Research Article / *Araştırma Makalesi*

Ege Journal of Medicine / *Ege Tıp Dergisi* 2026; 65 (3): 581-592

Computed tomography-derived muscle metrics and functional outcomes after proximal femoral nailing in older women with intertrochanteric fractures

Yaşlı kadın hastalarda intertrokanterik femur kırığı sonrası proksimal femoral çivileme: BT-türevli kas parametreleri ile fonksiyonel sonuçların ilişkisi

Fatih Erdem[1] Mustafa Çeltik[2]

[1]Department of Radiology, Ege University Faculty of Medicine, İzmir- Türkiye

[2]Department of Orthopaedics and Traumatology, Bakırçay University Faculty of Medicine, İzmir-Türkiye

ABSTRACT

Aim: To examine whether computed tomography (CT)-derived cross-sectional area (CSA) and radiodensity (Hounsfield units, HU) of the psoas, gluteus maximus, and gluteus medius-minimus are associated with postoperative function in women aged ≥65 years treated with a proximal femoral nail (PFN) for intertrochanteric fracture.

Materials and Methods: Sixty-three women aged ≥65 years undergoing PFN fixation for intertrochanteric fracture were analyzed retrospectively. Muscle measurements were obtained on standardized axial CT slices by manual tracing. Function was assessed with the Functional Ambulation Classification (FAC), Parker Mobility Score, Barthel Index, and modified Harris Hip Score (mHHS). Analyses included Spearman correlations with Benjamini-Hochberg false discovery rate (FDR) correction (24 comparisons in a predefined plan), HC3 robust linear regression adjusted for age and ASA, and area under the receiver-operating-characteristic curve (AUC) at clinically meaningful thresholds.

Results: The median age was 74 years (IQR 67.5-82.0); median follow-up nine months. Gluteus maximus CSA correlated with Barthel (rho=0.34, p=0.007) and FAC (rho=0.30, p=0.015); an exploratory gluteal CSA composite showed a slightly stronger correlation with Barthel (rho=0.35, p=0.005). Gluteus maximus CSA discriminated community ambulators (FAC≥4) with AUC=0.71 (95% CI 0.55-0.85), and gluteus medius-minimus CSA discriminated Barthel≥90 with AUC=0.73 (0.60-0.85). No association survived FDR correction. Added to age, ASA, and pre-fracture ambulation, the gluteal CSA composite contributed only 0.5-2.2% incremental R^2.

Conclusions: CT-derived gluteal muscle quantity showed the most consistent nominal association with function after PFN, but no association survived FDR correction and incremental value beyond routine clinical predictors was limited. The proposed cut-offs are hypothesis-generating and require prospective validation.

Keywords: Hip fractures, intertrochanteric fracture, sarcopenia; gluteal muscles, tomography, x-ray computed

ÖZ

Amaç: *İntertrokanterik femur kırığı nedeniyle proksimal femoral çivi (PFN) ile tedavi edilen 65 yaş ve üzeri kadın hastalarda bilgisayarlı tomografi (BT) ile ölçülen psoas, gluteus maksimus ve gluteus medius-minimus kaslarının kesitsel alan (KA) ve radyolojik dansite (Hounsfield ünitesi, HU) değerlerinin postoperatif fonksiyonel skorlarla ilişkisini incelemektir.*

Gereç ve Yöntem: *İntertrokanterik femur kırığı nedeniyle PFN ile tedavi edilen 65 yaş ve üzeri 63 kadın hasta retrospektif olarak incelendi. BT ölçümleri standart aksiyel kesitlerde elle çizim yöntemiyle yapıldı.*

Corresponding author: Fatih Erdem

Department of Radiology, Ege University Faculty of Medicine, İzmir- Türkiye

E-mail: *mdfatiherdem@gmail.com*

Application date: 03.06.2026 Accepted: 30.07.2026

Fonksiyonel değerlendirmede Fonksiyonel Ambulasyon Sınıflaması (FAC), Parker Mobilite Skoru, Barthel İndeksi ve Modifiye Harris Kalça Skoru (mHHS) kullanıldı. Analizler önceden tanımlanmış analiz planındaki 24 karşılaştırma için Benjamini-Hochberg FDR düzeltmeli Spearman korelasyonu, yaş ve ASA için düzeltilmiş HC3 sağlam doğrusal regresyon ve klinik anlamlı eşiklerde ROC eğrisi altında kalan alan (AUC) analizlerini içerdi.

Bulgular: *Ortanca yaş 74 yıl (ÇAA 67,5-82,0); ortanca takip 9 ay. Gluteus maksimus KA, Barthel (rho=0,34, p=0,007) ve FAC (rho=0,30, p=0,015) ile pozitif korelasyon gösterdi. Eksploratuvar gluteal KA kompoziti Barthel ile benzer veya hafif daha güçlü ilişki gösterdi (rho=0,35, p=0,005). Gluteus maksimus KA, FAC≥4 ayırımında AUC=0,71 (%95 GA 0,55-0,85); gluteus medius-minimus KA, Barthel≥90 ayırımında AUC=0,73 (0,60-0,85). FDR düzeltmesinden sonra hiçbir ilişki anlamlı kalmadı. Yaş, ASA ve kırık öncesi ambulasyona eklendiğinde gluteal KA kompozitinin inkremental R^2'si yalnızca %0,5-2,2 idi.*

Sonuç: *BT-türevli gluteal kas miktarı, PFN sonrası fonksiyonel iyileşme ile en tutarlı nominal ilişkiyi gösteren parametreydi; ancak FDR düzeltmesi sonrası hiçbir ilişki anlamlı kalmadı ve rutin klinik prediktörlerin ötesindeki inkremental değeri sınırlıydı. Önerilen kesim noktaları hipotez oluşturucu niteliktedir ve prospektif doğrulama gerektirir.*

Anahtar Sözcükler: *Kalça kırıkları, intertrokanterik kırık; sarkopeni, gluteal kaslar, tomografi, x-ışını bilgisayarlı*

INTRODUCTION

Hip fractures are a major cause of disability and mortality among older adults, and women are disproportionately affected. The global number of hip fractures is projected to nearly double by 2050, with persistent treatment gaps and substantial post-fracture mortality across nearly every healthcare system studied (1). Intertrochanteric fractures account for a large fraction of these injuries in elderly patients and are most commonly treated with a proximal femoral nail (PFN), with restoration of independent ambulation and activities of daily living as the principal therapeutic goal (2,3).

Functional recovery after surgical fixation, however, is far from uniform. Even with technically successful osteosynthesis, only a minority of patients return to their pre-fracture level of independence, and outcomes are particularly poor in women aged 65 years and older (3,4). This variability suggests that fixation quality alone is not sufficient to explain postoperative trajectory, and has motivated growing interest in patient-level musculoskeletal reserve, especially sarcopenia, as a determinant of recovery (4,5).

Sarcopenia, defined by the European Working Group on Sarcopenia in Older People as a progressive and generalized skeletal muscle disorder, is now recognized as muscle failure and is highly prevalent in geriatric fracture cohorts (5,6). Computed tomography (CT) provides an objective, opportunistic means of quantifying both muscle quantity and quality at the time of imaging already obtained for surgical planning. Cross-sectional area (CSA) reflects muscle mass, whereas mean radiodensity in Hounsfield units (HU) is a surrogate for intramuscular adipose infiltration, or myosteatosis (7,8). Lower psoas CSA and lower paravertebral or psoas attenuation on CT have been linked to increased mortality after hip fracture and to higher one-year mortality in older orthopaedic trauma populations (9–12).

Beyond the lumbar muscles, the gluteal compartment is biomechanically pivotal at the hip. Atrophy and fatty infiltration of the gluteus medius and minimus have been associated with fall-related proximal femoral fractures, and decreased postoperative gluteus medius CSA has been documented after cephalomedullary nailing (13–15). Hip abductor strength is a well-established correlate of post-fracture mobility (4,13). Most prior CT-based prognostic work, however, has focused on the psoas, has pooled men and women, and has prioritized mortality rather than the functional scales most relevant to geriatric rehabilitation.

We therefore conducted a retrospective study in a homogeneous cohort of older women undergoing PFN for intertrochanteric femoral fracture, in which CT-derived CSA and density of the psoas, gluteus maximus, and gluteus medius-minimus were related to four widely used functional outcome scales. Beyond the predefined Spearman analyses, we examined a gluteal CSA composite, discrimination for clinically meaningful thresholds,

and the incremental value of muscle measures over routine bedside predictors, to inform hypothesis-driven design of future prospective work.

MATERIALS and METHODS

Study design and ethics

This retrospective observational study was conducted at the Department of Orthopaedics and Traumatology, Bakırçay University Çiğli Research and Training Hospital. The study protocol was approved by the Bakırçay University Faculty of Medicine Ethics Committee (approval no. 2976; date: 13 May 2026), and approval was obtained before any study data were extracted from the hospital records. The study was conducted in accordance with the principles of the Declaration of Helsinki. Owing to the retrospective design and the use of anonymized records, the requirement for written informed consent was waived by the ethics committee.

Patients

Between March 2020 and November 2025, 220 consecutive female patients aged ≥65 years who underwent PFN fixation for intertrochanteric femoral fracture at our institution were screened. Patients were eligible if a preoperative pelvic and/or lumbar CT examination of sufficient image quality was available for standardized muscle assessment. Of the 220 screened patients, 157 were excluded: 93 did not have a suitable preoperative pelvic or lumbar CT examination available for muscle assessment, 18 had inadequate CT image quality or incomplete anatomical coverage, 7 had incomplete radiological measurements despite available CT imaging, 15 died before functional follow-up could be obtained, and 24 were lost to follow-up or had no retrievable postoperative functional outcome data. Because all included patients were women, sex was not used as an explanatory variable. Therefore, the final analytic cohort consisted of 63 unique patients.

Clinical variables and outcomes

Demographic, perioperative, and follow-up data were retrieved from hospital records and included age, fracture side, American Society of Anesthesiologists (ASA) class, implant length, length of hospital stay, perioperative hemoglobin values, recorded comorbidities, postoperative complications, and follow-up duration. Complications were recorded as any documented postoperative adverse event during follow-up. Pre-fracture ambulation status was graded as independent, cane or walker assisted, and wheelchair or bed-bound. For analysis, pre-fracture ambulation was coded as an ordinal variable, with higher values indicating poorer baseline mobility.

Postoperative function was evaluated at the most recent follow-up visit using four scales widely used in geriatric hip-fracture cohorts: the FAC (16), the Parker Mobility Score (17), the Barthel Index (18), and the mHHS (19). These scales capture complementary aspects of ambulation, community mobility, activities of daily living, and hip-specific function.

Computed tomography-based muscle measurements

All preoperative CT examinations were acquired on a 64-slice CT scanner (SOMATOM go.Up, Siemens Healthineers, Forchheim, Germany) as part of routine clinical trauma imaging. Because of the retrospective design, CT acquisition parameters such as slice thickness, contrast administration, tube voltage, and tube current were not prospectively standardized for research purposes. All measurements were performed on axial CT images using Probel Viewer software (Probel, İzmir, Türkiye) by a radiologist blinded to all clinical and functional data. All unilateral measurements were performed on the ipsilateral side corresponding to the fractured limb, as this side was the clinically relevant side for postoperative functional recovery and to maintain a consistent prespecified measurement side. During manual tracing, visible hematoma, peri-muscular fluid collection, and non-muscular soft tissue were excluded from the region of interest whenever present. The gluteus maximus muscle was measured on the first cranial axial slice on which the greater trochanter was visible. The combined gluteus medius-minimus CSA was measured on the most inferior axial slice on which the sacroiliac joint was still visible; on the same level, density analysis was restricted to the gluteus medius muscle alone because the gluteus medius and minimus could not always be reliably separated for HU measurement. The psoas muscle was measured at the L5 vertebral level. In most preoperative scans the L3-L4 levels used in mortality-focused studies lay above the superior border of the imaged field and were not captured;

L5 was the most cranial level consistently available, and requiring L3-L4 would have further reduced an already small sample. The psoas was traced on slices proximal to its confluence with the iliacus, so the iliacus was excluded. The region of interest was manually delineated along the muscle borders for each slice (Figure-1). Cross-sectional area was recorded in mm² and mean muscle density in HU, so that CSA served as an index of muscle quantity and HU as an index of muscle quality, consistent with prior opportunistic CT-based sarcopenia work (7,8,11). Each CT-based muscle measurement was performed twice by the same radiologist at different time points, with the observer blinded to the previous measurement values. The mean of the two measurements was used for statistical analysis. Intra-rater reliability was quantified using intraclass correlation coefficients calculated from the duplicate measurements.

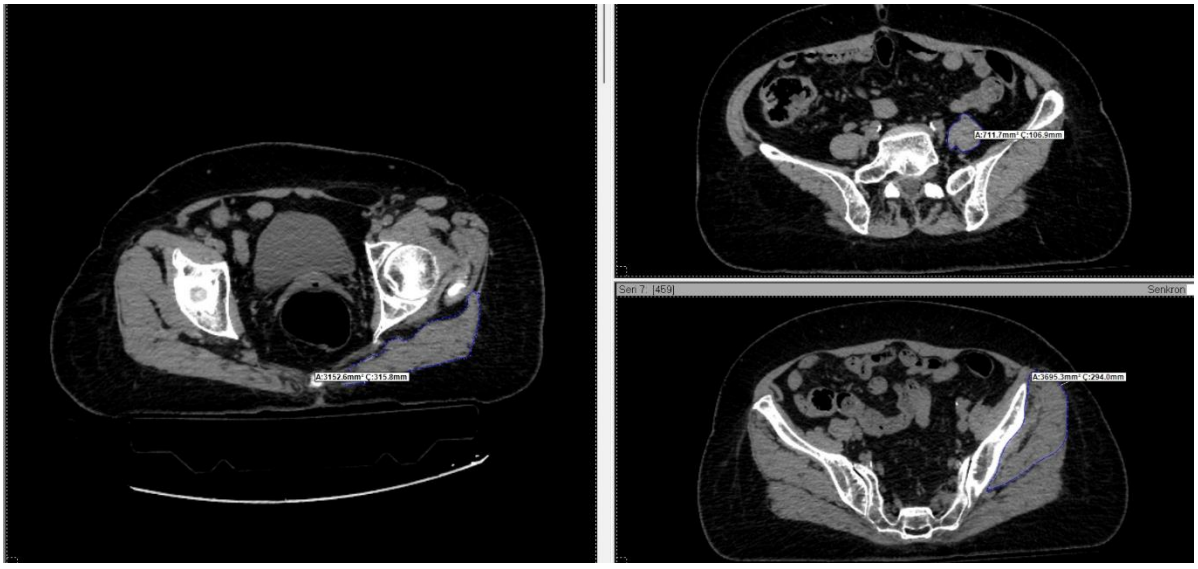

Figure-1. Representative axial computed tomography images showing manual region-of-interest tracing for cross-sectional area (CSA) measurement using Probel Viewer software (Probel, İzmir, Türkiye). Left panel: gluteus maximus, traced on the first cranial slice on which the greater trochanter was visible (traced CSA 3152.6 mm² in this example). Upper right panel: psoas at the L5 level (711.7 mm²). Lower right panel: gluteus medius-minimus, traced on the most inferior slice on which the sacroiliac joint was visible (3695.3 mm²). The region of interest was delineated along the muscle borders; visible hematoma, peri-muscular fluid collection, and non-muscular soft tissue were excluded. CSA was recorded in mm² and mean muscle density in Hounsfield units (the value labelled Ç on the software denotes the perimeter, not used in this study).

Statistical analysis

Continuous variables were summarized as mean ± standard deviation or median with interquartile range (IQR) according to distributional characteristics assessed by the Shapiro-Wilk test. Primary association analyses used Spearman rank correlation between each of the six muscle variables and each of the four functional scores, with Benjamini-Hochberg false discovery rate (FDR) correction across the 24 comparisons defined by a predefined analysis plan (six muscle parameters × four functional scores) (20). All subsequent analyses (gluteal and density composites, the discrimination analysis, and the incremental-value modelling) were not part of this plan and are reported as exploratory. Approximate 95% confidence intervals for Spearman rho were calculated using Fisher z transformation. Intra-rater reliability of duplicate CT measurements was summarized using intraclass correlation coefficients (ICCs).

Confounder-adjusted secondary analyses used separate linear regression models with HC3 robust standard errors. Outcomes and muscle variables were z-standardized so that coefficients approximate standardized outcome change per one standard deviation higher muscle parameter, adjusted for age and ASA class. Three additional analyses were performed. First, an unweighted z-score composite of the gluteus maximus and gluteus medius-minimus CSA values (gluteal CSA composite) was constructed, with an analogous

three-HU density composite and a four-score functional composite (z-scored FAC, Parker, Barthel, mHHS). Second, the discrimination of each muscle parameter for clinically meaningful thresholds (FAC ≥ 4 = community ambulator; Barthel ≥ 90 = high-level independence) was quantified using AUC with bootstrap 95% CIs (2000 resamples) and Youden-optimal cut-offs. Third, the incremental coefficient of determination (ΔR^2) of muscle parameters over a baseline clinical model (age, ASA, pre-fracture ambulation) was tested with a nested F-test. Group comparisons used Mann-Whitney U or Kruskal-Wallis tests for continuous and Fisher exact or chi-square tests for categorical variables. A two-sided $p<0.05$ was considered significant and a $q<0.05$ for FDR-adjusted analyses. Analyses were performed in Python 3 with NumPy, SciPy, statsmodels, scikit-learn, and pandas.

RESULTS

Cohort characteristics

Of the 220 screened patients, 63 women aged ≥65 years undergoing PFN for intertrochanteric fracture were analyzed. Median age was 74.0 years (IQR 67.5-82.0; mean 75.4 ± 8.5) and median follow-up 9.0 months (IQR 8.0-12.0). Forty-four patients (69.8%) were ASA class 3, and short nails were used in 55 (87.3%). Median length of stay was 5.0 days, and 12 patients (19.0%) had a recorded complication. Median FAC, Parker, Barthel, and mHHS scores were 4.0, 6.0, 88.0, and 77.0, respectively (Table-1). Intra-rater reliability was good to excellent: ICCs were 0.92 for psoas CSA, 0.90 for psoas density, 0.85 for gluteus maximus CSA, 0.82 for gluteus maximus density, 0.84 for gluteus medius-minimus CSA, and 0.84 for gluteus medius density.

Table-1. Baseline cohort characteristics, perioperative variables, functional scores, and computed tomography-derived muscle parameters of the 63 included patients.

Characteristic	Value
Number of patients	63
Sex, female, n (%)	63 (100.0)
Age, years, median (IQR)	74.0 (67.5-82.0)
Age, years, mean ± SD	75.4 ± 8.5
Fracture side, right, n (%)	31 (49.2)
ASA class 2, n (%)	18 (28.6)
ASA class 3, n (%)	44 (69.8)
ASA class 4, n (%)	1 (1.6)
Long nail, n (%)	8 (12.7)
Follow-up, months, median (IQR)	9.0 (8.0-12.0)
Length of stay, days, median (IQR)	5.0 (4.0-7.0)
Preoperative hemoglobin, g/dL	11.1 (10.2-12.2)
Postoperative hemoglobin, g/dL	9.4 (8.8-10.3)
Pre-fracture ambulation independent, n (%)	53 (84.1)
Any recorded complication, n (%)	12 (19.0)
FAC score, median (IQR)	4.0 (3.0-5.0)
Parker Mobility Score, median (IQR)	6.0 (5.0-8.0)
Barthel Index, median (IQR)	88.0 (72.0-96.5)
Modified Harris Hip Score, median (IQR)	77.0 (63.5-85.5)

Psoas CSA, mm², median (IQR)	656.0 (535.0-766.5)
Psoas density, HU, median (IQR)	45.0 (38.0-50.0)
Gluteus maximus CSA, mm², median (IQR)	3220.0 (2557.5-3767.5)
Gluteus maximus density, HU, median (IQR)	20.0 (10.0-29.5)
Gluteus medius-minimus CSA, mm², median (IQR)	3336.0 (2807.5-3803.5)
Gluteus medius density, HU, median (IQR)	32.0 (16.0-42.0)

ASA: American Society of Anesthesiologists; CSA: cross-sectional area; FAC: Functional Ambulation Classification; HU: Hounsfield units; IQR: interquartile range; SD: standard deviation.

Primary correlation analysis

In the predefined Spearman analysis, the most consistent signal was observed for gluteal CSA rather than for muscle density (Table-2, Figure-2). Gluteus maximus CSA correlated positively with the Barthel Index (rho=0.34, 95% CI 0.10 to 0.54; p=0.007), the FAC score (rho=0.30, p=0.015), and showed borderline associations with mHHS (rho=0.24, p=0.057) and the Parker Mobility Score (rho=0.23, p=0.066). Gluteus medius-minimus CSA correlated with the Barthel Index (rho=0.30, p=0.015) and mHHS (rho=0.25, p=0.049). Psoas CSA was not associated with any of the four scores, and density variables showed at most a borderline psoas density-Barthel signal (rho=0.23, p=0.064). After Benjamini-Hochberg correction across these 24 comparisons, no correlation remained statistically significant; the lowest q value was 0.124. Scatter plots are shown in Figure-3 and Figure-4.

Combining the gluteus maximus CSA and gluteus medius-minimus CSA variables into an unweighted z-score composite yielded a correlation that was similar to, or numerically slightly stronger than, that of either gluteal variable alone. The gluteal CSA composite correlated with the Barthel Index at rho=0.35 (p=0.005), with mHHS at rho=0.28 (p=0.028), and with the FAC score at rho=0.27 (p=0.034). A four-score functional composite correlated with the gluteal CSA composite at rho=0.28 (p=0.026). An analogous composite of the three HU density variables did not correlate with the functional composite (rho=0.12, p=0.34), reinforcing the impression that muscle quantity, not muscle quality, drives the observed signal in this cohort.

Table-2. Primary Spearman rank correlations between computed tomography-derived muscle parameters and postoperative clinical scores in 63 women.

Muscle parameter	FAC	Parker	Barthel	mHHS
Psoas CSA	0.07; p=0.61; q=0.84	0.05; p=0.70; q=0.88	0.19; p=0.13; q=0.36	0.15; p=0.24; q=0.53
Psoas density (HU)	0.10; p=0.44; q=0.71	-0.02; p=0.88; q=0.92	0.23; p=0.064; q=0.23	0.06; p=0.63; q=0.84
Gluteus maximus CSA	**0.30; p=0.015; q=0.12**	0.23; p=0.066; q=0.23	**0.34; p=0.007; q=0.12**	0.24; p=0.057; q=0.23
Gluteus maximus density (HU)	-0.01; p=0.92; q=0.92	-0.12; p=0.36; q=0.66	0.11; p=0.41; q=0.70	0.03; p=0.82; q=0.92
Gluteus medius-minimus CSA	0.17; p=0.18; q=0.42	0.03; p=0.79; q=0.92	**0.30; p=0.015; q=0.12**	**0.25; p=0.049; q=0.23**
Gluteus medius density (HU)	0.06; p=0.63; q=0.84	0.02; p=0.85; q=0.92	0.19; p=0.14; q=0.36	0.13; p=0.31; q=0.62
Gluteal CSA composite *	**0.27; p=0.034**	0.15; p=0.237	**0.35; p=0.005**	**0.28; p=0.028**

Each cell shows Spearman rho; nominal p value; Benjamini-Hochberg q value across the 24 comparisons of the predefined analysis plan. Bold denotes nominal p<0.05 (no correlation remained significant after FDR correction).

**The gluteal CSA composite is the unweighted z-score mean of gluteus maximus CSA and gluteus medius-minimus CSA and is an exploratory measure; it was not part of the predefined 24-comparison plan and therefore has no FDR-adjusted q value. Approximate 95% confidence intervals for rho (reported in the text) were derived using the Fisher z transformation, which is strictly valid for the Pearson coefficient and only approximate for the Spearman coefficient. CSA: cross-sectional area; FAC: Functional Ambulation Classification; HU: Hounsfield units; mHHS: modified Harris Hip Score.*

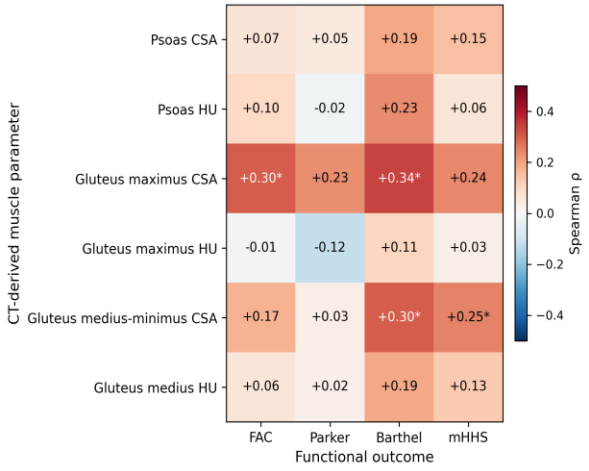

Figure-2. Heatmap of Spearman rank correlations between the six computed tomography-derived muscle parameters and the four postoperative functional scores. Color intensity encodes the magnitude and direction of rho; asterisks denote nominal p<0.05. After Benjamini-Hochberg false discovery rate correction across the 24 comparisons of the predefined analysis plan, no muscle-outcome correlation remained statistically significant.

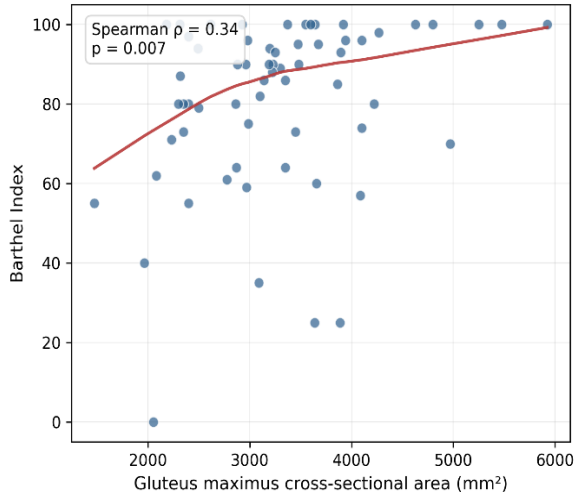

Figure-3. Scatter plot of gluteus maximus cross-sectional area (mm²) versus the Barthel Index in 63 women, with a locally weighted scatterplot smoothing (LOWESS) curve to depict the monotonic trend. Spearman rho=0.34, nominal p=0.007.

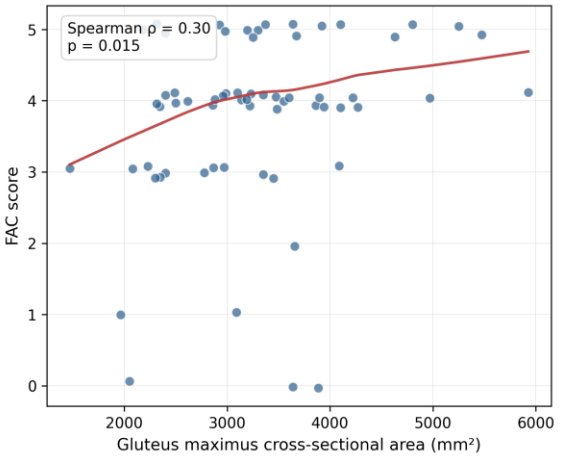

Figure-4. Scatter plot of gluteus maximus cross-sectional area (mm²) versus the Functional Ambulation Classification (FAC) score in 63 women, with a locally weighted scatterplot smoothing (LOWESS) curve to depict the monotonic trend. Spearman rho=0.30, nominal p=0.015.

Age- and ASA-adjusted models

In separate robust linear models adjusted for age and ASA class, the muscle-outcome associations were attenuated (Table-3). The strongest adjusted signal was for gluteus maximus CSA with the Parker Mobility Score (standardized β=0.24, 95% CI -0.01 to 0.50; p=0.061). Adjusted associations of gluteus maximus CSA with Barthel, mHHS, and FAC remained directionally consistent but non-significant, and none survived FDR correction. In exploratory full models including all six muscle variables with age and ASA, gluteus maximus CSA retained the largest coefficient for Parker (β=0.39, p=0.040); variance inflation factors were 1.46-1.84, indicating no severe multicollinearity. In an exploratory subgroup independent before fracture (n=53), the gluteal CSA composite was more strongly associated with Barthel (rho=0.38, p=0.005) than in the whole sample, although a formal muscle × pre-fracture ambulation interaction was not significant.

Table-3. Selected age- and ASA-adjusted robust linear regression models showing the strongest or clinically relevant muscle-outcome associations. Standardized beta coefficients represent outcome change per one-standard-deviation higher muscle parameter, adjusted for age and ASA class. Robust HC3 standard errors were used.

Muscle parameter	Clinical score	n	β (95% CI)	p	q_BH
Gluteus maximus CSA	Parker Mobility Score	63	0.24 (-0.01 to 0.50)	0.061	0.74
Gluteus maximus CSA	Barthel Index	63	0.23 (-0.05 to 0.50)	0.103	0.74
Gluteus maximus CSA	Modified Harris Hip Score	63	0.21 (-0.05 to 0.47)	0.118	0.74
Gluteus maximus CSA	FAC score	63	0.20 (-0.06 to 0.46)	0.134	0.74
Gluteus medius-minimus CSA	Modified Harris Hip Score	63	0.16 (-0.08 to 0.40)	0.181	0.74
Gluteus medius-minimus CSA	Barthel Index	63	0.16 (-0.08 to 0.39)	0.185	0.74
Gluteus maximus density (HU)	Parker Mobility Score	63	-0.13 (-0.37 to 0.11)	0.294	1.00
Gluteus maximus density (HU)	FAC score	63	-0.09 (-0.33 to 0.14)	0.441	1.00
Psoas density (HU)	Parker Mobility Score	63	-0.11 (-0.41 to 0.19)	0.475	1.00
Gluteus medius-minimus CSA	FAC score	63	0.08 (-0.15 to 0.31)	0.496	1.00

ASA: American Society of Anesthesiologists; CSA: cross-sectional area; FAC: Functional Ambulation Classification; HU: Hounsfield units. Outcomes and muscle variables were z-standardized before modeling; β therefore approximates the standardized outcome change per 1-SD higher muscle metric, adjusted for age and ASA class. The q_BH column shows Benjamini-Hochberg false discovery rate-adjusted p values across all 24 adjusted models.

Discrimination analysis

To express the findings as clinically interpretable effect sizes, the two most rehabilitation-relevant scores were dichotomized at established thresholds: community ambulator status (FAC≥4) and high-level independence in activities of daily living (Barthel Index ≥90). Forty-five patients (71.4%) reached FAC≥4 and 30 (47.6%) reached Barthel≥90 at last follow-up. Gluteus maximus CSA discriminated community ambulators with an AUC of 0.71 (95% CI 0.55-0.85; bootstrap, 2000 resamples), with a Youden-optimal cut-off of 2880 mm² (sensitivity 78%, specificity 56%). Gluteus medius-minimus CSA discriminated patients reaching Barthel ≥90 with an AUC of 0.73 (95% CI 0.60-0.85), with a Youden-optimal cut-off of 3288 mm² (sensitivity 80%, specificity 64%). Density measures and psoas CSA did not show discriminative advantage (AUCs 0.48-0.62). Notably, pre-fracture ambulation grade alone, used as a single predictor, gave an AUC of 0.78 for FAC≥4 and 0.65 for Barthel≥90, comparable to the muscle parameters (Table-4, Figure-5). Because these cut-offs were both derived and evaluated in the same sample, without cross-validation or an independent test set, the reported AUCs and operating characteristics are subject to in-sample optimism and almost certainly overestimate out-of-sample performance; they are exploratory and hypothesis-generating, not validated thresholds.

Table-4. Discrimination of computed tomography-derived muscle parameters and pre-fracture ambulation grade for two clinically meaningful functional outcome thresholds (FAC ≥ 4 = community ambulator; Barthel Index ≥ 90 = high-level independence).

Predictor	Outcome	AUC (95% CI)	Cut-off	Sens / Spec
Gluteus maximus CSA	FAC ≥ 4	**0.71 (0.55-0.85)**	2880 mm²	78% / 56%
Gluteal CSA composite	FAC ≥ 4	0.67 (0.50-0.81)	—	—

Pre-fracture ambulation grade	FAC ≥ 4	0.78 (0.65-0.89)	—	—
Gluteus medius-minimus CSA	Barthel ≥ 90	**0.73 (0.60-0.85)**	3288 mm²	80% / 64%
Gluteal CSA composite	Barthel ≥ 90	0.73 (0.60-0.84)	—	—
Gluteus maximus CSA	Barthel ≥ 90	0.68 (0.55-0.81)	—	—
Pre-fracture ambulation grade	Barthel ≥ 90	0.65 (0.51-0.78)	—	—
Psoas CSA	FAC ≥ 4	0.55 (0.39-0.71)	—	—
Psoas density (HU)	FAC ≥ 4	0.60 (0.45-0.75)	—	—

AUC: area under the receiver-operating-characteristic curve, with bootstrap 95% confidence intervals (2000 resamples). Cut-offs were derived using the Youden index. Cut-offs and operating characteristics are reported only for the two strongest predictors (highest AUC) of each outcome, in keeping with the exploratory nature of the analysis. CSA: cross-sectional area; FAC: Functional Ambulation Classification; HU: Hounsfield units.

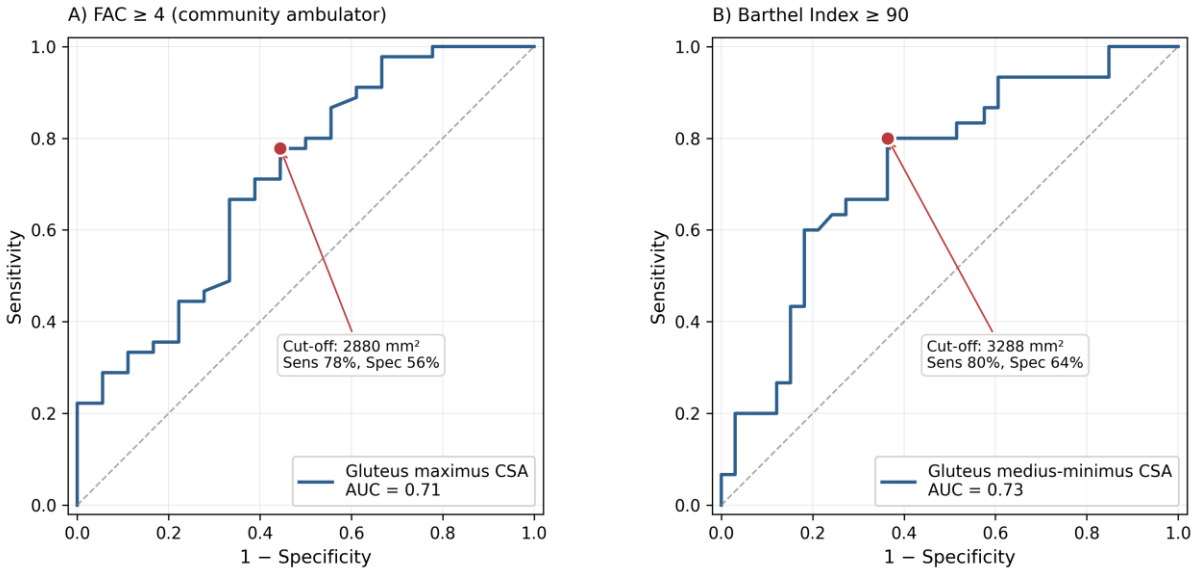

Figure-5. Receiver-operating-characteristic curves for gluteus maximus cross-sectional area discriminating community ambulator status (FAC ≥ 4) and gluteus medius-minimus cross-sectional area discriminating high-level activities-of-daily-living independence (Barthel Index ≥ 90). Youden-optimal cut-offs and their operating characteristics are indicated on the curves.

Incremental value over routine clinical predictors

In single-variable models, pre-fracture ambulation grade explained 53.4% of the variance in the Barthel Index, 33.8% of the variance in mHHS, and 34.2% of the variance in the Parker Mobility Score, whereas the strongest single muscle parameter (gluteus maximus CSA) explained approximately 7-9% and the gluteal CSA composite 3-10%, depending on the score. After adjustment for age, ASA class, and pre-fracture ambulation, adding the gluteal CSA composite contributed only 0.5-2.2% incremental R^2 across the four functional scales (nested F-test p between 0.09 and 0.52); the best-performing single muscle parameter (gluteus maximus CSA) added 1.3-3.0% (p between 0.08 and 0.17).

Exploratory and secondary observations

Pre-fracture ambulation grade was strongly inversely associated with all four functional scores (rho -0.50 to -0.63, all q<0.001), and regional muscle metrics co-varied (gluteus maximus with gluteus medius-minimus CSA, rho=0.56, q<0.001). Patients with a complication tended to have longer stays (median 6.5 vs 5.0 days; p=0.051), but no muscle parameter was robustly associated with complications.

DISCUSSION

In this homogeneous cohort of older women undergoing PFN for intertrochanteric femoral fracture, the CT parameter most consistently and directionally associated with postoperative function was gluteal muscle quantity, especially the CSA of the gluteus maximus and the combined gluteus medius-minimus. Psoas measurements and muscle density did not show a robust signal. After Benjamini-Hochberg correction across the 24 comparisons of the predefined analysis plan, however, no Spearman association remained significant, and adjustment for age and ASA attenuated all primary signals. These findings are therefore hypothesis-generating. Nevertheless, the directional consistency of the gluteal CSA signal across all four scales, its similar behaviour when combined into a composite (rho=0.35 with Barthel), and the discrimination of individual gluteal CSA measures for clinically meaningful thresholds (AUC 0.71-0.73) suggest that the gluteal compartment may be a more relevant candidate region than the psoas for future prospective studies. The gluteal CSA composite did not consistently outperform individual gluteal measurements; although it showed slightly stronger correlations with some continuous scores, its AUC for FAC ≥4 was lower than that of gluteus maximus CSA alone. This likely reflects differences between continuous association analyses and threshold-based discrimination, and reinforces the exploratory nature of the composite measure.

The result is biomechanically plausible. The gluteus maximus is the principal hip extensor and a major contributor to sit-to-stand and stair-climbing, captured by the mHHS and Barthel Index. The gluteus medius-minimus complex provides single-leg pelvic stabilization, a prerequisite for ambulation graded by the FAC and Parker Mobility Score. Hip abductor strength is a dominant correlate of post-fracture mobility (4,13), and imaging studies have shown that the abductor compartment undergoes both atrophy and fatty infiltration before fracture and is further compromised by intramedullary nailing through iatrogenic injury at the trochanteric entry point (14,15). That gluteal CSA, but not HU density, correlated with function in this relatively homogeneous cohort of older women is consistent with the idea that residual contractile muscle quantity dominates over qualitative changes that may already be advanced and homogeneous. However, the apparent predominance of CSA over HU should be interpreted cautiously, because advanced and relatively homogeneous intramuscular fatty infiltration in this older fracture cohort may have limited the ability of HU-based measures to discriminate postoperative functional differences.

A further point of practical importance emerges from a head-to-head comparison of predictors. Pre-fracture ambulation grade alone explained more than half of the variance in the Barthel Index and approximately a third of the variance in mHHS and Parker scores, whereas the strongest single muscle parameter explained approximately 7-9% and the gluteal CSA composite 3-10%. After adjustment for age, ASA, and pre-fracture ambulation, the gluteal CSA composite added only 0.5-2.2% incremental R^2 across the four scales. This does not negate the directional value of CT-derived gluteal CSA as a biological marker, but it suggests that when a simple, bedside-available pre-fracture ambulation grade is recorded, opportunistic CT muscle quantification provides only modest incremental prognostic information at this sample size. To our knowledge, this benchmark has not been reported elsewhere and should inform the design of future prospective work, which must be powered to detect small but biologically plausible incremental effects rather than marginal univariate correlations (21,22).

This study adds to the literature in several ways. By focusing only on older women treated with PFN for intertrochanteric fractures, it reduces heterogeneity related to sex, fracture location, and surgical method; the use of clinically meaningful thresholds (FAC ≥4, Barthel ≥90) allowed the imaging findings to be interpreted in functional terms; and the comparison with pre-fracture ambulation showed that CT-derived muscle measurements add limited prognostic information beyond a simple bedside variable.

Limitations should be acknowledged. The retrospective single-center design and sample size of 63 patients limit statistical power, particularly for confounder-adjusted models and analyses of complications, for which only 12 events were available. The screening process also resulted in a selected analytic cohort, because patients without suitable CT imaging, those who died before functional follow-up, and those without retrievable follow-up functional outcomes were excluded. Functional outcomes

were therefore available only for patients who survived to the most recent follow-up and had retrievable postoperative functional assessment, potentially enriching the sample for functional survivors. This survivorship and follow-up selection bias may have influenced the magnitude and direction of the observed muscle-function associations. As noted above, the discrimination metrics are optimistically biased because the cut-offs were derived and tested in the same cohort. The modified Harris Hip Score was validated primarily in younger hip-arthroscopy patients and not in elderly intertrochanteric-fracture patients, so its interpretation here should be cautious. Because the psoas was measured at L5 rather than the L3-L4 level used in most prior studies, our psoas values are not directly comparable with those reports, and this may partly explain the lack of a robust psoas signal. Intra-rater reliability of the duplicate measurements was good to excellent; however, all measurements were performed by a single radiologist, so inter-rater reliability could not be assessed. Muscle CSA values were not indexed to height, body mass index, or skeletal size because these were not consistently available, a recognized limitation of opportunistic CT-based sarcopenia work (7,8). Because measurements were performed on the ipsilateral fractured side and no contralateral control measurement was available, acute trauma-related edema, hematoma, pain-related positioning, or local soft-tissue changes may have influenced CSA and HU measurements. Although visible hematoma, peri-muscular fluid collection, and non-muscular soft tissue were excluded during manual tracing, the fractured side may not fully reflect pre-fracture muscle status. CT examinations were obtained as part of routine clinical trauma care rather than a prospectively standardized research protocol; therefore, variation in slice thickness, contrast administration, and exposure parameters may have influenced HU-based measurements and may have contributed to the weaker density findings. Although all CT scans were obtained before surgery and were therefore not affected by implant-related artifacts, they were acquired after the fracture event. DXA-based appendicular lean mass and grip strength, which complete the EWGSOP2 sarcopenia diagnosis (5), were not available, and comorbidity ascertainment relied on parsing of free-text records. CT was acquired at a single perioperative time point, so postoperative changes in gluteal CSA after nailing (14,15) could not be quantified, and the analysis is association-based and cannot establish causality.

CONCLUSION

In older women undergoing PFN for intertrochanteric fracture, CT-derived gluteal CSA showed the most consistent nominal associations with postoperative functional outcomes, whereas psoas measurements and muscle density did not show robust signals. However, no correlation in the predefined analysis plan survived FDR correction, and the incremental value of gluteal CSA beyond age, ASA class, and pre-fracture ambulation was small. These findings suggest that gluteal CSA may be a candidate imaging marker for future prospective validation, but it should not be interpreted as a stand-alone prognostic tool. Because the cohort was single-center and comprised exclusively older women from one regional population, assessed with a single software platform, these findings require external validation in larger, multicenter, and more diverse cohorts before clinical application.

Conflict of Interest: The authors declare that they have no conflicts of interest to disclose. No commercial relationship or financial support that could have influenced the present work is reported.

Ethics Approval: Bakırçay University Ethics Committee (onay no. 2976; tarih: 13 Mayıs 2026).
Funding: This study received no specific funding.

References

1. Sing CW, Lin TC, Bartholomew S, Bell JS, Bennett C, Beyene K, et al. Global Epidemiology of Hip Fractures: Secular Trends in Incidence Rate, Post-Fracture Treatment, and All-Cause Mortality. J Bone Miner Res Off J Am Soc Bone Miner Res. 2023 Aug;38(8):1064–75.
2. Mavrogenis AF, Panagopoulos GN, Megaloikonomos PD, Igoumenou VG, Galanopoulos I, Vottis CT, et al. Complications After Hip Nailing for Fractures. Orthopedics. 2016;39(1):e108-116.
3. Karagas MR, Lu-Yao GL, Barrett JA, Beach ML, Baron JA. Heterogeneity of hip fracture: age, race, sex, and geographic patterns of femoral neck and trochanteric fractures among the US elderly. Am J Epidemiol. 1996 Apr 1;143(7):677–82.

4. Stasi S, Papathanasiou G, Chronopoulos E, Galanos A, Papaioannou NA, Triantafyllopoulos IK. Association between abductor muscle strength and functional outcomes in hip-fractured patients: a cross-sectional study. J Musculoskelet Neuronal Interact. 2018 Dec 1;18(4):530–42.
5. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T, et al. Sarcopenia: revised European consensus on definition and diagnosis. Age Ageing. 2019 Jan 1;48(1):16–31.
6. Chiang MH, Kuo YJ, Chen YP. The Association Between Sarcopenia and Postoperative Outcomes Among Older Adults With Hip Fracture: A Systematic Review. J Appl Gerontol Off J South Gerontol Soc. 2021 Dec;40(12):1903–13.
7. Boutin RD, Bamrungchart S, Bateni CP, Beavers DP, Beavers KM, Meehan JP, et al. CT of Patients With Hip Fracture: Muscle Size and Attenuation Help Predict Mortality. AJR Am J Roentgenol. 2017 Jun;208(6):W208–15.
8. Boutin RD, Lenchik L. Value-Added Opportunistic CT: Insights Into Osteoporosis and Sarcopenia. AJR Am J Roentgenol. 2020 Sep;215(3):582–94.
9. Byun SE, Kim S, Kim KH, Ha YC. Psoas cross-sectional area as a predictor of mortality and a diagnostic tool for sarcopenia in hip fracture patients. J Bone Miner Metab. 2019 Sep;37(5):871–9.
10. Bae SJ, Lee SH. Computed tomographic measurements of the psoas muscle as a predictor of mortality in hip fracture patients: Muscle attenuation helps predict mortality in hip fracture patients. Injury. 2021 Jun;52(6):1456–61.
11. Touban BM, Pavlesen S, Smoak JB, Sayegh MJ, Wang J, Zhao J, et al. Decreased Lean Psoas Cross-Sectional Area Is Associated With Increased 1-Year All-Cause Mortality in Male Elderly Orthopaedic Trauma Patients. J Orthop Trauma. 2019 Jan;33(1):e1–7.
12. Yamashita M, Kamiya K, Matsunaga A, Kitamura T, Hamazaki N, Matsuzawa R, et al. Prognostic Value of Psoas Muscle Area and Density in Patients Who Undergo Cardiovascular Surgery. Can J Cardiol. 2017 Dec;33(12):1652–9.
13. Erinç S, Bozca MA, Bankaoğlu M, Çakırtürk S, Yahşi Y, Özdemir HM. Association of abductor hip muscle atrophy with fall-related proximal femur fractures in the elderly. Injury. 2020 Jul;51(7):1626–33.
14. Noda M, Saegusa Y, Takahashi M, Takada Y, Fujita M, Shinohara I. Decreased postoperative gluteus medius muscle cross-sectional area measured by computed tomography scan in patients with intertrochanteric fractures nailing. J Orthop Surg. 2017;25(3):2309499017727943.
15. Chi AS, Long SS, Zoga AC, Parker L, Morrison WB. Association of Gluteus Medius and Minimus Muscle Atrophy and Fall-Related Hip Fracture in Older Individuals Using Computed Tomography. J Comput Assist Tomogr. 2016;40(2):238–42.
16. Holden MK, Gill KM, Magliozzi MR, Nathan J, Piehl-Baker L. Clinical gait assessment in the neurologically impaired. Reliability and meaningfulness. Phys Ther. 1984 Jan;64(1):35–40.
17. Parker MJ, Palmer CR. A new mobility score for predicting mortality after hip fracture. J Bone Joint Surg Br. 1993 Sep;75(5):797–8.
18. Mahoney FI, Barthel DW. FUNCTIONAL EVALUATION: THE BARTHEL INDEX. Md State Med J. 1965 Feb;14:61–5.
19. Byrd JW, Jones KS. Prospective analysis of hip arthroscopy with 2-year follow-up. Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc. 2000 Sep;16(6):578–87.
20. Benjamini Y, Hochberg Y. Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. J R Stat Soc Ser B Methodol. 1995 Jan 1;57(1):289–300.
21. Lenchik L, Lenoir KM, Tan J, Boutin RD, Callahan KE, Kritchevsky SB, et al. Opportunistic Measurement of Skeletal Muscle Size and Muscle Attenuation on Computed Tomography Predicts 1-Year Mortality in Medicare Patients. J Gerontol A Biol Sci Med Sci. 2019 Jun 18;74(7):1063–9.
22. Inoue T, Maeda K, Nagano A, Shimizu A, Ueshima J, Murotani K, et al. Undernutrition, Sarcopenia, and Frailty in Fragility Hip Fracture: Advanced Strategies for Improving Clinical Outcomes. Nutrients. 2020 Dec 4;12(12):3743.