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Added Value of Dual-Energy CT and Low-Attenuation Muscle Quality Measures for Lower-Limb Function in Community-Dwelling Older Adults

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Article

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Abstract

This cross-sectional study examined whether computed tomography (CT)-derived measures of muscle quality, the low-attenuation muscle area (LAMA) ratio and dual-energy CT fat fraction (DECT-FF), were associated with physical function independently of muscle quantity measured by the CT skeletal muscle index (CT-SMI) in older adults. L3-level DECT images were obtained from 58 prospectively enrolled community-dwelling older adults in Fukushima, Japan. We assessed how CT-SMI, the LAMA ratio, and DECT-FF were related to the 30-second chair-stand test (CS-30; n = 50) and grip strength (n = 58). After accounting for age, sex, and CT-SMI, both the LAMA ratio ($p = 0.031$) and DECT-FF ($p = 0.045$) were independently associated with CS-30 performance, whereas neither was independently associated with grip strength. CS-30 performance did not differ between the lower and upper quartiles of CT-SMI scores standardized within each sex ($p = 0.478$), but differed between quartiles when CT-SMI was combined with either the LAMA ratio ($p = 0.005$) or DECT-FF ($p < 0.001$). CT-derived muscle quality measures provided information beyond muscle quantity for explaining lower-limb physical function. DECT-FF may be particularly useful when a muscle quality measure less affected by differences between scanners is needed.

1. Introduction

Computed tomography (CT) is a well-established modality for assessing skeletal muscle quantity. Measuring muscle cross-sectional area or volume on CT images enables objective, quantitative assessment of muscle quantity [1, 2]. In particular, single-slice assessment at the level of the third lumbar vertebra (L3) has been extensively validated as a surrogate for whole-body skeletal muscle mass [3] and provides prognostic information independent of body mass index in patients with malignancy [4], supporting its clinical application.

More recently, Hounsfield unit (HU) values have been used to extend CT assessment from muscle quantity to muscle quality. Deterioration of muscle quality refers primarily to fat infiltration within and between muscle fibers (myosteatosis), which is associated with insulin resistance, chronic inflammation, disuse atrophy, and altered force-generating properties [5, 6]. Mean muscle attenuation and the low-attenuation muscle area (LAMA) ratio have been used as CT-based quality indices [1, 7], and reference values derived from healthy living kidney donors have recently become available [8]. However, HU values obtained with single-energy acquisition vary with the patient's body habitus and scanner settings [9]. A systematic review also documented the absence of international consensus regarding the HU thresholds (e.g., − 190 to − 30 HU) and methods used to define myosteatosis [10]. These limitations hinder standardization of HU-based muscle quality assessment.

The demand for objective muscle quality assessment is increasing in the context of sarcopenia care and health promotion in the aging global population [11, 12]. Established criteria, including those of the Asian Working Group for Sarcopenia (AWGS) 2019, recommend evaluating muscle quantity using bioelectrical impedance analysis (BIA) or dual-energy X-ray absorptiometry (DXA) [11]. However, these modalities

primarily assess muscle quantity. Because age-related decline in physical function can occur with deteriorating muscle quality (fat infiltration) even when muscle quantity is preserved, muscle quality may capture pathological changes that quantity alone cannot [5, 13]. Accordingly, the AWGS 2025 consensus update shifted its emphasis from disease diagnosis to maintaining and promoting muscle health from middle age onward and explicitly highlighted the importance of quality assessment [14]. Thus, standardized quantitative indices of muscle quality are clinically needed.

Dual-energy CT (DECT) may help meet this need. Skeletal muscle, which is composed principally of water and protein, and adipose tissue have different effective atomic numbers and therefore distinct attenuation characteristics across X-ray spectra of different energies. By applying material decomposition algorithms to differences in X-ray absorption at two energy levels [15], DECT quantifies the volumetric fat fraction within a voxel (DECT-FF) without relying on the simple HU thresholding required for single-energy CT. This approach may be less dependent on tube voltage and patient body habitus [16, 17]. DECT-FF has been reported to correlate closely with proton density fat fraction measured using 3 T magnetic resonance imaging (MRI), a reference method, supporting its potential as a reproducible imaging biomarker with reduced interscanner variability [17, 18].

Although DECT and the clinical need for standardized muscle quality assessment are both emerging, evidence connecting them remains limited. Specifically, the convergent validity of DECT-FF and the conventional LAMA ratio, and whether either index is associated with physical function independently of muscle quantity, have remained insufficiently examined. Furthermore, the potential of DECT for functional imaging applications in health promotion for older adults remains unclear. We therefore used L3-level CT body composition analysis in community-dwelling older adults to examine whether CT-derived muscle quality indices (DECT-FF and the LAMA ratio) were associated with physical function (the 30-second chair-stand test [CS-30] and grip strength) independently of muscle quantity (CT-SMI). We used hierarchical multiple regression and comparisons of sex-standardized composite scores combining muscle quantity and quality. We also evaluated whether incorporating muscle quality provided additional information about physical function beyond muscle quantity alone.

2. Methods

2.1 Study Participants

This cross-sectional study included 58 community-dwelling adults aged 65 years or older. The present study was a secondary analysis of data from a cross-sectional study designed primarily to compare muscle cell mass estimated using a whole-body counter with conventional muscle mass measurements. Recruitment was conducted between December 2025 and March 2026 using local community magazines and flyers distributed in Fukushima City and Date City, Fukushima, Japan. During the recruitment period, 263 individuals applied to participate. The predefined exclusion criteria included a history of stroke, Parkinson’s disease, severe cognitive or psychiatric impairment, severe cardiac disease, musculoskeletal disorders, and implanted medical devices (e.g., cardiac pacemakers) or life-

support medical devices (e.g., physiological monitors). Six applicants met the exclusion criteria during prescreening. Of the remaining 257 eligible applicants, 60 were randomly selected using random number generation. All selected individuals participated, and no replacements were required. The sample size was determined by the examination capacity available for this study, and no a priori power calculation was performed for the present analyses. After enrollment, two participants were excluded from the analysis because of their medical histories, leaving 58 participants for analysis. Data were collected over 3 days in March 2026. Participants received a 30-min face-to-face verbal explanation of the study and provided written informed consent. They then participated in a 90-min session comprising CT imaging, physical function assessments, and body composition measurements. This study was approved by the Fukushima Medical University Research Ethics Committee (Approval No. REC2025-147). The study was conducted in accordance with the Declaration of Helsinki and the Ethical Guidelines for Medical and Biological Research Involving Human Subjects in Japan. The flow of participant recruitment and enrollment is shown in Fig. 1.

2.2 CT Image Analysis

DECT imaging was performed using a SOMATOM go.Top scanner (Siemens Healthineers, Erlangen, Germany) with a split-filter technique [15]. Participants were positioned supine in a feet-first orientation and scanned during an end-expiratory breath-hold. The imaging protocol comprised two acquisitions: an initial scout (topogram) image followed by a diagnostic helical scan. The scanning parameters were as follows: tube voltage, AuSn 120 kV using gold (Au) and tin (Sn) filters; rotation time, 0.5 s; tube current–time product, 60 mAs; pitch, 0.4; detector collimation, 64 × 0.6 mm (total, 38.4 mm); slice thickness, 5 mm; field of view, 400 mm; and reconstruction kernel, Qr40. Scans were performed with a fixed tube current and without automatic exposure control over a 3-cm range centered on the third lumbar vertebra (L3). No intravenous contrast material was administered. The volume CT dose index (CTDIvol) for the helical scan was 1.65 mGy.

Axial CT images in Digital Imaging and Communications in Medicine (DICOM) format were extracted from the picture archiving and communication system. Tissue segmentation was performed on a single axial slice at the L3 level and included the trunk musculature (psoas major, paraspinal, and abdominal wall muscles) (Fig. 2). The single-slice approach has been widely adopted because cross-sectional tissue areas measured on one axial image correlate closely with the corresponding whole-body tissue volumes [1, 3]. The L3 level was selected because it includes trunk muscles that contribute to movements involving the pelvic girdle and lower extremities.

Dual-energy fat fraction maps were first generated on a syngo.via workstation (version 8.0.0.0; Siemens Healthineers) using a three-material decomposition algorithm and exported in DICOM format with the original CT images. Skeletal muscle, adipose tissue, and low-attenuation compartments were then segmented on the original CT images using a semi-automated method based on an in-house script written in Python, version 3.14.5 (Python Software Foundation; https://www.python.org) that applied HU thresholding; a single operator (a radiological technologist with 25 years of experience) who was blinded

to the physical function results manually corrected the outer muscle boundaries as needed. All segmentation results were then visually checked by two co-investigators. A previous phantom study reported excellent reproducibility of CT-based muscle area measurements under varying scan parameters [19]. Because the fat fraction map and original CT image were derived from the same acquisition and had identical reconstruction geometry, the segmentation mask was applied directly to the fat fraction map without additional registration. Thus, the area-based indices and fat fraction were obtained from the same region of interest. The following body composition indices were calculated from a single L3 slice:

CT skeletal muscle area (CT-SMA): Skeletal muscle cross-sectional area (cm^2) was defined using a threshold of − 29 to + 150 HU. Because the lower bound lies above the attenuation range of intermuscular adipose tissue (IMAT; −190 to − 30 HU), IMAT was excluded from CT-SMA by definition.

CT skeletal muscle index (CT-SMI): CT-SMA was normalized to the square of the participant's height (cm^2/m^2) to obtain CT-SMI, consistent with the body-size adjustment reported to be optimal for L3-level muscle area [20]. CT-SMI was used as an index of muscle quantity.

LAMA ratio: To quantify low-attenuation muscle tissue as a proxy for myosteatosis, the low-attenuation muscle area between − 29 and + 29 HU was calculated and expressed as a percentage of total CT-SMA.

DECT-FF: The mean fat fraction (%) across all pixels within the segmented muscle region on the fat fraction map was calculated and defined as DECT-FF.

CT-SMI served as the index of muscle quantity, whereas the LAMA ratio and DECT-FF served as indices of muscle quality.

2.3 Physical Function Assessment and BIA Measurement

Physical function was assessed using two performance measures. Lower-limb physical function was assessed using the 30-second chair-stand test (CS-30) [21], which measures the number of sit-to-stand repetitions completed within 30 s. Participants used a standard chair (seat height, 40 cm) without armrests and began in an upright seated position with their arms folded across the chest. After the verbal command "1, 2, 3, go," they repeatedly stood and sat at their preferred pace for 30 s, and the total number of completed repetitions was recorded. The CS-30 was selected because repeated sit-to-stand performance requires coordinated activity of the pelvic-girdle, trunk, and lower-limb muscles. Eight participants could not perform the CS-30 because of physical health problems; therefore, complete data were available for 50 participants. Upper-limb function was evaluated using maximal grip strength (kg), measured with a digital handgrip dynamometer (GRIP-D, T.K.K5401, Takei Kiki Kogyo Co., Ltd., Tokyo, Japan). Grip strength was measured twice for each hand in the standing position, and the maximum value of the four trials was used for analysis. Grip strength was measured in all participants (n = 58) and served as an upper-limb comparison for the trunk-based CT indices. Height and weight were measured using standard scales, and body mass index was calculated as weight divided by height squared (kg/m^2).

As a reference measure of muscle quantity, whole-body skeletal muscle mass (SMM; kg) was obtained using a multifrequency BIA system (InBody S10; InBody Japan Inc., Tokyo, Japan). The SMM output from the device was divided by the square of the participant's height to calculate skeletal muscle index, hereafter termed BIA-SMI.

All physical function and body composition measurements were performed according to a standardized protocol by several trained student assessors who were unaware of the CT and other measurement results.

2.4 Statistical Analysis

Baseline characteristics, physical measurements, BIA-SMI, and CT-derived measures are presented as mean ± standard deviation. Differences between men and women were assessed using independent-samples t tests. Relationships between continuous variables were evaluated using Pearson's correlation coefficients. BIA-SMI was used as a reference measure to evaluate the convergent validity of CT-SMI. We also assessed the prevalence of sarcopenia among all participants using the AWGS 2019 criteria [11].

To assess whether CT-derived muscle quality indices explained physical function beyond muscle quantity and the covariates, we performed hierarchical multiple linear regression using ordinary least squares. Muscle quantity (M1: M0 + CT-SMI) was added to the base model (M0: age + sex), followed separately by the LAMA ratio (M2: M1 + LAMA ratio) and DECT-FF (M3: M1 + DECT-FF). M2 and M3 were each compared with M1. The change in R^2 (ΔR^2) was calculated to evaluate the added explanatory value of each muscle quality index, and its statistical significance was tested using an F-change test. Variance inflation factors (VIFs) were calculated to assess multicollinearity, with VIF < 5 considered acceptable. Sex was coded as 1 for men and 0 for women. The regression analyses included 50 participants for CS-30 and 58 participants for grip strength. Regression assumptions were examined using the Shapiro–Wilk test for normality of residuals, the Breusch–Pagan test for homoscedasticity, and Cook's distance for influential observations. As a sensitivity analysis for the correlation analyses, Spearman's rank correlation coefficients were also calculated.

To account for sex-related differences, CT-SMI, the LAMA ratio, and DECT-FF were standardized as z scores separately within men and women. Because higher LAMA ratio and DECT-FF values indicate poorer muscle quality, whereas higher CT-SMI indicates greater muscle quantity, the z scores for the two quality indices were multiplied by − 1 so that higher values consistently represented more favorable muscle status. Three composite scores were then calculated as unweighted sums of the sign-aligned z scores: (i) quantity alone (CT-SMI z score), (ii) quantity plus quality (CT-SMI z score + sign-inverted LAMA ratio z score), and (iii) quantity plus quality (CT-SMI z score + sign-inverted DECT-FF z score). These composite scores and the quartile comparisons were not prespecified in the study protocol and were conducted as exploratory analyses. For each score, participants were ranked across the full analytic sample (n = 58), and the 14 participants with the highest scores (upper quartile) and the 14 with the lowest scores (lower quartile) were selected; the remaining 30 participants were excluded from this comparison. No tied scores occurred at the quartile boundaries, and quartile membership was not

recalculated among participants with complete CS-30 data. Physical function was compared between quartiles using Welch's two-sample t test. Quartiles were defined relative to the study sample and do not represent established clinical cutoffs. All tests were two-sided, and the significance level was set at $p < 0.05$. Because the correlation, regression, and quartile analyses were exploratory, no adjustment for multiple comparisons was applied. All statistical analyses were performed using SPSS Statistics, version 30 (IBM Corp., Armonk, NY, USA). Assumption checks and sensitivity analyses were performed using Python with the statsmodels (version 0.15.0) and SciPy (version 1.17.1) libraries. Data were visualized using R, version 4.3.1 (R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1 Baseline Characteristics

The baseline characteristics of the participants are summarized in Table 1. The mean age was 73.8 ± 5.1 years. The mean CT-SMI was 45.2 ± 8.7 cm^2/m^2 (men: 51.1 ± 8.3; women: 40.0 ± 4.8), the LAMA ratio was 41.2 ± 11.5%, and the DECT-FF was 16.6 ± 2.9%. The average CS-30 score was 18.1 ± 4.3 repetitions (n = 50), and the mean grip strength was 30.8 ± 8.1 kg (n = 58). According to the AWGS 2019 criteria, no participants were classified as having sarcopenia (0/58).

3.2 Relationships Among CT-Based Muscle Quantity and Quality Measures

CT-SMI was strongly positively correlated with BIA-SMI ($r = 0.822$, $p < 0.001$, $n = 58$). The two CT-derived muscle quality indices were moderately positively correlated with each other (LAMA ratio vs. DECT-FF, $r = 0.691$, $p < 0.001$) (Figure 3a). Both quality indices were inversely correlated with muscle quantity (CT-SMI): the correlation was weak to moderate for the LAMA ratio ($r = −0.406$, $p = 0.002$) and moderate for DECT-FF ($r = −0.637$, $p < 0.001$) (Figure 3b, c).

3.3 Univariate Correlations Between CT Indices and Physical Function

In univariate analyses, CS-30 was significantly correlated with all CT-derived muscle quantity and quality indices. CS-30 was positively correlated with CT-SMI ($r = 0.320$, $p = 0.023$) and inversely correlated with the LAMA ratio ($r = −0.395$, $p = 0.005$) and DECT-FF ($r = −0.413$, $p = 0.003$) (Figure 4). Grip strength was positively correlated with CT-SMI ($r = 0.566$, $p < 0.001$) and inversely correlated with DECT-FF ($r = −0.381$, $p = 0.003$); its inverse correlation with the LAMA ratio was not statistically significant ($r = −0.230$, $p = 0.083$). Spearman's rank correlations showed the same pattern, except that the inverse correlation between the LAMA ratio and grip strength reached statistical significance ($\rho = −0.318$, $p = 0.015$).

3.4 Additional Contribution to Explaining Physical Function in Hierarchical Multiple Regression

For CS-30, the CT-derived muscle quality indices explained additional variance beyond age, sex, and CT-SMI. The base model (M0: age + sex) had an R^2 of 0.059, and adding CT-SMI (M1) increased the explained variance. Adding the LAMA ratio to M1 (M2) increased R^2 by 0.087 (8.7 percentage points; F-change test, $F(1, 45) = 4.95$, $p = 0.031$), and the LAMA ratio was independently associated with CS-30 performance (unstandardized coefficient B = −0.125, 95% confidence interval [CI] −0.239 to −0.012, $p = 0.031$). Similarly, adding DECT-FF to M1 (M3) increased R^2 by 0.076 (7.6 percentage points; F-change test, $F(1, 45) = 4.27$, $p = 0.045$), and DECT-FF was independently associated with CS-30 performance (unstandardized coefficient B = −0.566, 95% CI −1.117 to −0.014, $p = 0.045$) (Table 2, Figure 5). The maximum VIF in M3 was 2.28, below the threshold of 5, indicating low multicollinearity. The residuals of the CS-30 models showed no marked departure from normality (Shapiro–Wilk $p \geq 0.060$) or homoscedasticity (Breusch–Pagan $p \geq 0.119$), and no observation had a Cook's distance > 0.5 (maximum, 0.324).

Conversely, the muscle quality indices did not explain significant additional variance in grip strength. The base model (M0: age + sex) had an R^2 of 0.613. Adding CT-SMI (M1) produced only a small increase ($\Delta R^2 = 0.004$). Subsequent addition of the LAMA ratio (M2) was not significant ($\Delta R^2 = 0.014$; F-change test, $F(1, 53) = 2.08$, $p = 0.155$). Addition of DECT-FF (M3) also did not reach statistical significance ($\Delta R^2 = 0.024$; F-change test, $F(1, 53) = 3.62$, $p = 0.062$). These findings indicate that the L3-level CT-derived muscle quality indices were not independently associated with upper-limb grip strength in this sample.

3.5 Sex-Adjusted Composite Scores of CT-Derived Muscle Quantity and Quality in Relation to Physical Function

To account for sex-related differences, CT-SMI, the LAMA ratio, and DECT-FF were standardized as z scores within each sex to create composite scores of CT-derived muscle quantity and quality (Figure 6a). Both the lower and upper quartiles included men and women after sex standardization.

CS-30 performance did not differ between the lower and upper quartiles of the CT-SMI score alone ($p = 0.478$; n = 12 and 10, respectively). However, when either CT muscle quality index was included in the composite score, CS-30 performance differed significantly between quartiles (CT-SMI + LAMA ratio: $p = 0.005$, n = 11 and 11; CT-SMI + DECT-FF: $p < 0.001$, n = 13 and 11) (Figure 6b). Thus, CS-30 performance differed between quartiles only when either muscle quality indicator was included in the composite score. Representative pairs of male and female participants from the upper and lower quartiles of the CT-SMI + DECT-FF composite score, with comparable muscle quantity, are shown in Supplementary Figs. S1 and S2, respectively. Grip strength did not differ between quartiles for any composite score ($p = 0.712–0.805$; n = 14 per quartile), consistent with regional specificity (Figure 6c).

4. Discussion

This study found that the CT-derived muscle quality indices—the LAMA ratio and DECT-FF—were associated with lower-limb physical function measured using the CS-30, independently of CT-SMI. First, both indices retained significant explanatory value for CS-30 after adjustment for age, sex, and CT-SMI. Second, CS-30 performance differed between the upper and lower quartiles of composite scores combining CT-derived muscle quantity and quality, whereas it did not differ between quartiles defined by CT-SMI alone. Third, neither quality index was independently associated with grip strength, suggesting that the associations were regionally specific to muscle groups represented at the L3 level. Although the two CT-derived quality indices are based on different measurement principles—HU thresholding for the LAMA ratio and material decomposition of dual-energy data for DECT-FF—both were associated with CS-30 performance. This convergence is a principal strength of the findings and is consistent with fat infiltration having biological relevance distinct from muscle loss in age-related muscle pathology [5, 13].

The imaging measurements showed expected relationships with the reference measure and with each other. CT-SMI derived from a single L3 slice was strongly correlated with BIA-SMI ($r = 0.822$), consistent with a recent prospective cohort study reporting close agreement between CT-based body composition analysis and BIA for fat mass and muscle mass [22]. This correlation supports convergent validity but does not by itself establish agreement or interchangeability between the methods. The two CT-derived quality indicators were positively correlated ($r = 0.691$), suggesting that HU thresholding and three-material decomposition captured overlapping aspects of fat infiltration. Both were inversely correlated with muscle quantity (LAMA ratio, $r = -0.406$; DECT-FF, $r = -0.637$), suggesting that muscle loss and fat infiltration may occur together with aging. The maximum VIF was 2.28, indicating that multicollinearity was unlikely to have substantially distorted the CS-30 model estimates. These findings are consistent with the possibility that fat infiltration may be present even when muscle quantity is preserved and that modalities focused on quantity, such as BIA and DXA, may not identify this feature [5].

The sex-standardized composite-score analysis provided a complementary assessment of these relationships. After standardization within each sex, CS-30 performance did not differ between the upper and lower quartiles of CT-SMI alone ($p = 0.478$). In contrast, CS-30 performance differed between quartiles of both composite scores incorporating a CT-derived muscle quality indicator (CT-SMI + LAMA ratio, $p = 0.005$; CT-SMI + DECT-FF, $p < 0.001$). Thus, participants in the lower quartile of the quantity-only score were not necessarily those with poorer lower-limb function; group differences emerged when muscle quality was incorporated. Supplementary Figs. S1 and S2 illustrate participants with comparable CT-SMI but marked differences in both muscle quality indices and CS-30 performance. Similar separation with the conventional HU threshold-based LAMA ratio supports the potential applicability of this approach when DECT is unavailable. These findings suggest that an integrated quantity-plus-quality assessment may complement existing sarcopenia criteria [11, 12] and refine risk stratification [5]. However, the quartiles were defined within this study sample and do not represent established clinical cutoffs.

The contrast between CS-30 and grip strength suggests anatomical specificity of the L3-level CT body composition indices. For grip strength, the base model (age + sex) explained a large proportion of the

variance (R^2 = 0.613), and adding CT-SMI or either CT-derived quality index produced little improvement. Although DECT-FF was inversely correlated with grip strength in the univariate analysis (r = − 0.381), its partial regression coefficient became positive in the multivariable model (B = 0.611, p = 0.062). This reversal may reflect statistical suppression after adjustment for sex, although this interpretation was not directly tested. The maximum VIF of 2.11 suggests that conventional multicollinearity was low. In this cohort, the quality of the trunk and pelvic-girdle muscles represented at L3 was not independently associated with maximal strength in the anatomically and functionally distant upper-limb muscles. Large-scale CT analyses have likewise shown that age-related declines in muscle attenuation and fatty degeneration vary by anatomical site, sex, and age [23]. A recent study comparing lumbar vertebral levels for opportunistic CT screening found that trunk muscle measurements at all levels correlated with grip strength and that muscle attenuation at L1 showed a stronger association with physical performance in men [24]. L3 remains the standard level for estimating whole-body skeletal muscle mass, but differences in functional predictive capacity between L1 and L3 warrant further investigation.

The choice between the two CT-derived quality indices should not be based on effect size alone. In this study, the incremental explanatory value of the LAMA ratio was slightly greater than that of DECT-FF (ΔR^2 = 0.087 vs. 0.076). The potential advantage of DECT-FF lies in measurement standardization and reproducibility. The LAMA ratio is practical and sensitive within an institution using a consistent scanner and protocol; however, its underlying HU values may vary with body habitus, tube voltage, and scanner or vendor characteristics [9]. In contrast, DECT-FF estimates the volumetric fat fraction through three-material decomposition using paired low- and high-energy attenuation values [16, 17]. This approach may be less sensitive to scanner-related variability than fixed HU thresholds, although cross-scanner and cross-vendor standardization requires direct validation. The LAMA ratio may therefore be suitable for pragmatic screening within an institution, whereas DECT-FF may be better suited to multicenter studies, longitudinal follow-up, and development of standardized clinical cutoffs. By quantifying both indices in the same cohort under a fixed acquisition protocol, this study provides preliminary comparative data for such work. Supporting the prognostic potential of DECT-FF, a previous study of critically ill patients found that DECT-derived muscle fat fraction independently predicted overall survival [25].

These findings support further evaluation of opportunistic screening. Older adults frequently undergo abdominal CT and, increasingly, DECT for diagnosing acute abdominal conditions or staging and monitoring malignancies. Secondary analysis of routine images with automated tools could support stratification of sarcopenia and functional risk without additional image acquisition [26]. Because many such examinations use contrast enhancement, the applicability of DECT-FF under these conditions is clinically relevant. A previous study found no significant difference between portal-venous phase DECT and multi-echo Dixon MRI for fat quantification in the erector spinae and psoas major muscles [18], suggesting that the approach may not be restricted to unenhanced examinations. Whether absolute DECT-FF values from the present unenhanced cohort are directly transferable to contrast-enhanced acquisitions remains to be determined. A recent opportunistic screening study reported that intermuscular adipose tissue (IMAT) influenced overall muscle density more strongly than intramuscular

fat content [27]. Separate segmentation of IMAT and skeletal muscle, as performed here, may therefore help distinguish muscle quantity from different fat compartments when evaluating muscle quality.

This study has some limitations. First, the cohort largely comprised functionally independent, relatively robust, community-dwelling older adults. At a mean age of 73.8 years, grip strength (men, 37.4 ± 6.9 kg; women, 25.0 ± 3.3 kg) exceeded published reference values for age-matched community-dwelling Japanese adults (men, 31.7 kg; women, 20.4 kg) [28], and CS-30 performance (men, 18.9 ± 3.3; women, 17.4 ± 5.0 repetitions) was at or above the upper end of the corresponding normative range (25th–75th percentiles for ages 70–79 years: men, 11–17; women, 10–15) [29]. None of the participants met the AWGS 2019 criteria for sarcopenia (0/58). Volunteer and selection biases may therefore limit generalizability to populations with frailty or sarcopenia, and the independent value of the quality indices should be evaluated in such cohorts. Second, no established population reference values exist for DECT-FF or the LAMA ratio; therefore, the present values could not be compared directly with those of previous reports. Third, this was a relatively small single-center study (n = 58), and the sample size was determined by feasibility rather than a formal power calculation. The CS-30 analysis used complete cases after excluding eight participants who could not perform the test; because these participants may have been frailer, their exclusion may have biased the association estimates. Fourth, potentially relevant confounders, including habitual physical activity, detailed nutritional status, and severity of chronic comorbidities, were not measured or fully adjusted for, leaving the possibility of residual confounding. Finally, the cross-sectional design precludes causal or temporal inferences. Multicenter longitudinal studies that account for these factors are needed to determine the long-term prognostic value of DECT-FF and the LAMA ratio and to validate cutoffs for incident sarcopenia.

5. Conclusion

The CT-derived muscle quality indices, the LAMA ratio and DECT-FF, provided information beyond muscle quantity (CT-SMI) for explaining lower-limb physical function measured using the CS-30 in community-dwelling older adults. Despite their different measurement principles, both quality indices explained additional variance in CS-30 performance after adjustment for age, sex, and CT-SMI, and the low VIFs indicated limited multicollinearity. The LAMA ratio, which requires only single-energy acquisition, may be useful within an institution using a consistent scanner and protocol, whereas DECT-FF may offer advantages when standardization across institutions and scanners is required. Simultaneous CT-based assessment of muscle quantity and quality warrants further evaluation as an opportunistic approach to muscle health assessment in older adults.

Declarations

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Author Contribution

Conceptualization and study design: T.O. CT image acquisition and analysis: M.T., H.S., Y.Hi., T.K. Physical function assessment: T.S., K.O. Body composition (BIA) and laboratory data acquisition: A.Y., Y.Ho., R.H., T.K., T.W. Formal statistical analysis: M.T. Writing—original draft: M.T. Writing—review and editing: all authors. Supervision and funding acquisition: T.O. All authors read and approved the final manuscript.

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Data Availability

The datasets analyzed in the current study are not publicly available due to institutional and ethical restrictions on individual-level imaging and health data, but are available from the corresponding author (T.O.) upon reasonable request, subject to approval by the Fukushima Medical University Research Ethics Committee.

Code availability

The custom Python script used for semi-automated image segmentation is not publicly available but is available from the corresponding author upon reasonable request.

References

1. Mourtzakis, M. et al. A practical and precise approach to quantification of body composition in cancer patients using computed tomography images acquired during routine care. *Appl. Physiol. Nutr. Metab.* **33**, 997–1006 (2008).
2. Mitsiopoulos, N. et al. Cadaver validation of skeletal muscle measurement by magnetic resonance imaging and computerized tomography. *J. Appl. Physiol.* **85**, 115–122 (1998).
3. Shen, W. et al. Total body skeletal muscle and adipose tissue volumes: estimation from a single abdominal cross-sectional image. *J. Appl. Physiol.* **97**, 2333–2338 (2004).
4. Martin, L. et al. Cancer cachexia in the age of obesity: skeletal muscle depletion is a powerful prognostic factor, independent of body mass index. *J. Clin. Oncol.* **31**, 1539–1547 (2013).
5. Correa-de-Araujo, R. et al. Myosteatosis in the context of skeletal muscle function deficit: an interdisciplinary workshop at the National Institute on Aging. *Front. Physiol.* **11**, 963 (2020).

6. Addison, O., Marcus, R. L., LaStayo, P. C. & Ryan, A. S. Intermuscular fat: a review of the consequences and causes. *Int. J. Endocrinol.* 309570 (2014). (2014).
7. Goodpaster, B. H., Kelley, D. E., Thaete, F. L., He, J. & Ross, R. Skeletal muscle attenuation determined by computed tomography is associated with skeletal muscle lipid content. *J. Appl. Physiol.* **89**, 104–110 (2000).
8. Martin, D. et al. Age- and sex-specific reference values for CT-based low skeletal muscle quantity and quality in healthy living kidney donors. *Front. Physiol.* **16**, 1566463 (2025).
9. Pigneur, F. et al. Skeletal muscle density is highly dependent on CT instrumentation. *Radiology* **307**, e222839 (2023).
10. Amini, B., Boyle, S. P., Boutin, R. D. & Lenchik, L. Approaches to assessment of muscle mass and myosteatosis on computed tomography: a systematic review. *J. Gerontol. Biol. Sci. Med. Sci.* **74**, 1671–1678 (2019).
11. Chen, L. K. et al. Asian Working Group for Sarcopenia: 2019 consensus update on sarcopenia diagnosis and treatment. *J. Am. Med. Dir. Assoc.* **21**, 300–307 (2020).
12. Cruz-Jentoft, A. J. et al. Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing*. **48**, 16–31 (2019).
13. Goodpaster, B. H. et al. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. *J. Gerontol. Biol. Sci. Med. Sci.* **61**, 1059–1064 (2006).
14. Chen, L. K. et al. A focus shift from sarcopenia to muscle health in the Asian Working Group for Sarcopenia 2025 Consensus Update. *Nat. Aging*. **5**, 2164–2175 (2025).
15. McCollough, C. H., Leng, S., Yu, L. & Fletcher, J. G. Dual- and multi-energy CT: principles, technical approaches, and clinical applications. *Radiology* **276**, 637–653 (2015).
16. Molwitz, I. et al. Fat quantification in dual-layer detector spectral computed tomography: experimental development and first in-patient validation. *Invest. Radiol.* **57**, 463–469 (2022).
17. Molwitz, I. et al. Skeletal muscle fat quantification by dual-energy computed tomography in comparison with 3T MR imaging. *Eur. Radiol.* **31**, 7529–7539 (2021).
18. Gassenmaier, S. et al. Quantification of liver and muscular fat using contrast-enhanced dual source dual energy computed tomography compared to an established multi-echo Dixon MRI sequence. *Eur. J. Radiol.* **142**, 109845 (2021).
19. Kim, D. W. et al. Reliability of skeletal muscle area measurement on CT with different parameters: a phantom study. *Korean J. Radiol.* **22**, 624–633 (2021).
20. Derstine, B. A. et al. Optimal body size adjustment of L3 CT skeletal muscle area for sarcopenia assessment. *Sci. Rep.* **11**, 279 (2021).
21. Jones, C. J., Rikli, R. E. & Beam, W. C. A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. *Res. Q. Exerc. Sport*. **70**, 113–119 (1999).
22. Fehrenbach, U. et al. Concordance between single-slice abdominal computed tomography-based and bioelectrical impedance-based analysis of body composition in a prospective study. *Eur. Radiol.*

35, 8000–8011 (2025).

23. Figueiredo, P. et al. Computed tomography-based skeletal muscle and adipose tissue attenuation: variations by age, sex, and muscle. *Exp. Gerontol.* **149**, 111306 (2021).
24. Liu, X. et al. Optimal lumbar vertebral level for trunk muscle CT assessments in opportunistic sarcopenia screening: a cross-sectional study. *BMJ Open.* **15**, e083165 (2025).
25. Erley, J. et al. Dual-energy CT muscle fat fraction as a new imaging biomarker of body composition and survival predictor in critically ill patients. *Eur. Radiol.* **34**, 7408–7418 (2024).
26. Pickhardt, P. J. et al. Automated CT biomarkers for opportunistic prediction of future cardiovascular events and mortality in an asymptomatic screening population: a retrospective cohort study. *Lancet Digit. Health*. **2**, e192–e200 (2020).
27. Guo, X. et al. Intermuscular adipose tissue affected muscle density more than intramuscular adipose tissue content with opportunistic screening at abdominal CT. *Sci. Rep.* **15**, 8172 (2025).
28. Seino, S. et al. Reference values and age and sex differences in physical performance measures for community-dwelling older Japanese: a pooled analysis of six cohort studies. *PLoS ONE*. **9**, e99487 (2014).
29. Rikli, R. E. & Jones, C. J. Functional fitness normative scores for community-residing older adults, ages 60–94. *J. Aging Phys. Act.* **7**, 162–181 (1999).

Tables

Tables 1 & 2 are available in the Supplementary Files section.

Figures

Figure 1

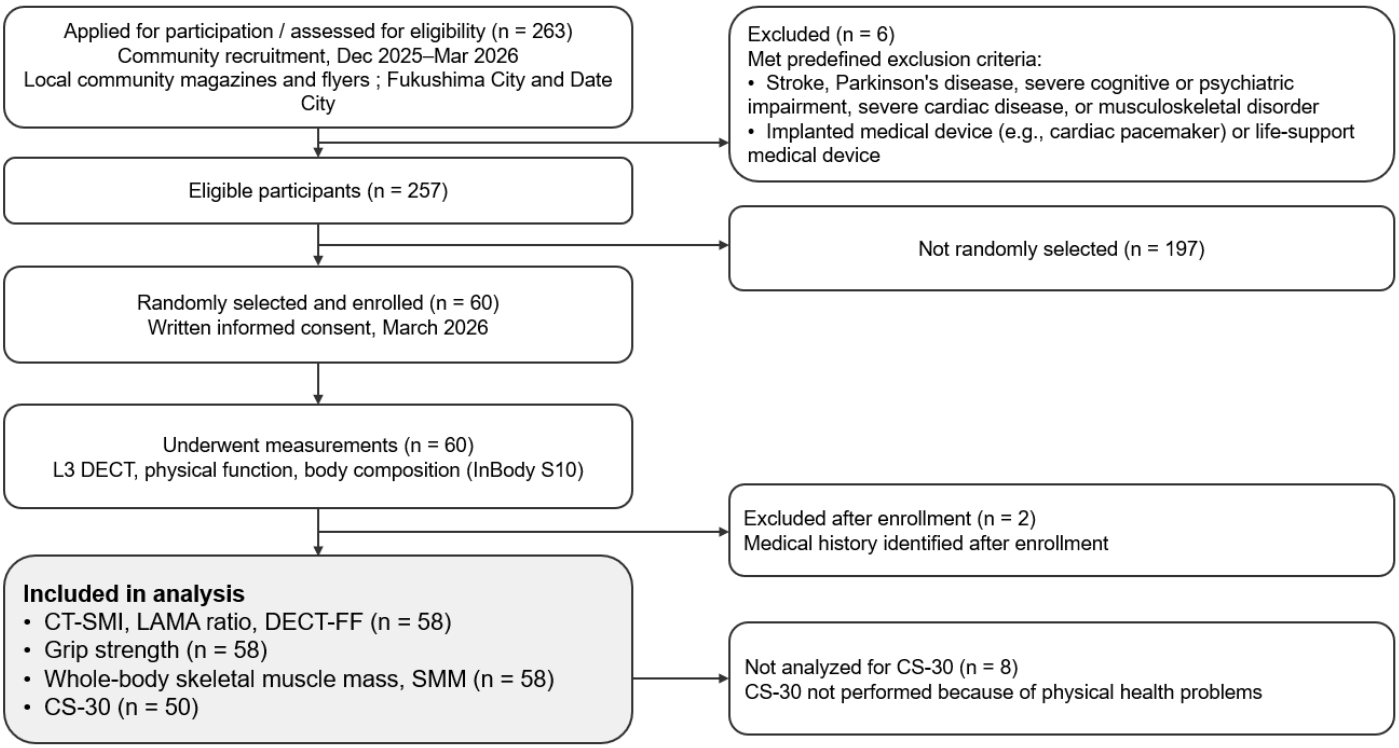


Figure 1

Participant recruitment and enrollment flow.

Flow of community-dwelling older adults through recruitment, eligibility screening, random selection, enrollment, and analysis. Participants were recruited from Fukushima City and Date City, Fukushima, Japan, between December 2025 and March 2026 using local community magazines and flyers. Of 263 applicants, six met the predefined exclusion criteria (stroke, Parkinson’s disease, severe cognitive or psychiatric impairment, severe cardiac disease, musculoskeletal disorders, or an implanted medical device such as a cardiac pacemaker or a life-support medical device such as a physiological monitor). Of 257 eligible individuals, 60 were randomly selected and enrolled after providing written informed consent. All 60 participants underwent L3-level dual-energy CT, physical function assessment, and body composition measurement (InBody S10). Two participants were subsequently excluded from the analysis because of their medical histories, leaving 58 participants. Eight participants could not perform the 30-second chair-stand test (CS-30) because of physical health problems; therefore, CS-30 analyses included 50 participants, whereas analyses of the other indices included all 58 participants.

Figure 2

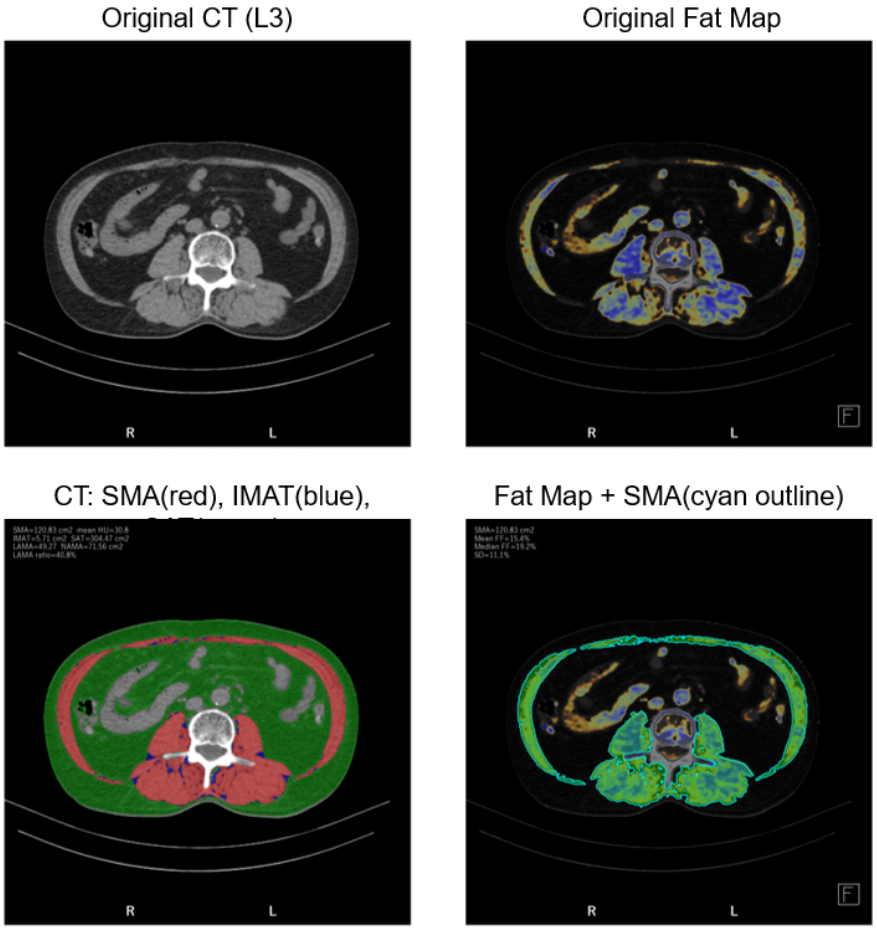


Figure 2

Representative dual-energy computed tomography image at the third lumbar vertebra level with semi-automated skeletal muscle segmentation.

Cross-sectional dual-energy CT (DECT) image at the inferior endplate of the L3 vertebra illustrating semi-automated tissue segmentation. Skeletal muscle area (SMA) was defined as pixels with Hounsfield unit (HU) values from −29 to +150 HU. Within the SMA, low-attenuation muscle area (LAMA; −29 to +29 HU) was used as a proxy for myosteatosis. The DECT-derived fat fraction (DECT-FF) was obtained from a fat fraction map generated using a three-material decomposition algorithm and averaged over the same SMA region, providing pixel-wise quantification of intramuscular fat. SAT, subcutaneous adipose tissue; IMAT, intermuscular adipose tissue; NAMA, normal-attenuation muscle area (30–150 HU).

Figure 3

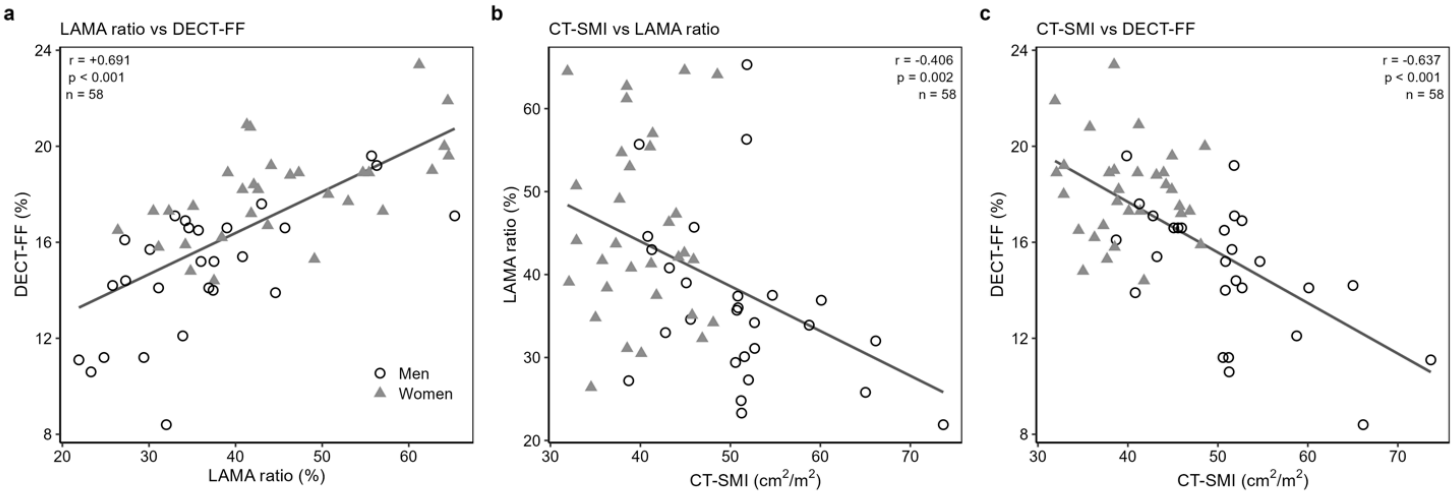


Figure 3

Convergent validity of dual muscle quality indices and their relationships with skeletal muscle quantity.

Scatter plots showing pairwise relationships among CT body composition indices. (a) Positive correlation between the LAMA ratio and DECT-FF, supporting the convergent validity of the two quality metrics derived using different measurement principles ($r = 0.691$, $p < 0.001$, $n = 58$). (b) Inverse correlation between CT-SMI and the LAMA ratio ($r = -0.406$, $p = 0.002$, $n = 58$). (c) Inverse correlation between CT-SMI and DECT-FF ($r = -0.637$, $p < 0.001$, $n = 58$). The correlations in panels (b) and (c) indicate that both quality indices provide information that is partly distinct from muscle quantity. In all panels, open circles represent men, triangles represent women, and the gray line represents the linear regression fit. CT-SMI, computed tomography skeletal muscle index; LAMA, low-attenuation muscle area; DECT-FF, dual-energy computed tomography fat fraction.

Figure 4

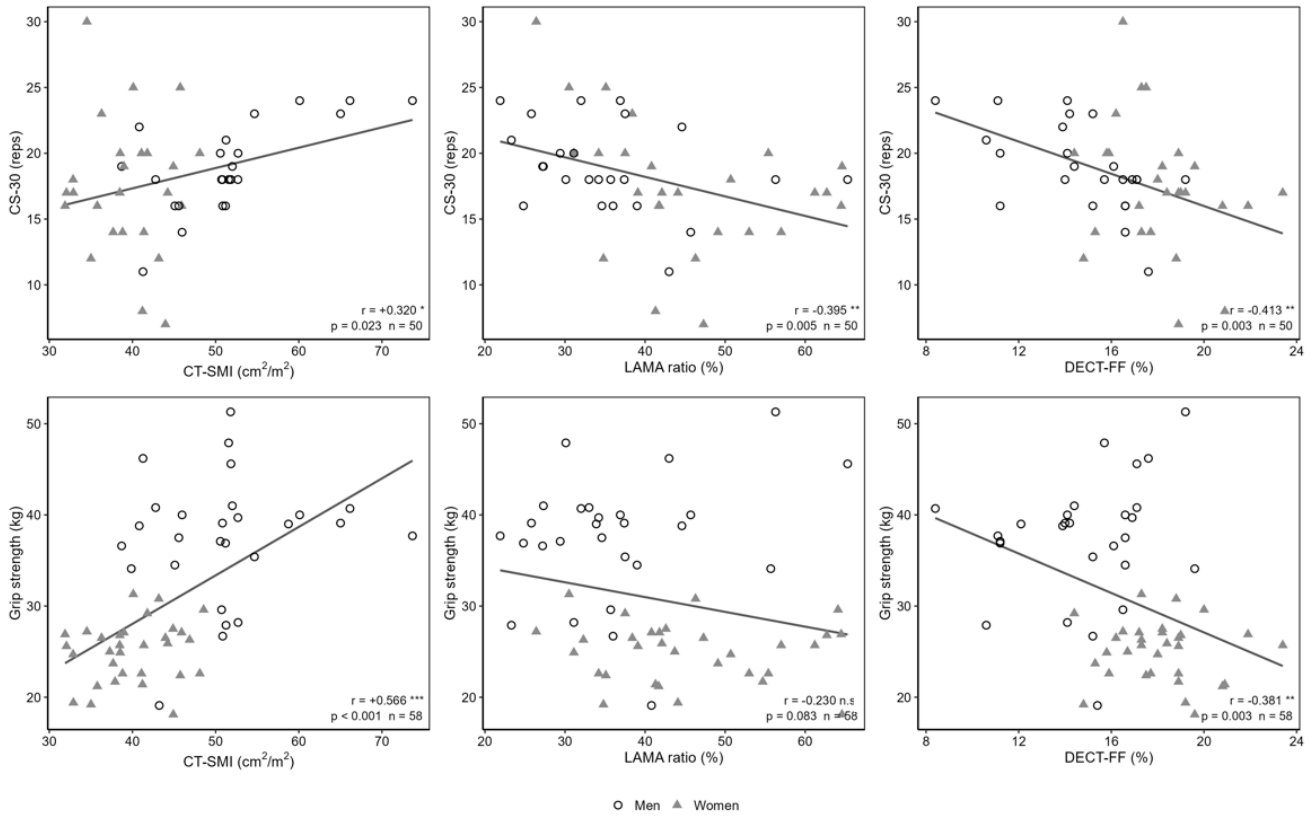


Figure 4

Unadjusted associations between CT body composition indices and physical performance outcomes.

A 2 × 3 matrix of scatter plots showing unadjusted associations between two physical performance measures (rows: CS-30, n = 50; grip strength, n = 58) and three CT body composition indices (columns: CT-SMI, LAMA ratio, and DECT-FF). Pearson's r and significance levels are shown in each panel (*** p < 0.001, ** p < 0.01, * p < 0.05; n.s., not significant). CT-SMI was positively associated with both outcomes (CS-30, r = 0.320, p = 0.023; grip strength, r = 0.566, p < 0.001). The LAMA ratio was inversely associated with CS-30 (r = −0.395, p = 0.005) but not grip strength (r = −0.230, p = 0.083). DECT-FF was inversely associated with CS-30 (r = −0.413, p = 0.003) and grip strength (r = −0.381, p = 0.003). Open circles represent men, triangles represent women, and the gray line represents the linear regression fit. CS-30, 30-second chair-stand test; CT-SMI, computed tomography skeletal muscle index; LAMA, low-attenuation muscle area; DECT-FF, dual-energy computed tomography fat fraction.

Figure 5

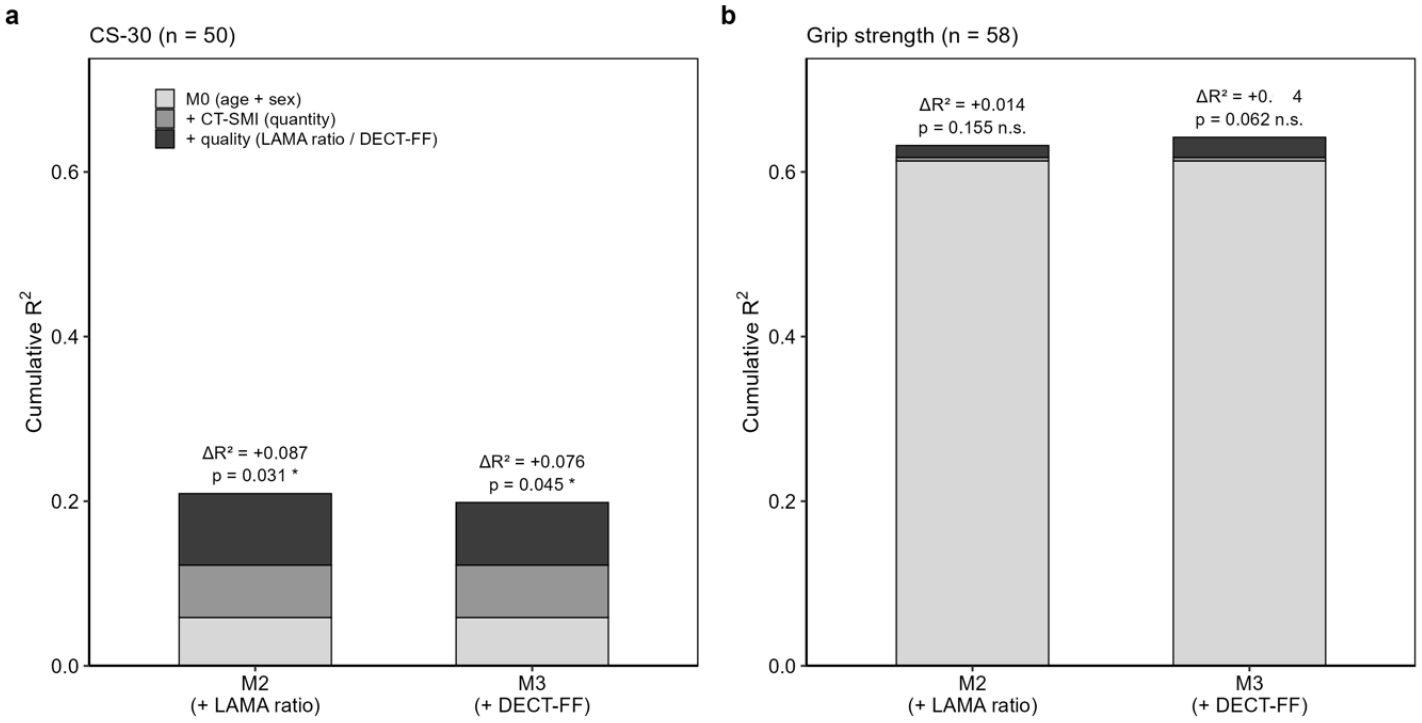


Figure 5

Incremental explained variance (ΔR²) of muscle quality indices in hierarchical multiple regression for physical performance.

Stacked bar charts show cumulative R² for two physical performance outcomes: CS-30 (a; n = 50) and grip strength (b; n = 58). For each outcome, two extended models are shown: M2 (M1 + LAMA ratio) and M3 (M1 + DECT-FF), where M1 includes age, sex, and CT-SMI. Bar segments represent R² attributable to the base model (M0: age + sex; light gray), the increment for CT-SMI (medium gray), and the increment for the muscle quality index (dark gray). Statistical significance of the muscle quality index ΔR² is shown above each bar (* p < 0.05). For CS-30, both M2 (ΔR² = 0.087, p = 0.031) and M3 (ΔR² = 0.076, p = 0.045) explained significant additional variance beyond CT-SMI. For grip strength, neither quality index explained significant additional variance (M2, ΔR² = 0.014, p = 0.155; M3, ΔR² = 0.024, p = 0.062). CS-30, 30-second chair-stand test; CT-SMI, computed tomography skeletal muscle index; LAMA, low-attenuation muscle area; DECT-FF, dual-energy computed tomography fat fraction.

Figure 6

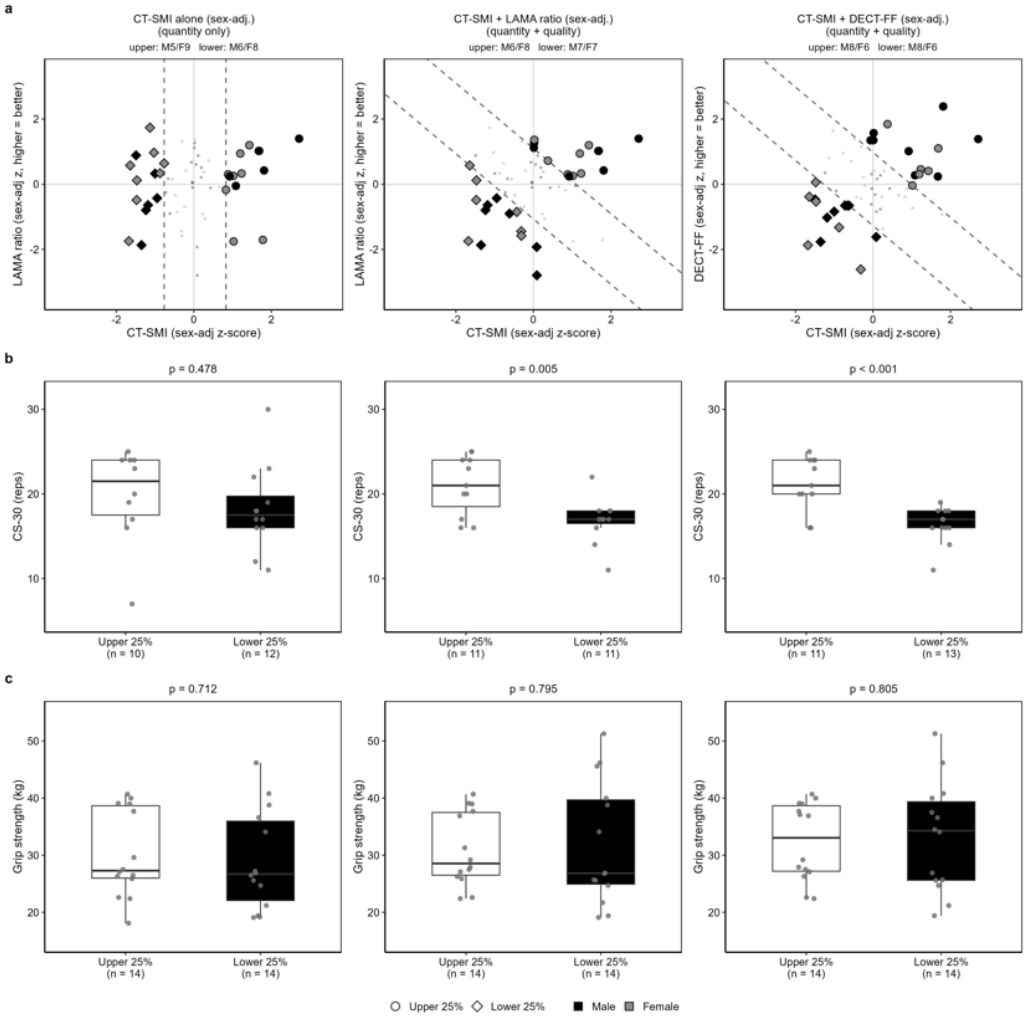


Figure 6

Sex-adjusted composite scores of muscle quantity and quality and physical performance (upper vs. lower quartiles).

CT-SMI, the LAMA ratio, and DECT-FF were standardized as z scores within each sex to account for sex-related differences. Composite scores were calculated as (i) quantity alone (CT-SMI), (ii) quantity plus quality (CT-SMI + LAMA ratio), and (iii) quantity plus quality (CT-SMI + DECT-FF). For each score, the upper and lower quartiles were compared, and the middle 50% was excluded. (a) Scatter plots of sex-adjusted CT-SMI (x-axis, z score) against the sign-inverted z score of the LAMA ratio or DECT-FF (y-axis), oriented so that higher values indicate more favorable muscle quality; fill color indicates sex (black, men; gray, women), and symbol shape indicates group (circle, upper quartile; diamond, lower quartile; small dot, middle 50%). (b) CS-30 and (c) grip strength were compared between the upper and lower quartiles using Welch's two-sample t test. CS-30 performance did not differ between quartiles of the quantity-only score ($p = 0.478$) but differed between quartiles of the quantity-plus-quality scores (CT-SMI + LAMA ratio, $p = 0.005$; CT-SMI + DECT-FF, $p < 0.001$). Grip strength did not differ between quartiles for any score ($p = 0.712–0.805$). Quartiles were defined using the full cohort (n = 58; 14 participants per quartile). Because eight participants could not perform the CS-30, the number analyzed in panel (b) was smaller (n = 10–13

per group); panel (c) included all 14 participants per group. CT-SMI, computed tomography skeletal muscle index; LAMA, low-attenuation muscle area; DECT-FF, dual-energy computed tomography fat fraction; CS-30, 30-second chair-stand test.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryFigure20260907.pdf
- Tables.docx