea University Anam Hospital, Soonchunhyang University Bucheon Hospital, and Wonju Severance Christian Hospital. Patients with hepatocellular carcinoma and parenchymal renal disease were excluded. Liver cirrhosis was diagnosed histologically or clinically. The protocol was approved by the Human Ethics Committee of the Korea University Anam Hospital and conformed to the ethical guidelines of the 2008 Declaration of Helsinki. A waiver of consent was obtained, and the patient records were anonymized and de-identified prior to analysis.

Data collection

Data on age, sex, height, body weight, body mass index (BMI), underlying liver diseases, and results of the baseline laboratory tests were collected for each patient. Baseline laboratory tests consisted of platelet count, international normalized ratio (INR), serum aspartate aminotransferase (AST), alanine aminotransferase (ALT), bilirubin, albumin, creatinine (Cr), and sodium levels. The

model for end-stage liver disease (MELD) score was calculated using the following equation: $9.57 \times \log_e$ (creatinine, mg/dL)$+3.78 \times \log_e$ (bilirubin, mg/dL)$+11.2 \times \log_e$ (INR)$+6.43$.[28] Clinical, laboratory, and radiological data used for the analysis were obtained within 1 week of the CT image used to quantify skeletal muscle mass.

Measurement of skeletal muscle area and definition of sarcopenia

Two axial images one at the L3 vertebral body and one at the level of the umbilicus were selected for each case. To determine PMTH, axial and transverse thickness of right psoas muscle was measured at the level of the umbilicus. Axial psoas muscle thickness was defined as the largest diameter of psoas muscle on an axial view (Fig. 1). Transversal psoas muscle thickness was defined as the diameter of psoas muscle perpendicular to the axial diameter. Psoas muscle thickness was normalized to the patient's height. For SMI, skeletal muscle area (cm^2) was measured by a trained operator with the NIH ImageJ software which enables specific tissue demarcation using previously reported Hounsfield unit thresholds (for skeletal muscle, -29 to +150).[29] The skeletal muscle area at L3 vertebra was normalized to the patient's height squared (m^2).

Sarcopenia was defined by previously published cutoffs: (1) sex-specific cutoffs of SMI (≤ 52.4 cm^2/m^2 in men and ≤ 38.5 cm^2/m^2 in women) for SMI-sarcopenia[14]; (2) cutoff of PMTH (<16.8 mm/m) for PMTH-sarcopenia (sex-nonspecific PMTH sarcopenia, SnPMTH-sarcopenia).[27]
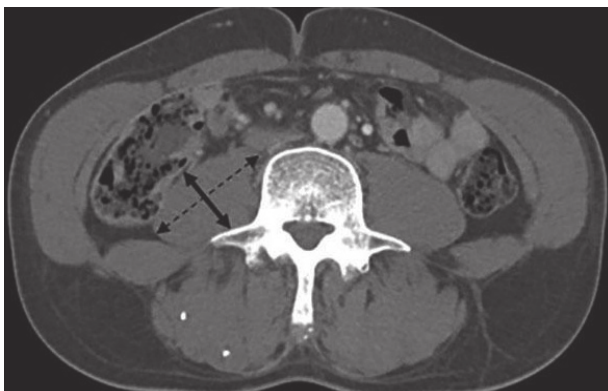
Figure 1. Measurement of psoas muscle thickness/height at the level of the umbilicus on a computed tomography (CT) scan image. Axial CT scan at the level of the umbilicus in a patient with hepatitis B virus-related cirrhosis and a model for end-stage liver disease (MELD) score of 10 with no ascites. Psoas muscle thickness corresponds to the diameter of transversal psoas muscle (left-right arrow) perpendicular to the axial diameter (dotted left-right arrow).

Statistical analysis

Statistical analyses were performed using the Statistical Package for the Social Science (SPSS) version 20.0 for Windows (IBM Corp., Armonk, NY, USA). All data are expressed as either mean±standard deviation for continuous variables or number of patients (percentage) for categorical variables. Groups were compared using the chi-square test for categorical variables and Student's t-test for quantitative variables. The area under the receiver operating characteristic curve (AUROC) and 95% confidence interval (CI) were used to find the optimal values of sex-specific psoas muscle thickness/height (SsPMTH)-sarcopenia to predict SMI-sarcopenia. Survival time was calculated as the time interval from the date of the abdominal CT scan to death or to the end of the follow-up. Patients who had liver transplantation were censored at the time of liver transplantation. Survival curves were constructed using the Kaplan-Meier method, and differences were assessed by the log-rank test. A Cox regression analysis was performed to find which variables were predictors of mortality. Hazard ratios (HRs) and 95% CIs were calculated. A two-tailed P-value of less than 0.05 was considered statistically significant.

RESULTS

Baseline characteristics

Table 1 presents baseline characteristics of all included patients. A total of 653 patients were included. The average age was 53.6±10.2 years and 499 patients (76.4%) were men. Alcoholic liver disease was the most common underlying liver disease (326 patients, 49.9%), followed by chronic viral hepatitis (269 patients, 41.0%). Most of the cause of chronic viral hepatitis was chronic hepatitis B (244 of 269 patients, 90.7%). The average MELD score was 11.4±4.8. Ascites was absent in 332 patients (50.8%), mild in 197 patients (30.2%), and moderate in 124 patients (19.0%).

Sarcopenia defined by SMI

Two hundred forty-one (36.9%) patients met the criteria for SMI-sarcopenia. In this group, men and alcoholic liver disease were more common than those that did not meet the threshold for SMI-sarcopenia (Table 2). Serum bilirubin level and the MELD score were significantly higher in patients with SMI-sarcopenia, while BMI and serum sodium level were significantly lower compared to

Table 1. Baseline characteristics of all included patients with liver cirrhosis

	All patients (n=653)
Age (years)	53.6±10.2
Male (n, %)	499 (76.4)
BMI (kg/m^2)	23.6±3.8
PMTH (mm/m)	17.4 ± 4.0
Underlying liver disease (n, %)	
Viral	268 (41.0)
Alcohol	326 (49.9)
Others	59 (9.0)
Diabetes (n, %)	181 (27.7)
Platelet count (×10^9/L)	103.6±64.6
INR	1.3±0.3
AST (IU/L)	79.8±159.8
ALT (IU/L)	60.0±78.5
Bilirubin (mg/dL)	2.5±3.8
Albumin (g/dL)	3.4±0.7
Creatinine (mg/dL)	0.8±0.3
Sodium (mEq/L)	137.6±4.0
MELD score	11.4±4.8

Values are presented as mean±SD or n (%).
BMI, body mass index; PMTH, psoas muscle thickness/height; INR, international normalized ratio; AST, aspartate aminotransferase; ALT, alanine aminotransferase; MELD, model for end stage liver disease.

those without SMI-sarcopenia. PMTH was significantly lower in the patients with SMI-sarcopenia compared to those without SMI-sarcopenia (15.8±3.6 mm/m vs. 18.4±4.0 mm/m, $P<0.001$). On a multivariate binary regression analysis, the presence of SMI-based sarcopenia was independently associated with male sex (odds ratio [OR], 7.657; 95% CI, 4.190–13.992; $P<0.001$), lower BMI (OR, 0.709; 95% CI, 0.661–0.761; $P<0.001$), and serum bilirubin level (OR, 1.068; 95% CI, 1.013–1.125; $P=0.015$) (Table 3).

Sarcopenia defined by PMTH

PMTH was significantly higher in men than in women (18.1±3.8 mm/m vs. 15.2±3.9 mm/m, $P<0.001$). PMTH was well correlated with SMI (Pearson's correlation coefficient, 0.526; $P<0.001$) (Fig. 2A). The Pearson's correlation coefficient differed between men (0.505, $P<0.001$) (Fig. 2B) and women (0.380, $P<0.001$) (Fig. 2C). Following previous cutoff value, PMTH was less than 16.8 mm/m in 290 patients (44.4%) and they were defined as sex-nonspecific

psoas muscle thickness/height (SnPMTH)-sarcopenia.

The AUROCs of PMTH for predicting SMI-sarcopenia were 0.779 (95% CI, 0.739–0.819) in men (Fig. 3A) and 0.842 (95% CI, 0.772–0.912) in women (Fig. 3B). The best cutoff values for predicting SMI-sarcopenia were 17.3 mm/m in men (sensitivity, 65.3%; specificity, 76.3%) and 10.4 mm/m in women (sensitivity, 31.2%; specificity, 90.6%). Using these cutoff values, sarcopenia was diagnosed in 230 patients (35.2%) and they were defined as SsPMTH-sarcopenia.

When sarcopenia was diagnosed using the SnPMTH-sarcopenia, more women were defined as sarcopenic. Serum bilirubin level was significantly higher in patients with SnPMTH-sarcopenia, while BMI, serum albumin, and creatinine levels were significantly lower. The MELD score did not differ between the two groups (11.8±4.9 vs. 11.1±4.7, $P=0.083$) (Table 2). On multivariate binary regression analysis, the presence of SnPMTH-sarcopenia was independently associated with female sex (OR, 4.794; 95% CI, 3.046–7.545; $P<0.001$), lower BMI (OR, 0.777; 95% CI, 0.734–0.822; $P<0.001$), and serum albumin level (OR, 0.486; 95% CI, 0.366–0.645; $P<0.001$) (Table 4).

When sarcopenia was defined with SsPMTH-sarcopenia, men and those with alcoholic liver disease were more frequently defined as sarcopenic. Serum bilirubin level and the MELD score were significantly higher in patients with SsPMTH-sarcopenia, while BMI and serum sodium level were significantly lower (Table 2). On multivariate binary regression analysis, the presence of SsPMTH-sarcopenia was independently associated with sex (OR, 5.558; 95% CI, 3.109–9.937; $P<0.001$), lower BMI (OR, 0.759; 95% CI, 0.712–0.810; $P<0.001$), alcoholic liver disease (OR, 1.592; 95% CI, 1.080–2.346; $P=0.019$), and serum albumin level (OR, 0.417; 95% CI, 0.288–0.603; $P<0.001$) (Table 5).

Mortality

Cumulative survival rate differed significantly according to the presence of sarcopenia (Fig. 4). With the definition of sarcopenia by SMI, survival rates at 1, 2, and 3 years were 97.7%, 93.3%, and 88.3%, respectively, in patients without sarcopenia, while those were 86.2%, 81.0%, and 78.8%, respectively, in patients with sarcopenia ($P<0.001$) (Fig. 4A). With the definition of sarcopenia by sex-nonspecific cutoff of PMTH the survival rates at 1, 2, and 3 years were 95.3%, 91.5%, and 88.4%, respectively, in patients without sarcopenia, while those were 91.4%, 85.6%, and 80.6%, respectively, in patients with sarcopenia ($P=0.024$) (Fig. 4B). With the definition of sarcopenia by sex-specific cutoff of PMTH, survival rates

Table 2. Baseline characteristics according to the presence of sarcopenia based on the SMI and sex-nonspecific and sex-specific PMTH definitions

	Sarcopenia by SMI definition			Sarcopenia by sex-nonspecific PMTH definition			Sarcopenia by sex-specific PMTH definition		
	Pts with sarcopenia (n=241)	Pts without sarcopenia (n=412)	P-value	Pts with sarcopenia (n=290)	Pts without sarcopenia (n=363)	P-value	Pts with sarcopenia (n=230)	Pts without sarcopenia (n=423)	P-value
Age (years)	53.0±9.6	53.9±10.4	0.257	54.4±10.8	52.9±9.6	0.075	54.0±9.8	53.4±10.4	0.443
Male (n, %)	225 (93.4)	274 (66.5)	<0.001	188 (64.8)	311 (85.7)	<0.001	211 (91.7)	288 (68.1)	<0.001
BMI (kg/m^2)	21.6±3.0	24.8±3.7	<0.001	22.2±3.3	24.7±3.7	<0.001	21.8±3.3	24.6±3.7	<0.001
PMTH (mm/m)	15.8±3.6	18.4±4.0	<0.001	13.8±2.3	20.4±2.4	<0.001	14.1±2.5	19.3±3.5	<0.001
Underlying liver disease (n, %)			<0.001			0.007			<0.001
Viral	78 (32.4)	190 (46.1)		108 (37.2)	160 (44.1)		71 (30.9)	197 (46.6)	
Alcohol	146 (60.6)	180 (43.7)		145 (50.0)	181 (49.9)		146 (63.5)	180 (42.6)	
Others	17 (7.1)	42 (10.2)		37 (12.8)	22 (6.1)		13 (5.7)	46 (10.9)	
Diabetes (n, %)	72 (29.9)	109 (26.5)	0.346	82 (28.3)	99 (27.3)	0.776	75 (32.6)	106 (25.1)	0.040
Platelet count (×10^9/L)	98.9±60.7	106.3±66.8	0.154	103.5±64.6	103.7±59.8	0.965	104.2±64.9	103.2±64.6	0.855
INR	1.3±0.3	1.3±0.3	0.748	1.3±0.3	1.3±0.3	0.126	1.3±0.3	1.3±0.3	0.643
AST (IU/L)	79.7±102.0	79.9±185.5	0.984	77.4±104.9	81.8±192.8	0.731	73.0±96.0	83.6±185.5	0.421
ALT (IU/L)	55.0±63.8	63.0±85.9	0.207	56.6±67.1	62.8±86.5	0.313	52.6±53.8	64.1±88.9	0.075
Bilirubin (mg/dL)	3.1±4.5	2.2±3.3	0.007	2.8±4.3	2.2±3.4	0.045	3.0±4.6	2.2±3.3	0.026
Albumin (g/dL)	3.3±0.6	3.4±0.7	0.051	3.2±0.6	3.5±0.7	<0.001	3.2±0.6	3.5±0.7	<0.001
Creatinine (mg/dL)	0.9±0.3	0.8±0.2	0.107	0.8±0.3	0.9±0.3	0.003	0.8±0.3	0.8±0.3	0.505
Sodium (mEq/L)	137.0±4.3	137.9±3.8	0.006	137.3±4.6	137.8±3.5	0.174	137.1±4.7	137.9±3.5	0.028
MELD score	12.0±5.3	11.1±4.4	0.017	11.8±4.9	11.1±4.7	0.083	11.9±5.0	11.2±4.7	0.045

Values are presented as mean±SD or n (%) unless otherwise indicated.
SMI, skeletal muscle index; PMTH, psoas muscle thickness/height; Pts, patients; BMI, body mass index; INR, international normalized ratio; AST, aspartate aminotransferase; ALT, alanine aminotransferase; MELD, model for end stage liver disease.

Table 3. Univariate and multivariate binary regression analyses for the presence of sarcopenia based on the SMI definition

	Rating	Univariate		Multivariate	
		OR (95% CI)	*P*-value	OR (95% CI)	*P*-value
Age	Years	0.991 (0.976–1.007)	0.274		
Sex	0=female; 1=male	7.083 (4.099–12.237)	<0.001	7.657 (4.190–13.992)	<0.001
BMI	kg/m^2	0.734 (0.690–0.782)	<0.001	0.709 (0.661–0.761)	<0.001
Underlying liver disease	0=other; 1=alcohol	1.981 (1.433–2.737)	<0.001	1.337 (0.907–1.1971)	0.142
Diabetes	0=no; 1=yes	1.184 (0.833–1.684)	0.346		
Platelet count	×10^9/L	0.998 (0.996–1.001)	0.155		
INR	Ratio	1.083 (0.665–1.764)	0.748		
AST	IU/L	1.000 (0.999–1.001)	0.984		
ALT	IU/L	0.999 (0.996–1.001)	0.212		
Bilirubin	mg/dL	1.063 (1.018–1.110)	0.006	1.068 (1.013–1.125)	0.015
Albumin	g/dL	0.784 (0.613–1.002)	0.052		
Creatinine	mg/dL	1.677 (0.909–3.094)	0.098		
Sodium	mEq/L	0.943 (0.906–0.982)	0.005	1.337 (0.907–1.971)	0.142

SMI, skeletal muscle index; OR, odds ratio; CI, confidence interval; BMI, body mass index; INR, international normalized ratio; AST, aspartate aminotransferase; ALT, alanine aminotransferase.

at 1, 2, and 3 years were 96.2%, 92.4%, and 89.7%, respectively, in patients without sarcopenia, while those were 90.2%, 84.1%, and 78.5%, respectively, in patients with sarcopenia (*P*=0.002) (Fig. 4C).

On a univariate Cox regression analysis, the presence of sarcopenia was significantly associated with mortality when any definition was applied. In addition, underlying liver disease, platelet count, INR, serum bilirubin, albumin, creatinine, and sodium levels were significantly associated with mortality (Table 6).

A multivariate Cox regression analysis was performed after adjusting for underlying liver disease, platelet count, INR, bilirubin, albumin, Cr, and sodium levels. SMI-sarcopenia (HR, 1.841; 95% CI, 1.072–3.164; *P*=0.027) and SsPMTH-sarcopenia (HR, 1.818; 95% CI, 1.056–3.130; *P*=0.031) were significantly associated with mortality, but there was no significant association between SnPMTH-sarcopenia and mortality (HR, 1.613; 95% CI, 0.950–2.739; *P*=0.077) (Table 7).

DISCUSSION

In this study, PMTH was well correlated with SMI, and the AUROC of PMTH for predicting sarcopenia defined by SMI was relatively high in both men and women suggesting that PMTH is a more simple, objective, and readily available method to assess skel-

etal muscle mass. Similarly to previous studies, SMI-based sarcopenia was predictive of mortality, independently of other possible confounders. Interestingly, we found that sex-specific PMTH-based sarcopenia was significantly associated with mortality, while sex-nonspecific PMTH-based sarcopenia was not.

A number of studies showed men had significantly more skeletal muscle mass than in women, even after adjustment for body weight and height.[30-33] Moreover, the association between sarcopenia and functional decline is stronger in men than in women.[34,35] These differences may be a natural result of the different exposure of sex hormones and the greater amount of physical activity in men. In muscle quantification studies based on magnetic resonance imaging, the muscle mass of the psoas major showed significant sex differences while the rectus abdominis, latissimus dorsi, or thigh muscles did not.[36,37] Reasons for these sex differences are still unknown, but a greater functional requirement of trunk musculature might be associated with greater development of the psoas muscle in men who perform more physical activities than women.[38-40] Also, during growth, women experience a lower increase in waist circumference than men. This morphological difference in the abdominal region might be associated with the difference in psoas muscle mass between the sexes.[41-44]

Recently, CT with image analysis programs is being increasingly used to assess skeletal muscle mass. Abdominal CT would be difficult to justify for muscle mass measurements alone due to cost and
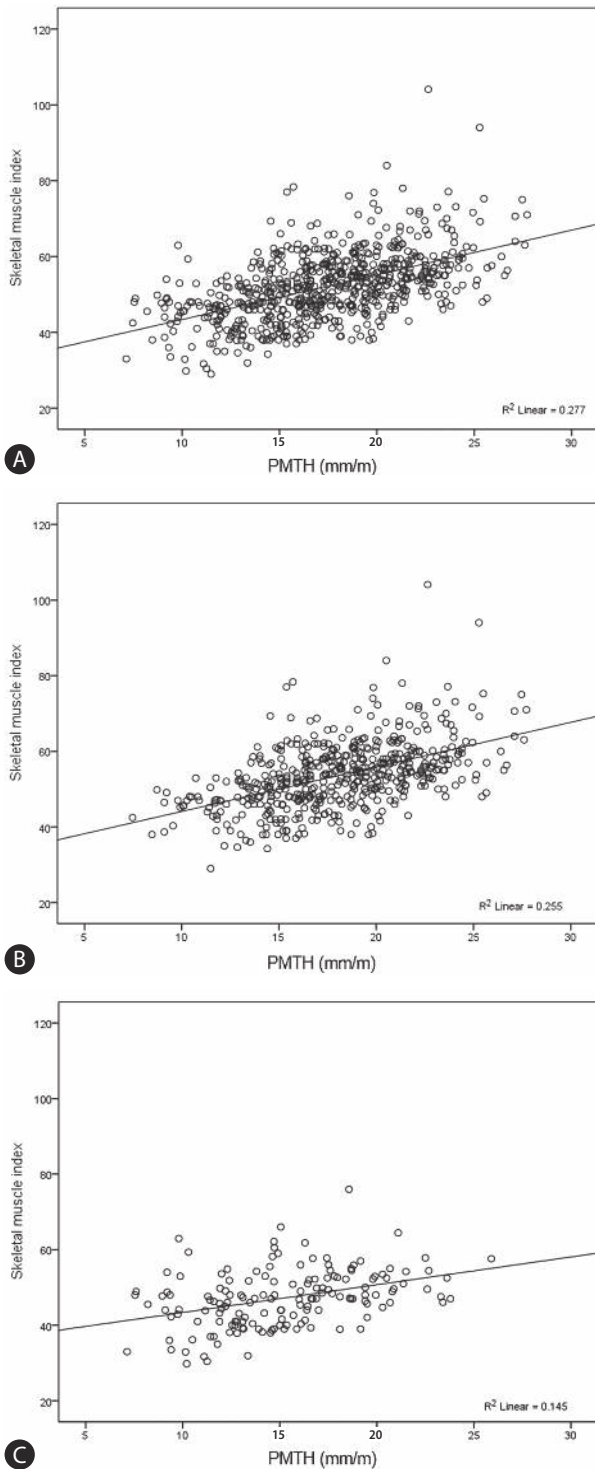
Figure 2. Correlation between psoas muscle thickness/height and skeletal muscle index. Correlation between psoas muscle thickness/height and skeletal muscle index in all enrolled patients (A), in men (B), and in women (C). PMTH was well correlated with SMI (Pearson's correlation coefficient, 0.526; $P<0.001$) (A). The Pearson's correlation coefficient differed between men (0.505, $P<0.001$) (B) and women (0.380, $P<0.001$) (C). PMTH, psoas muscle thickness/height; SMI, skeletal muscle index.

radiation exposure. However, as most patients with liver cirrhosis have surveillance scans for detecting focal liver lesions,[10] additional CT scans for measuring muscle mass are not usually needed.

Previous researchers have suggested that PMTH, measured on CT at the level of the umbilicus, may be predictive of mortality in cirrhotic patients independently of the MELD and MELD-Na scores. They also suggested that the optimal cutoff point of 16.8 mm/m be used to predict mortality in both sexes.[27] However, contrary to other studies, when this cutoff value was applied, sarcopenia was more frequent in women than in men. Besides, the mean MELD score (11.8±4.9 vs. 11.1±4.7, $P=0.083$) and mortality (HR, 1.613; 95% CI, 0.950–2.739; $P=0.077$) were not significantly different between patients with and without SnPMTH sarcopenia. These results could be indicative of weakness of SnPMTH in predicting prognosis of cirrhotic patients. As amount of muscle mass differs with gender (lower in females)[25] after adjustment for height, applying different cutoff values based on sex would be more appropriate. Therefore, we found the sex-specific cutoffs of PMTH (<17.3 mm/m in men and <10.4 mm/m in women) to be the optimal values for predicting sarcopenia defined by SMI. Among 290 patients (44.4%) classified as sarcopenic by SnPMTH, 60 (9.2%) were classified as non-sarcopenic by SsPMTH. Sarcopenia defined by sex-specific PMTH (HR, 1.818; 95% CI, 1.056–3.130; $P=0.031$) was significantly associated with mortality.

It is hard to compare the results of the previous study and our current study due to the disparities between the cohorts. First, mean MELD score was higher in the previous study (16.0±7) than in our study (11.4±4.8). This was because only patients registered for deceased donor liver transplantation were enrolled in the previous study, while we included all patients with liver cirrhosis who had an abdominal CT scan. Therefore, mortality at 6 months was higher in the previous study (12.3%) than in our study (3.7%). Second, the previous study included HCC patients (46%), who were excluded in our study in consideration of the impact of HCC on mortality. Our data more clearly shows the clinical effect of sarcopenia in cirrhotic patients. Lastly, mean BMI (23.6±3.8 kg/m^2 vs. 26.2±4.7 kg/m^2) and mean PMTH was lower in our study. This disparity may have been caused by the differences in body size, lifestyle, and cultural background between Asian and Caucasian populations.[45] However, the prevalence of sarcopenia is usually not higher in Asians compared to Caucasians, although mean BMI and mean muscle mass are lower in Asians. This difference may be due to the characteristics of older Asian people, who have walked and performed more physical activities since their early adulthood because of the underdeveloped living conditions and transportation.
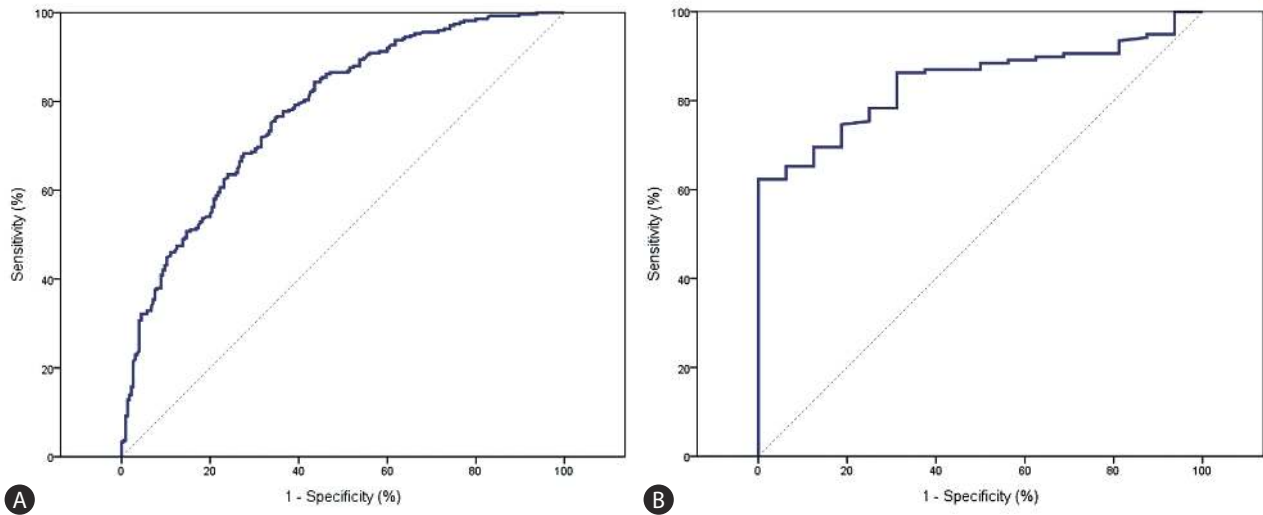
Figure 3. Area under the receiver operating characteristic curve for detecting sarcopenia. Area under the receiver operating characteristic curve for detecting sarcopenia defined by smooth muscle index based on psoas muscle thickness/height in men (A) and in women (B). The area under the receiver operating characteristic curve of psoas muscle thickness/height for predicting skeletal muscle index-sarcopenia was 0.779 (95% confidence interval [CI], 0.739-0.819) in men (A) and 0.842 (95% CI, 0.772-0.912) in women (B).

Table 4. Univariate and multivariate binary regression analyses for the presence of sarcopenia based on the sex-nonspecific PMTH definition

	Rating	Univariate		Multivariate	
		OR (95% CI)	*P*-value	OR (95% CI)	*P*-value
Age	Years	1.014 (0.999–1.030)	0.072		
Sex	0=male; 1=female	3.245 (2.219–4.744)	<0.001	4.794 (3.046–7.545)	<0.001
BMI	kg/m^2	0.811 (0.770–0.854)	<0.001	0.777 (0.734–0.822)	<0.001
Underlying liver disease	0=other; 1=alcohol	1.006 (0.738–1.369)	0.972		
Diabetes	0=no; 1=yes	1.051 (0.745–1.484)	0.776		
Platelet count	×10^9/L	1.000 (0.998–1.002)	0.965		
INR	Ratio	1.451 (0.897–2.347)	0.129		
AST	IU/L	1.000 (0.999–1.001)	0.733		
ALT	IU/L	0.999 (0.997–1.001)	0.316		
Bilirubin	mg/dL	1.043 (1.000–1.088)	0.051		
Albumin	g/dL	0.569 (0.445–0.729)	<0.001	0.486 (0.366–0.645)	<0.001
Creatinine	mg/dL	0.378 (0.194–0.733)	0.004	0.714 (0.346–1.474)	0.362
Sodium	mEq/L	0.973 (0.935–1.011)	0.161		

PMTH, psoas muscle thickness/height; OR, odds ratio; CI, confidence interval; BMI, body mass index; INR, international normalized ratio; AST, aspartate aminotransferase; ALT, alanine aminotransferase.

This study has several limitations. First, it is a retrospective study, and PMTH was measured by only one clinician. We could not evaluate inter-observer variance, although several studies have already shown relatively good agreement between observers. Second, PMTH has inherent limitations. Transverse psoas muscle thickness was measured at the level of the umbilicus, but the level of the umbilicus may vary if ascites is present. However, umbilical level can

be easily identified on a CT scan than given level of the lumbar section, because sacralization of the L5 vertebrae and lumbar wedge fractures in patients with osteoporosis make detection of given lumbar level difficult.[27] In a recent systematic review and meta-analysis on the impact of CT-assessed skeletal muscle mass on outcomes in liver transplant candidates,[22] only one study measured skeletal muscle mass using PMTH.[27] Further studies validating the

Table 5. Univariate and multivariate binary regression analyses for the presence of sarcopenia based on the sex-specific PMTH definition

	Rating	Univariate		Multivariate	
		OR (95% CI)	*P*-value	OR (95% CI)	*P*-value
Age	Years	1.006 (0.990–1.022)	0.451		
Sex	0=female; 1=male	5.206 (3.120–8.687)	<0.001	5.558 (3.109–9.937)	<0.001
BMI	kg/m^2	0.780 (0.737–0.827)	<0.001	0.759 (0.712–0.810)	<0.001
Underlying liver disease	0=other; 1=alcohol	2.346 (1.686–3.265)	<0.001	1.592 (1.080–2.346)	0.019
Diabetes	0=no; 1=yes	1.447 (1.017–2.059)	0.040	1.513 (0.997–2.297)	0.052
Platelet count	×10^9/L	1.000 (0.998–1.003)	0.855		
INR	Ratio	1.123 (0.688–1.834)	0.643		
AST	IU/L	0.999 (0.998–1.001)	0.438		
ALT	IU/L	0.998 (0.995–1.000)	0.081		
Bilirubin	mg/dL	1.052 (1.009–1.097)	0.018	1.072 (0.990–1.161)	0.085
Albumin	g/dL	0.560 (0.433–0.725)	<0.001	0.417 (0.288–0.603)	<0.001
Creatinine	mg/dL	0.805 (0.426–1.522)	0.505		
Sodium	mEq/L	0.952 (0.914–0.992)	0.018	1.002 (0.954–1.054)	0.922

PMTH, psoas muscle thickness/height; OR, odds ratio; CI, confidence interval; BMI, body mass index; INR, international normalized ratio; AST, aspartate aminotransferase; ALT, alanine aminotransferase.
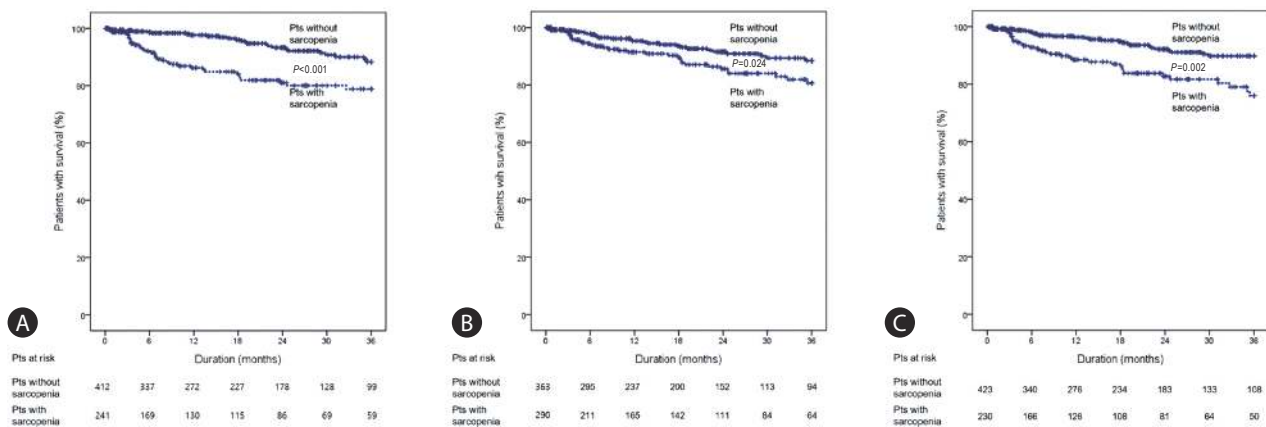
Figure 4. Kaplan-Meier analysis for survival according to the presence of sarcopenia. Kaplan-Meier curve for cumulative survival of patients with liver cirrhosis according to the presence of sarcopenia defined by smooth muscle index (A), sex-nonspecific PMTH (B), and sex-specific PMTH (C). With the definition of sarcopenia based on SMI, survival rates at 1, 2, and 3 years were 97.7%, 93.3%, and 88.3%, respectively, in patients without sarcopenia, while they were 86.2%, 81.0%, and 78.8% in patients with sarcopenia (*P*<0.001) (A). With the definition of sarcopenia based on the sex-nonspecific cut-off of PMTH, the survival rates at 1, 2, and 3 years were 95.3%, 91.5%, and 88.4%, respectively, in patients without sarcopenia, while they were 91.4%, 85.6%, and 80.6% in patients with sarcopenia (*P*=0.024) (B). With the definition of sarcopenia by sex-specific cutoff of PMTH, survival rates at 1, 2, and 3 years were 96.2%, 92.4%, and 89.7%, respectively, in patients without sarcopenia, while they were 90.2%, 84.1%, and 78.5% in patients with sarcopenia (*P*=0.002) (C). Pts, patients; PMTH, psoas muscle thickness/height; SMI, skeletal muscle index.

efficacy of PMTH in patients with liver cirrhosis are needed. Lastly, assessment of muscle mass by CT scan also should be taken into account. Since muscle strength and amount of fat content is related to CT attenuation, CT attenuation is often lower in the muscles of cirrhotic patients compared to controls.[25] It is uncertain whether

sarcopenia in cirrhotic patients can be diagnosed with hounsfield unit alone. To overcome these limitations, numerous measurement methods have been suggested, however, few studies have directly compared the different methods so far.

In conclusion, we found that PMTH measured on a single axial

Table 6. Univariate Cox regression analysis for mortality

	Rating	HR (95% CI)	*P*-value
SMI-sarcopenia	0, no; 1, yes	2.710 (1.622–4.528)	<0.001
SnPMTH-sarcopenia	0, no; 1, yes	1.784 (1.071–2.973)	0.026
SsPMTH-sarcopenia	0, no; 1, yes	2.202 (1.314–3.692)	0.003
Age	Years	1.009 (0.984–1.034)	0.495
Sex	0, female; 1, male	1.873 (0.922–3.805)	0.083
BMI (kg/m^2)	kg/m^2	0.978 (0.913–1.047)	0.514
Underlying liver disease	0, other; 1, alcohol	1.629 (0.972–2.730)	0.064
Diabetes	0, no; 1, yes	0.991 (0.570–1.722)	0.974
Platelet count	×10^9/L	0.995 (0.990–1.000)	0.037
INR	Ratio	3.798 (2.114–6.825)	<0.001
AST	IU/L	0.998 (0.995–1.002)	0.348
ALT	IU/L	0.999 (0.996–1.002)	0.520
Bilirubin	mg/dL	1.103 (1.065–1.142)	<0.001
Albumin	g/dL	0.382 (0.252–0.577)	<0.001
Creatinine	mg/dL	5.697 (2.552–12.721)	<0.001
Sodium	mEq/L	0.876 (0.833–0.921)	<0.001

HR, hazard ratio; CI, confidence interval; SMI, skeletal muscle index; SnPMTH, sex-nonspecific psoas muscle thickness/height; SsPMTH, sex-specific psoas muscle thickness/height; BMI, body mass index; INR, international normalized ratio; AST, aspartate aminotransferase; ALT, alanine aminotransferase.

Table 7. Cox regression analysis adjusted for underlying liver disease, platelet count, INR, and serum bilirubin, albumin, creatinine, and sodium levels

	Rating	HR (95% CI)	*P*-value
SMI-sarcopenia	0, no; 1, yes	1.841 (1.072–3.164)	0.027
SnPMTH-sarcopenia	0, no; 1, yes	1.613 (0.950–2.739)	0.077
SsPMTH-sarcopenia	0, no; 1, yes	1.818 (1.056–3.130)	0.031

INR, international normalized ratio; HR, hazard ratio; CI, confidence interval; SMI, skeletal muscle index; SnPMTH, sex-nonspecific psoas muscle thickness/height; SsPMTH, sex-specific psoas muscle thickness/height.

CT scan image at the level of the umbilicus may be a good substitute for SMI and an independent prognostic factor for mortality in cirrhotic patients. Additionally, applying different cutoff values based on sex improves the prognostic value of PMTH.

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Conflicts of Interest

The authors have no conflicts of interest to disclose.

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