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Association Between Pelvic Bone Computed Tomography-Derived Body Composition and Patient Outcomes in Older Adults With Proximal Femur Fracture

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Objective: To investigate the association between pelvic bone computed tomography (CT)-derived body composition and patient outcomes in older adult patients who underwent surgery for proximal femur fractures.
Materials and Methods: We retrospectively identified consecutive patients aged ≥ 65 years who underwent pelvic bone CT and subsequent surgery for proximal femur fractures between July 2018 and September 2021. Eight CT metrics were calculated from the cross-sectional area and attenuation of the subcutaneous fat and muscle, including the thigh subcutaneous fat (TSF) index, TSF attenuation, thigh muscle (TM) index, TM attenuation, gluteus maximus (GM) index, GM attenuation, gluteus medius and minimus (Gmm) index, and Gmm attenuation. The patients were dichotomized using the median value of each metric. Multivariable Cox regression and logistic regression models were used to determine the association between CT metrics with overall survival (OS) and postsurgical intensive care unit (ICU) admission, respectively.
Results: A total of 372 patients (median age, 80.5 years; interquartile range, 76.0–85.0 years; 285 females) were included. TSF attenuation above the median (adjusted hazard ratio [HR], 2.39; 95% confidence interval [CI], 1.41–4.05), GM index below the median (adjusted HR, 2.63; 95% CI, 1.33–5.26), and Gmm index below the median (adjusted HR, 2.33; 95% CI, 1.12–4.55) were independently associated with shorter OS. TSF index (adjusted odds ratio [OR], 6.67; 95% CI, 3.13–14.29), GM index (adjusted OR, 3.45; 95% CI, 1.49–7.69), GM attenuation (adjusted OR, 2.33; 95% CI, 1.02–5.56), Gmm index (adjusted OR, 2.70; 95% CI, 1.22–5.88), and Gmm attenuation (adjusted OR, 2.22; 95% CI, 1.01–5.00) below the median were independently associated with ICU admission.
Conclusion: In older adult patients who underwent surgery for proximal femur fracture, low muscle indices of the GM and gluteus medius/minimus obtained from their cross-sectional areas on preoperative pelvic bone CT were significant prognostic markers for predicting high mortality and postsurgical ICU admission.
Keywords: Sarcopenia; Adipopenia; Gluteus muscle; Pelvic bone CT

INTRODUCTION

Hip fractures in older adults represent a major public health problem associated with increased mortality, physical disability, and socioeconomic burden [1]. Overall, 4.5 million cases of disability due to hip fractures are recorded annually [2]. As life expectancy increases, the estimated number of hip fractures is expected to increase to approximately 6.3–8.2 million cases by 2050 [3]. Among fragility fractures, hip fractures have the highest mortality and morbidity rates [4]. Although advanced age, male sex, comorbidities, and high American Society of Anesthesiologists (ASA) score have already been established as poor prognostic factors in hip fractures [5], further research is required to identify additional prognostic factors and improve clinical outcomes in these patients.

Sarcopenia is associated with poor clinical outcomes in

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various cancers [6,7] and chronic diseases [8,9]. Computed tomography (CT) has been used to assess sarcopenia status because it can quantify skeletal muscle mass by measuring the cross-sectional area. In addition, CT attenuation of tissues helps evaluate tissue quality. Consequently, CT-determined cross-sectional area and attenuation of muscle and adipose tissue have become well-established imaging biomarkers under various conditions [10-12]. While some studies have reported CT-measured sarcopenia as a poor prognostic factor for proximal femur fracture [13,14], these studies targeted muscles at the level of the third lumbar vertebra, which requires additional abdominal CT scanning.

The gluteus muscle plays an important role in falls and fall-related hip fracture [15-17]. Although it seems reasonable to presume that the quantity and quality of these muscles may affect patient outcomes after proximal femur fracture, the role of these muscles in the prognosis of hip fractures has not yet been identified. In addition, recent studies have revealed that body composition, including skeletal muscle and adipose tissue, has a synergistic effect in the older adult population [18,19]. Given that most hip fractures are treated surgically and that many patients who are scheduled for surgery undergo pelvic bone CT, it would be meaningful to identify the prognostic impact of muscles and adipose tissue measured using preoperative CT on patient outcomes. Therefore, this study aimed to investigate the association between preoperative pelvic bone CT-derived body tissue composition, overall survival (OS), and admission to the intensive care unit (ICU) after surgery in older adult patients who underwent surgery for proximal femur fracture.

MATERIALS AND METHODS

Study Design and Patients

The Institutional Review Board of Gil Medical Center approved this retrospective study and waived the requirement for informed consent (IRB No. GCIRB2022-041). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Overall, 512 consecutive older adult patients (≥ 65 years) who underwent surgery for proximal femur fractures between July 2018 and September 2021 at Gil Medical Center were reviewed. Proximal femur fracture was defined as a fracture of the proximal end segment according to the Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA) classification. Among these 512 patients, 420 with available preoperative pelvic bone CT scans were evaluated. A single radiologist reviewed the CT image quality and medical records of each patient. Thereafter, the following exclusion criteria were applied: 1) high-energy trauma (e.g., traffic accident, falling from height accident) (n = 13); 2) pathologic fracture due to tumorous conditions (n = 8); 3) poor image quality (e.g., severe metallic artifact or motion artifact) (n = 16); and 4) inappropriate anatomical position of the patient (e.g., hip abduction or semi-decubitus position due to pain) (n = 11). None of the patients had any muscular disorders in our study population. A total of 372 patients who underwent surgical treatment for proximal femur fracture caused by ground-level falls were included in this study (Fig. 1).

Data Collection

Data on demographic characteristics, bone mineral density, ASA status [20], pre-trauma walking ability, fracture location, type of surgery, and clinical outcomes were collected from electronic medical records. The presence and location of concomitant acute fractures of the contralateral femur, sacrococcygeal bone, or pelvic bone were also evaluated. Body mass index was calculated (weight [kg]/height [m^2]) and categorized according to the Asia-Pacific classification (underweight: < 18.5 kg/m^2; normal weight: 18.5–22.9 kg/m^2; overweight: 23–24.9 kg/m^2; and obese: ≥ 25.0 kg/m^2) [21]. Walking ability before trauma was classified using the modified Koval index as follows: 0, non-ambulatory; 1, activity confined to the room (creeping or rolling); 2, household ambulatory with a cane or walker/crutches; 3, independent household ambulator;

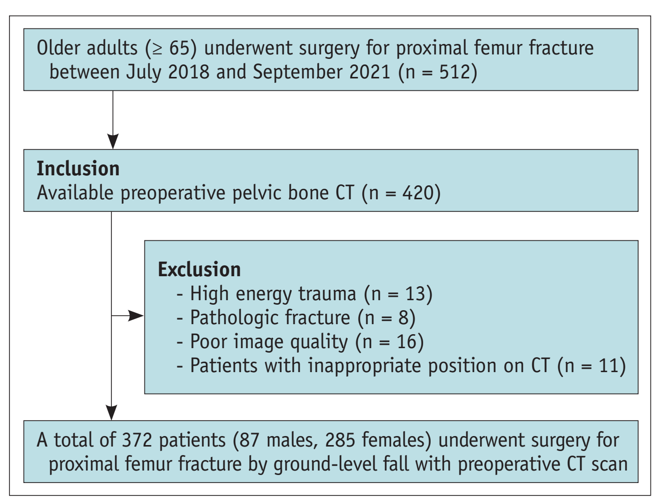

Fig. 1. Flowchart of patient selection process. CT = computed tomography

4, community ambulatory with a cane or walker/crutches; and 5, independent community ambulator [22,23]. We also recorded the dates of admission, last follow-up visit, and death to calculate the OS as the primary outcome of this study, defined as the time from the date of admission to the date of any-cause death. The date of death was obtained from the electronic medical records or the National Survival Statistics Database. Patients without any events were censored at the final follow-up visit. The secondary outcome was postoperative ICU admission.

CT Imaging

All preoperative pelvic bone CT scans were obtained using one of the two 128-channel multi-detector scanners (Somatom Definition Edge or Somatom Definition Flash; Siemens). Unenhanced pelvic bone CT was performed from the fourth lumbar vertebra to the proximal femoral diaphysis with the following parameters: section thickness, 3 mm; section interval, 3 mm; tube voltage, 100 kVp; tube current and autonomic tube current modulation (CARE dose 4D, Siemens); and sharp reconstruction kernel (B60, Siemens).

Image Analysis

Body composition analyses were performed using commercial software (Aquarius iNtuition version 4.4.13, TeraRecon). All measurements were analyzed by a musculoskeletal radiologist with 6 years of experience who was blinded to the patient data. To minimize the effects of edema and hematoma, the CT images of the contralateral side of the fracture were analyzed. We determined three axial scan levels that were modified from previous literature [24-26] as follows: at the distal margin of the gluteal tuberosity, the cross-sectional area (cm^2) and attenuation (Hounsfield unit [HU]) of the proximal thigh muscle (TM), including all compartment muscles, and the subcutaneous fat layer were measured. The cross-sectional area and attenuation of the gluteus maximus (GM) muscle were measured at the level of the trochanteric fossa of the femur. We combined the gluteus medius and minimus (Gmm) muscles and measured their cross-sectional areas and attenuation at the proximal margin of the third sacral vertebral level. After manual segmentation of the region of interest, semiautomatic assessment of the skeletal muscle area and the subcutaneous fat area was performed based on predefined tissue attenuation (-29 to +150 HU for muscle, -190 to -30 HU for fat) (Fig. 2) [27]. For normalization, the cross-sectional areas of all muscles and thigh subcutaneous fat (TSF) (cm^2) were divided by the height squared (m^2) to calculate TM (cm^2/m^2), TSF (cm^2/m^2), GM (cm^2/m^2), and Gmm (cm^2/m^2) indexes. The mean attenuation values (HU) of the TSF, TM, GM muscle, and Gmm muscles were also measured.

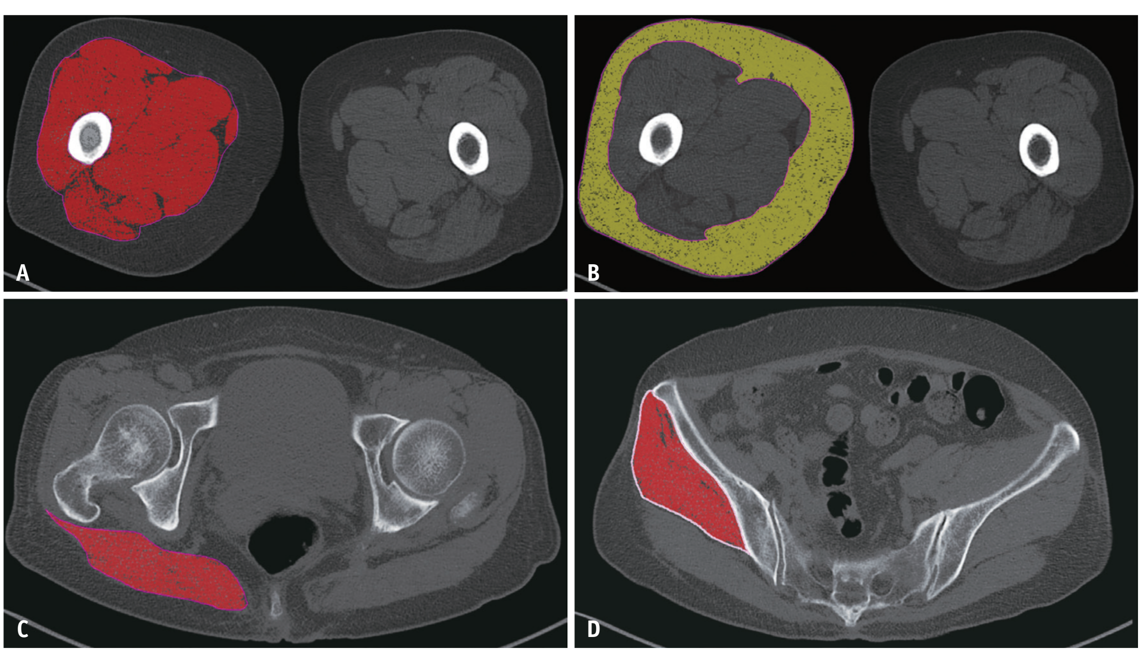

Fig. 2. Analysis of body composition in a 67-year-old female with left femoral neck fracture. **A:** Proximal thigh muscle at the distal margin of the gluteal tuberosity. **B:** Proximal thigh subcutaneous fat at the distal margin of the gluteal tuberosity. **C:** Gluteus maximus muscle at the level of trochanteric fossa of the femur. **D:** Gluteus medius and minimus muscle at the proximal margin of the third sacral level.

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Statistical Analysis

Patients were divided into two groups based on the median values for each CT metric, that is below vs. above the median. Event-time distributions of OS were characterized using the Kaplan-Meier method and compared between the below- and above-median value groups using the log-rank test.

To identify independent predictors for OS, univariable and multivariable Cox proportional hazards models with stepwise selection were used, with age (per 10 years), sex (male/female), ASA score (< 3/≥ 3), and modified Koval index (< 4/≥ 4) being fixed considering their clinical significance [28,29]. Logistic regression was used to estimate the odds ratio (OR) and the corresponding 95% confidence interval (CI) for the risk of ICU admission associated with the covariates and values derived from muscle and fat. Multivariable logistic regression analysis was performed using stepwise selection in the same manner. All statistical analyses were performed using MedCalc® version 20.027 (MedCalc Software Ltd.). Statistical significance was set at $P < 0.05$.

RESULTS

Patient Characteristics

The median patient age was 80.5 years (interquartile range [IQR], 76.0–85.0 years) and there were 87 males and 285 females. The median follow-up period after the date of admission was 7.7 months (IQR, 3.4–16.7 months). The median interval between the date of CT and surgery was 4 days (IQR, 2–5 days), and all CT scans were obtained within a week of the trauma. Fifteen patients had concomitant acute fractures of the sacrococcygeal or pelvic bones (sacrum, n = 5; ischium, n = 2; coccyx, n = 2; pubis, n = 1; multifocal, n = 5). None of the patients had acute bilateral fractures of the femur. The median cut-off values of the CT metrics for dichotomization were as follows: TSF index, 26.7 cm^2/m^2; TSF attenuation, -106.0 HU; TM index, 27.4 cm^2/m^2; TM attenuation, 47.6 HU; GM index, 9.0 cm^2/m^2; GM attenuation, 42.5 HU; Gmm index, 9.2 cm^2/m^2; and Gmm attenuation, 48.9 HU. Baseline patient characteristics are shown in Table 1.

Table 1. Patient Characteristics

Variable	Patients (n = 372)
Age*, yr	80.5 (76.0–85.0)
Sex (male:female)†	87:285 (23.4:76.6)
BMI*, kg/m^2	22.0 (19.5–24.1)
BMI category†	
Underweight (< 18.5 kg/m^2)	62 (16.7)
Normal weight (18.5–22.9 kg/m^2)	177 (47.6)
Overweight (23.0–24.9 kg/m^2)	63 (16.9)
Obese (≥ 25.0 kg/m^2)	70 (18.8)
BMD†	
Normal (T score ≥ -1)	10 (2.7)
Osteopenia (-2.5 < T score < -1)	89 (23.9)
Osteoporosis (T score ≤ -2.5)	245 (65.9)
Unavailable	28 (7.5)
Poor physical status (ASA score ≥ 3)†	124 (33.3)
Low walking ability before trauma (Modified Koval index < 4)†	67 (18.0)
Fracture location†	
Trochanteric region	223 (59.9)
Neck	149 (40.1)
Head	0 (0)
Type of surgery†	
Internal fixation	227 (61.0)
Hemiarthroplasty	123 (33.1)
Total hip replacement	22 (5.9)
Concomitant acute fracture at sacrococcygeal or pelvic bone†	15 (4.0)
Death†	62 (16.7)
Admission to ICU after surgery†	75 (20.2)
CT metrics*	
TSF index, cm^2/m^2	26.7 (19.1–34.9)
TSF attenuation, HU	-106.0 (-109.0– -103.0)
TM index, cm^2/m^2	27.4 (23.7–31.3)
TM attenuation, HU	47.6 (44.4–50.3)
GM index, cm^2/m^2	9.0 (7.3–10.6)
GM attenuation, HU	42.5 (38.2–46.1)
Gmm index, cm^2/m^2	9.2 (7.8–10.7)
Gmm attenuation, HU	48.9 (45.0–51.6)

*Data are presented as the median (interquartile range), †Data are presented as the n (%). ASA = American Society of Anesthesiologists, BMD = bone mineral density, BMI = body mass index, GM = gluteus maximus, Gmm = gluteus medius and minimus, ICU = intensive care unit, TM = thigh muscle, TSF = thigh subcutaneous fat, CT = computed tomography

Overall Survival

The overall mortality rate was 16.7% (62/372 patients). Given that the mortality rate was less than 50%, the median OS was undefined. Kaplan-Meier survival analysis and log-rank test (namely, comparison between below and above median value groups) revealed that OS significantly differed for most CT metrics, including TSF index ($P = 0.005$), TSF attenuation ($P < 0.001$), TM index ($P < 0.001$), TM attenuation ($P = 0.001$), GM index ($P < 0.001$) (Fig. 3A),

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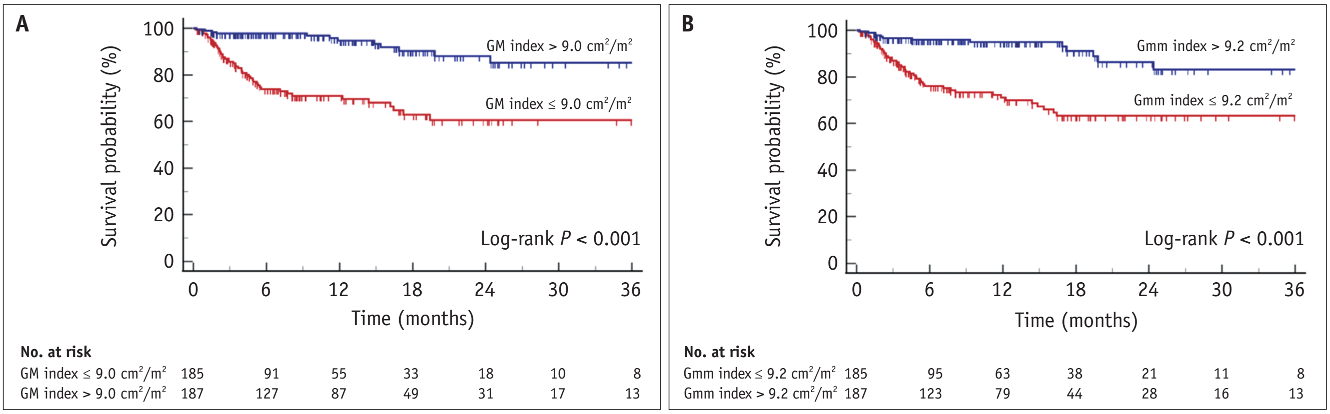

Fig. 3. Kaplan-Meier curve of overall survival. **A:** According to the gluteus maximus index. **B:** According to the gluteus medius and minimus index. GM = gluteus maximus, Gmm = gluteus medius and minimus

Gmm index (P < 0.001) (Fig. 3B), and Gmm attenuation (P = 0.002). However, the OS did not significantly differ between the GM attenuation groups (P = 0.884).

Univariable Cox regression analysis showed that old age; ASA score ≥ 3; modified Koval index < 4; TSF index below the median; TSF attenuation above the median; and TM index, TM attenuation, GM index, Gmm index, and Gmm attenuation below the median were associated with poor OS. In multivariable analysis, TSF attenuation above the median (adjusted HR, 2.39; 95% CI, 1.41–4.05; P = 0.001), GM index below the median (adjusted HR, 2.63; 95% CI, 1.33–5.26; P = 0.005), and Gmm index below the median (adjusted HR, 2.33; 95% CI, 1.12–4.55; P = 0.015) were the only independent predictive variables that remained significant after adjusting for age, sex, ASA score, and modified Koval index (Table 2).

ICU Admission

The ICU admission rate after surgery was 20.2% (75/372 patients). Univariable logistic regression analysis showed that older age, ASA score ≥ 3, modified Koval index < 4, TSF index below the median, TSF attenuation above the median, and TM index, TM attenuation, GM index, GM attenuation, Gmm index, and Gmm attenuation below the median were associated with ICU admission after surgery. Among these, TSF index (adjusted OR, 6.67; 95% CI, 3.13–14.29; P < 0.001), GM index (adjusted OR, 3.45; 95% CI, 1.49–7.69; P = 0.004), GM attenuation (adjusted OR, 2.33; 95% CI, 1.02–5.56; P = 0.045), Gmm index (adjusted OR, 2.70; 95% CI, 1.22–5.88; P = 0.015), and Gmm attenuation (adjusted OR, 2.22; 95% CI, 1.01–5.00; P = 0.047) below the median were significant variables for predicting ICU admission, independent of age, sex, ASA score, and modified Koval index (Table 3).

DISCUSSION

This study demonstrated the prognostic value of preoperative pelvic bone CT-derived body composition, including the area and attenuation of the skeletal muscles and subcutaneous fat, in relation to mortality and ICU admission in older adult patients who underwent surgical treatment for proximal femur fractures. Low GM and Gmm indices were independent poor prognostic factors for both OS and ICU admission. In addition, high attenuation of TSF was associated with higher mortality, and low attenuation of the GM and Gmm muscles and a low TSF index were associated with ICU admission, implying that gluteal muscles and TSF could affect clinical outcomes.

Some studies have shown that sarcopenia of the trunk muscle is a poor prognostic factor in fragility hip fractures [13,14]. Although CT of the third lumbar vertebra is a validated method for evaluating muscle quantity [30], most patients with femoral fractures do not undergo CT at the third lumbar vertebral level unless they have comorbidities. Therefore, we selected three levels that could be easily identified on pelvic bone CT, which is routinely performed preoperatively. Given that the gluteal muscles play an essential role in maintaining gait stability in terms of their function as the largest hip extensors, abductors, and rotators [31], the prognostic value of these muscles may be reasonable. However, to the best of our knowledge, no study has examined the gluteal muscles in the context of clinical outcomes in older adults. Although our study may imply that maintaining sufficient gluteal muscle quantity would be beneficial not only to prevent falls or fall-related hip fracture

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Table 2. Cox Proportional Analysis for Overall Survival

Variables	Univariable Analysis			Multivariable Analysis*		
	HR	95% CI	*P*	Adjusted HR	95% CI	*P*
Age (per 10 years)	1.82	1.25–2.66	0.002	1.03	0.99–1.07	0.112
Female sex (ref: male)	0.70	0.41–1.22	0.209	0.60	0.34–1.08	0.086
BMI						
Underweight (< 18.5 kg/m^2)	1.43	0.77–2.66	0.264			
Normal weight (18.5–22.9 kg/m^2)	Ref					
Overweight (23.0–24.9 kg/m^2)	0.83	0.40–1.75	0.624			
Obese (≥ 25.0 kg/m^2)	0.55	0.24–1.25	0.153			
BMD (category)						
Normal (T score ≥ -1.0)	Ref					
Osteopenia (-2.5 < T score < -1.0)	0.65	0.27–1.58	0.345			
Osteoporosis (T score ≤ -2.5)	0.79	0.37–1.69	0.543			
ASA score						
< 3	Ref					
≥ 3	2.68	1.63–4.43	< 0.001	1.49	0.87–2.55	0.146
Modified Koval index						
≥ 4	Ref					
< 4	2.04	1.18–3.57	0.011	0.98	0.52–1.85	0.958
Fracture location						
Trochanteric region	Ref					
Neck	0.61	0.35–1.05	0.075			
Type of surgery						
Internal fixation	Ref					
Hemiarthroplasty or total hip arthroplasty	0.84	0.50–1.43	0.525			
Concomitant acute fracture at sacrococcygeal or pelvic bone						
Absent	Ref					
Present	0.68	0.24–1.91	0.463			
CT metrics†						
TSF index (cm^2/m^2) (≤ median)	2.08	1.23–3.57	0.007			
TSF attenuation (HU) (> median)	2.36	1.41–3.96	0.001	2.39	1.41–4.05	0.001
TM index (cm^2/m^2) (≤ median)	2.44	1.43–4.17	0.001			
TM attenuation (HU) (≤ median)	2.33	1.37–3.85	0.002			
GM index (cm^2/m^2) (≤ median)	5.00	2.63–9.09	< 0.001	2.63	1.33–5.26	0.005
GM attenuation (HU) (≤ median)	1.04	0.63–1.72	0.885			
Gmm index (cm^2/m^2) (≤ median)	4.00	2.22–7.14	< 0.001	2.33	1.12–4.55	0.015
Gmm attenuation (HU) (≤ median)	2.27	1.33–3.85	0.002			

*Variables were selected through Cox proportional hazard analysis with stepwise procedure, with age, sex, American Society of Anesthesiologists (ASA) score (< 3/≥ 3), and modified Koval index (< 4/≥ 4) being fixed. Variables remaining in the final model are only shown, †For thigh subcutaneous fat (TSF) attenuation, value below the median was used as reference, whereas those above the median are used as reference values for other metrics. BMD = bone mineral density, BMI = body mass index, CI = confidence interval, GM = gluteus maximus, Gmm = gluteus medius and minimus, HR = hazard ratio, TM = thigh muscle, Ref = reference, CT = computed tomography

[15-17], but also to reduce mortality or ICU admission, the association between gluteal muscle indices and whole-body muscle mass with respect to significance as a prognostic factor was not assessed in this study. In this context, whether the prognostic significance of gluteal muscles is independent of whole-body muscle mass or skeletal muscle index measured at the third lumbar vertebra or whether it reflects them requires further investigation.

According to the revised European consensus on definition and diagnosis of sarcopenia, low skeletal muscle strength and function are essential in the diagnosis of sarcopenia [32]. Therefore, sarcopenia cannot be defined

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Table 3. Logistic Regression Analysis for ICU Admission after Surgery

Variables	Univariable Analysis			Multivariable Analysis*		
	OR	95% CI	*P*	Adjusted OR	95% CI	*P*
Age (per 10 years)	1.72	1.16–2.54	0.007	1.00	0.95–1.05	0.929
Female sex (ref: male)	1.42	0.75–2.69	0.282	2.01	0.87–4.67	0.104
BMI						
Underweight (< 18.5 kg/m^2)	1.74	0.91–3.35	0.095			
Normal weight (18.5–22.9 kg/m^2)	Ref					
Overweight (23.0–24.9 kg/m^2)	0.79	0.38–1.66	0.532			
Obese (≥ 25.0 kg/m^2)	0.62	0.28–1.38	0.242			
BMD (category)						
Normal (T score ≥ -1.0)	Ref					
Osteopenia (-2.5 < T score < -1.0)	0.44	0.10–1.89	0.267			
Osteoporosis (T score ≤ -2.5)	0.58	0.15–2.34	0.447			
ASA score						
< 3	Ref					
≥ 3	7.07	4.04–12.34	< 0.001	4.99	2.52–9.49	< 0.001
Modified Koval index						
≥ 4	Ref					
< 4	2.13	1.18–3.85	0.013	0.90	0.42–1.96	0.797
Fracture location						
Trochanteric region	Ref					
Neck	1.14	0.69–1.91	0.605			
Type of surgery						
Internal fixation	Ref					
Hemiarthroplasty or total hip arthroplasty	1.30	0.78–2.17	0.319			
Concomitant acute fracture at sacrococcygeal or pelvic bone						
Absent	Ref					
Present	0.49	0.16–1.47	0.982			
CT metrics†						
TSF index (cm^2/m^2) (≤ median)	5.00	2.70–9.09	< 0.001	6.67	3.13–14.29	< 0.001
TSF attenuation (HU) (>median)	1.11	0.67–1.84	0.691			
TM index (cm^2/m^2) (≤ median)	4.55	2.56–8.33	< 0.001			
TM attenuation (HU) (≤ median)	2.33	1.40–3.85	0.002			
GM index (cm^2/m^2) (≤ median)	10.00	4.76–20.00	< 0.001	3.45	1.49–7.69	0.004
GM attenuation (HU) (≤ median)	2.70	1.59–4.76	< 0.001	2.33	1.02–5.56	0.045
Gmm index (cm^2/m^2) (≤ median)	7.69	3.85–14.29	< 0.001	2.70	1.22–5.88	0.015
Gmm attenuation (HU) (≤ median)	3.57	2.04–6.25	< 0.001	2.22	1.01–5.00	0.047

*Variables were selected through logistic regression with stepwise procedure, with age, sex, American Society of Anesthesiologists (ASA) score (< 3/≥ 3), and modified Koval index (< 4/≥ 4) being fixed. Variables remaining in the final model are only shown, †For thigh subcutaneous fat (TSF) attenuation, value below the median was used as reference, whereas those above the median are used as reference values for other metrics. ICU = intensive care unit, BMD = bone mineral density, BMI = body mass index, CI = confidence interval, GM = gluteus maximus, Gmm = gluteus medius and minimus, OR = odds ratio, TM = thigh muscle, Ref = reference, CT = computed tomography

solely based on muscle mass measured using CT, which does not fully represent muscle function. However, recent studies have suggested that CT-derived muscle metrics may indirectly reflect muscle strength [26,33]. CT-derived muscle attenuation is an indicator of fat infiltration in the muscle; increasing lipids by 1 g/100 mL decreases CT attenuation by 1 HU [34]. Considering that low attenuation of the gluteal muscles is associated with ICU admission, attenuation of these muscles may be helpful as additional indirect surrogate markers of sarcopenia to compensate for the limitations of area measurement.

However, it remains unclear why GM and Gmm attenuation

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were not associated with OS in our study. Although presumptive, fat infiltration with aging that predominates in the GM could be a possible explanation considering that the GM has the lowest CT attenuation among the lower limb muscles [17]. Moreover, fallers have significantly lower attenuation of the GM and Gmm muscles than non-fallers [17]. As our study population included older adult fallers, the prognostic value of GM and Gmm attenuation may have been masked.

Regarding subcutaneous fat, a TSF index below the median was associated with an increased risk of ICU admission. Accumulating evidence suggests that fat wasting is a poor prognostic factor associated with increased cancer-related and all-cause mortality [10,35]. Recently, Kim et al. [24] reported that a decreased TSF area was independently associated with poor survival in patients with hip fractures, which is comparable to our study. In addition, TSF attenuation above the median value was associated with increased mortality, similar to previous findings that increased fat attenuation could predict death in older adults [36]. Although the prognostic implications of adipose tissue are unclear, fibrosis or inflammation of the adipose tissue and decreased energy reserves associated with decreased adipose tissue mass may be possible explanations [37], which could result in increased attenuation and decreased area on CT.

In contrast, TM index and attenuation were not significant prognostic factors, similar to the results reported by Kim et al. [24]. Similarly, Newman et al. [38] argued that low muscle mass in the lower and upper extremities was not strongly associated with mortality in older adults. Given the functional importance of the gluteal muscles described above, we speculate that the gluteal muscle mass may have more prognostic value than the TM mass; however, this should be investigated in future studies.

This study has some limitations. First, it was conducted at a single institution with an exclusively Asian population. Second, as we dichotomized the CT metrics using their medians as cutoff values, substantial information may have been lost. Third, the presence of residual or unmeasured confounding factors may have been possible despite multivariable analyses. Finally, although we measured the contralateral side of the fracture to minimize the effect of trauma, the asymmetry of the patients' lower extremities, particularly due to previous fractures in the pelvic region, may have affected our results.

In conclusion, the GM and medius/minimus indices obtained from the cross-sectional areas of pelvic bone CT are significant prognostic markers for predicting OS and ICU admission for proximal femur fracture in older adult patients. In addition, attenuation of the gluteal muscles also showed potential as a prognostic factor for ICU admission. Further studies are warranted to understand the biology underlying their prognostic value and determine the optimized cutoff values for these metrics that could be used for patient risk stratification.

Availability of Data and Material

The datasets generated or analyzed during the study are available from the corresponding author on reasonable request.

Conflicts of Interest

Young Cheol Yoon, a contributing editor of the *Korean Journal of Radiology*, was not involved in the editorial evaluation or decision to publish this article. All remaining authors have declared no conflicts of interest.

Author Contributions

Conceptualization: Tae Ran Ahn, Ji Hyun Lee. Data curation: Tae Ran Ahn. Formal analysis: Ji Hyun Lee, Kyunga Kim. Investigation: Tae Ran Ahn. Methodology: Young Cheol Yoon, Hyun Su Kim. Project administration: Tae Ran Ahn. Resources: Tae Ran Ahn. Software: Ji Hyun Lee. Supervision: Young Cheol Yoon, Hyun Su Kim, Kyunga Kim. Validation: Tae Ran Ahn. Visualization: Tae Ran Ahn. Writing—original draft: Tae Ran Ahn. Writing—review & editing: Ji Hyun Lee.

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