

Trunk Muscle Quantity, Quality, and Two-Year Recovery in Older Women After Sagittal Adult Spinal Deformity Surgery

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Abstract

Purpose

To determine whether dual-energy X-ray absorptiometry (DXA)-derived trunk lean mass corresponds to computed tomography (CT)-based local muscle size and attenuation, and to describe 2-year recovery after surgery for sagittal adult spinal deformity (ASD).

Methods

This single-center cohort study included 121 women aged 60 years or older with sagittal ASD and no major coronal curve. Ninety-two had analyzable preoperative L3 CT and paired DXA data. CT cross-sectional area (CSA) represented local muscle quantity and CT attenuation represented local radiodensity. Associations between DXA trunk lean mass and five prespecified CT metrics were tested with false-discovery-rate correction. Radiographic, physical-performance, and disability outcomes were assessed preoperatively and at 2 years.

Results

DXA trunk lean mass correlated with psoas CSA ($r = 0.49$; adjusted $p = 0.005$) but not with multifidus CSA or attenuation of the multifidus, erector spinae, or psoas. Sagittal alignment improved substantially. Stride length, one-leg standing, stand-up performance, and Locomo-25 improved, whereas gait speed, grip strength, and two-step outcomes did not. Oswestry Disability Index and Roland-Morris Disability Questionnaire scores improved in 91 matched patients.

Conclusion

DXA trunk lean mass and CT attenuation provide complementary rather than interchangeable information. Two-year recovery after sagittal ASD correction was clinically meaningful but domain specific. Multimodal muscle assessment may help characterize preoperative muscle phenotype, although prognostic use requires prospective validation.

Introduction

Adult spinal deformity (ASD) in older adults is associated with pain, impaired mobility, locomotive dysfunction, and loss of independence. Corrective surgery can substantially improve sagittal alignment and patient-reported disability, but recovery of objective physical performance is variable and may lag behind radiographic correction [1–6]. Identifying clinically interpretable measures of muscle reserve is therefore relevant to perioperative assessment and rehabilitation planning.

Paraspinal and psoas degeneration are common in ASD and have been associated with malalignment, surgical complexity, and early postoperative mobility [7–10]. However, a recent systematic review found marked heterogeneity in imaging-based muscle metrics and no definitive association with patient-reported outcomes, underscoring the need for standardized measurement and cautious interpretation [11]. One source of heterogeneity is that distinct modalities are often grouped under the broad label of “muscle mass.”

DXA-derived trunk lean mass estimates regional lean soft tissue quantity. CT CSA quantifies the local anatomical size of a selected muscle, whereas CT attenuation is the mean radiodensity within that region and is commonly used as a proxy for muscle composition and fatty infiltration [12–14]. These measures are biologically related but not equivalent. Their same-patient relationship has been incompletely characterized in a phenotype-homogeneous surgical ASD cohort.

We therefore examined older women with predominantly sagittal ASD after excluding major coronal deformity. The primary objective was to determine whether DXA-derived trunk lean mass corresponded to CT-based local muscle quantity and quality. The secondary objective was to describe 2-year changes in sagittal alignment, physical performance, and disability. We hypothesized that DXA trunk lean mass would correlate more strongly with CT CSA than with CT attenuation.

Methods

Study design and participants

This single-center cohort study retrospectively analyzed prospectively maintained clinical, radiographic, body-composition, CT, and physical-performance data from consecutive women who underwent corrective surgery for ASD between 2016 and 2022. The source cohort comprised 121 women aged 60 years or older with a minimum 2-year follow-up. Sagittal ASD was defined by at least one of the following institutional radiographic criteria: C7 sagittal vertical axis (SVA) > 50 mm, pelvic tilt (PT) > 30°, or pelvic incidence minus lumbar lordosis (PI-LL) mismatch > 10°. Patients with a major coronal curve (Cobb angle > 30°) were excluded; consequently, the source cohort corresponded to Scoliosis Research Society-Schwab coronal type N [15].

Among the 121 eligible patients, 92 had preoperative CT images suitable for standardized L3 muscle analysis and evaluable whole-body DXA and constituted the imaging analytic cohort. Outcome analyses used complete paired observations for each measure, without imputation. The study was approved by the Institutional Review Board of [institution blinded for review] (approval No. 1181), and all participants provided written informed consent. The study followed the Declaration of Helsinki and STROBE reporting recommendations.

Surgical treatment and rehabilitation

The standard correction strategy included lateral interbody fusion from L2-L3 through L4-L5, posterior interbody fusion at L5-S1, and long posterior fixation with pelvic anchors. Cantilever correction and, when required, osteotomy were selected according to deformity rigidity and the anatomical spinal osteotomy classification [16]. The upper instrumented vertebra (UIV) was selected by the treating surgeons after considering deformity extent, thoracic kyphosis, junctional anatomy, curve flexibility, bone quality, and the need to avoid a structurally compromised vertebra. Postoperative rehabilitation followed the institutional pathway but was individualized according to neurological status, pain, frailty, and postoperative course.

DXA and CT assessment of trunk muscles

Whole-body DXA was performed using a QDR-DELPHI/DPX-NT system (Hologic, Waltham, MA, USA). The value labeled “trunk muscle mass” in the source database was the DXA-derived trunk lean soft tissue mass (g). Because DXA cannot isolate skeletal muscle from all other lean soft tissues within the trunk region, this variable is termed trunk lean mass throughout the present report.

Preoperative CT was acquired with an eight-slice multidetector scanner (LightSpeed Ultra; GE Healthcare, Milwaukee, WI, USA; section thickness 0.83 mm). At the superior endplate level of L3, bilateral regions of interest were manually traced along the fascial boundaries of the multifidus, erector spinae, and psoas major muscles (Fig. 1). CT CSA, expressed in mm², represented local muscle size and was available for the multifidus and psoas major. CT attenuation, expressed in Hounsfield units (HU), was calculated as the mean voxel value within the region of interest and represented muscle radiodensity; lower values generally indicate greater fatty infiltration, although acquisition settings influence HU [13, 14]. Bilateral values were averaged. Two orthopedic surgeons blinded to clinical outcomes performed the measurements independently, and their mean value was used. Figure 2 summarizes the conceptual distinction among DXA trunk lean mass, CT CSA, and CT attenuation.

Standardized 2-year postoperative CT was not routinely obtained. Therefore, the present analysis was intentionally restricted to preoperative muscle phenotype and did not evaluate postoperative muscle remodeling.

Radiographic, physical-performance, and disability outcomes

Full-length standing anteroposterior and lateral radiographs were obtained preoperatively and at 2 years. Two board-certified spine surgeons independently measured PT, sacral slope (SS), lumbar lordosis (LL), PI-LL mismatch, SVA, T5-T12 thoracic kyphosis (TK), global tilt (GT), and T1 pelvic angle (TPA); observer means were used.

Physical performance was assessed preoperatively and at 2 years. Comfortable gait speed and stride length were calculated during a 10-m walk. Handgrip strength was measured bilaterally and averaged. One-leg standing time with eyes open was measured twice per side and averaged. The stand-up test was

scored from 0 to 8, with higher scores indicating better performance. The two-step test recorded maximal two-stride distance and the height-normalized two-step value. Locomotive dysfunction was assessed with the 25-question Geriatric Locomotive Function Scale (Locomo-25), for which lower scores indicate less disability [17, 18]. The Oswestry Disability Index (ODI) and Roland-Morris Disability Questionnaire (RDQ) were available as paired preoperative and 2-year measurements in 91 patients and were treated as exploratory patient-reported outcomes [19, 20].

Statistical analysis

Continuous variables are presented as mean $\pm$ standard deviation and categorical variables as number (percentage). Preoperative and 2-year paired measurements were compared with the Wilcoxon signed-rank test because several outcomes were non-normally distributed or ordinal. The primary cross-modality analysis used Pearson correlation coefficients to examine the association of DXA trunk lean mass with five CT metrics: multifidus CSA, multifidus attenuation, erector spinae attenuation, psoas CSA, and psoas attenuation. To limit false-positive findings across these five comparisons, p values were adjusted with the Benjamini-Hochberg false discovery rate procedure. Two-sided adjusted $p < 0.05$ was considered statistically significant. Secondary outcome comparisons and ODI/RDQ analyses were descriptive and exploratory. No missing values were imputed. Analyses were performed with Prism 9.0 (GraphPad Software, San Diego, CA, USA).

Use of generative AI

OpenAI ChatGPT was used to assist with English-language editing, manuscript organization, and formatting. The authors critically reviewed and revised all output, verified the scientific content and references, and take full responsibility for the submitted work.

Results

Cohort characteristics

The source cohort included 121 women with sagittal ASD and no major coronal curve; all were SRS-Schwab coronal type N. The UIV was T8 or above in 36 patients (29.8%) and T9-T11 in 85 (70.2%). The 92-patient imaging cohort had a mean age of 72.7 ± 5.4 years and body mass index of 22.7 ± 3.7 kg/m². Mean DXA trunk lean mass was $16,584.8 \pm 2,064.7$ g (Table 1).

Table 1

Cohort characteristics and baseline muscle measures. Values are mean $\pm$ standard deviation unless otherwise specified. ASD, adult spinal deformity; CSA, cross-sectional area; CT, computed tomography; DXA, dual-energy X-ray absorptiometry; HU, Hounsfield unit; UIV, upper instrumented vertebra; YAM, young adult mean

Variable	Value
Source surgical cohort	
Women, n	121
SRS-Schwab coronal type N, n (%)	121 (100)
UIV T8 or above, n (%)	36 (29.8)
UIV T9-T11, n (%)	85 (70.2)
Imaging analytic cohort	
Age, years	72.7 $\pm$ 5.4 (n = 92)
Body mass index, kg/m ²	22.7 $\pm$ 3.7 (n = 92)
Bone mineral density, %YAM	74.2 $\pm$ 11.4 (n = 92)
DXA-derived trunk lean mass, g	16,584.8 $\pm$ 2,064.7 (n = 92)
Multifidus CSA, mm ²	215.4 $\pm$ 70.5 (n = 92)
Multifidus attenuation, HU	18.6 $\pm$ 21.2 (n = 92)
Erector spinae attenuation, HU	11.8 $\pm$ 25.4 (n = 92)
Psoas major CSA, mm ²	312.1 $\pm$ 102.7 (n = 92)
Psoas major attenuation, HU	44.9 $\pm$ 6.4 (n = 92)

Two-year radiographic and clinical recovery

All sagittal radiographic parameters improved at 2 years (Table 2). PT decreased from 40.2° $\pm$ 12.1° to 13.7° $\pm$ 9.0°, PI-LL improved from 48.7° $\pm$ 21.0° to -8.6° $\pm$ 10.5°, and SVA decreased from 138.2 $\pm$ 73.5 mm to 16.8 $\pm$ 28.8 mm (all p < 0.001). Physical recovery was domain specific: stride length, one-leg standing time, stand-up score, and Locomo-25 improved, whereas gait speed, handgrip strength, two-step distance, and two-step value did not change significantly. In the 91-patient exploratory subset, ODI and RDQ also improved (Table 2).

Table 2

Preoperative and 2-year postoperative outcomes. Values are mean $\pm$ standard deviation. P values are from the Wilcoxon signed-rank test. Higher stand-up scores indicate better performance; lower Locomo-25 scores indicate less locomotive dysfunction. GT, global tilt; LL, lumbar lordosis; ODI, Oswestry Disability Index; PI, pelvic incidence; PT, pelvic tilt; RDQ, Roland-Morris Disability Questionnaire; SS, sacral slope; SVA, sagittal vertical axis; TK, T5-T12 thoracic kyphosis; TPA, T1 pelvic angle

Variable	Preoperative	2-year postoperative	Paired n	P value
Radiographic outcomes				
PT, °	40.2 $\pm$ 12.1	13.7 $\pm$ 9.0	121	< 0.001
SS, °	11.4 $\pm$ 14.4	34.5 $\pm$ 8.9	121	< 0.001
LL, °	2.0 $\pm$ 25.9	57.4 $\pm$ 11.0	121	< 0.001
PI-LL, °	48.7 $\pm$ 21.0	-8.6 $\pm$ 10.5	121	< 0.001
SVA, mm	138.2 $\pm$ 73.5	16.8 $\pm$ 28.8	121	< 0.001
TK, °	23.2 $\pm$ 11.9	39.8 $\pm$ 12.1	121	< 0.001
GT, °	57.3 $\pm$ 17.6	13.6 $\pm$ 8.8	121	< 0.001
TPA, °	47.1 $\pm$ 16.5	10.7 $\pm$ 8.3	121	< 0.001
Physical performance				
Gait speed, m/s	1.01 $\pm$ 0.32	1.07 $\pm$ 0.25	91	0.065
Gait stride, m	0.51 $\pm$ 0.13	0.55 $\pm$ 0.11	90	0.026
One-leg standing, s	17.7 $\pm$ 16.7	22.4 $\pm$ 23.0	91	0.048
Handgrip strength, kg	18.3 $\pm$ 4.3	17.9 $\pm$ 4.0	91	0.514
Stand-up test, points	1.6 $\pm$ 1.2	2.8 $\pm$ 1.6	91	0.002
Two-step distance, cm	145.5 $\pm$ 51.8	152.8 $\pm$ 36.5	91	0.375
Two-step value	0.99 $\pm$ 0.35	1.04 $\pm$ 0.25	91	0.395
Locomo-25 score	43.6 $\pm$ 20.1	30.2 $\pm$ 18.6	91	< 0.001
Patient-reported disability				
ODI score	18.6 $\pm$ 6.2	9.1 $\pm$ 5.7	91	0.008
ODI, %	37.1 $\pm$ 12.5	18.2 $\pm$ 11.3	91	0.008
RDQ	12.3 $\pm$ 4.4	7.3 $\pm$ 5.0	91	0.031

Relationship between DXA and CT muscle metrics

DXA trunk lean mass correlated with psoas CSA ($r = 0.49$; unadjusted $p = 0.001$; false-discovery-rate-adjusted $p = 0.005$). It was not significantly associated with multifidus CSA or CT attenuation of the multifidus, erector spinae, or psoas (Table 3). Thus, the only robust cross-modality association was between a regional DXA quantity measure and local psoas size; no attenuation measure was interchangeable with DXA trunk lean mass.

Table 3

Association of DXA-derived trunk lean mass with CT muscle measures. Pearson correlation coefficients are shown. False-discovery-rate-adjusted P values were calculated with the Benjamini-Hochberg procedure across the five prespecified comparisons. CSA, cross-sectional area; CT, computed tomography; DXA, dual-energy X-ray absorptiometry; FDR, false discovery rate

CT measure	Construct	n	r	Unadjusted P	FDR-adjusted P
Multifidus CSA	Local quantity	92	0.28	0.082	0.205
Multifidus attenuation	Local quality	92	0.05	0.780	0.965
Erector spinae attenuation	Local quality	92	-0.09	0.587	0.965
Psoas major CSA	Local quantity	92	0.49	0.001	0.005
Psoas major attenuation	Local quality	92	0.01	0.965	0.965

Discussion

This study reframes preoperative trunk muscle imaging as a measurement-interpretation problem rather than as a standalone prediction model. In a sagittal-only ASD cohort, DXA trunk lean mass was related to psoas size but not to CT attenuation. Meanwhile, 2-year recovery was heterogeneous: alignment, stride, balance, stand-up performance, Locomo-25, and exploratory disability scores improved, whereas gait speed, grip strength, and two-step performance did not. These findings support three practical conclusions: muscle quantity and quality should be reported separately; a global DXA value cannot substitute for local CT composition; and direct functional assessment remains necessary even after successful radiographic correction.

The distinction among the three measures is clinically important. DXA estimates lean soft tissue over a broad trunk region and therefore reflects regional quantity but is not muscle specific. CT CSA isolates a selected muscle and quantifies its local size. CT attenuation describes radiodensity within that muscle and is sensitive to intramuscular fat and acquisition conditions. The association between DXA trunk lean mass and psoas CSA is consistent with prior work showing that DXA-derived trunk lean mass can reflect selected trunk-muscle size [12]. The lack of association with attenuation is also biologically plausible: a muscle may be large but contain substantial fatty infiltration, or small yet remain relatively radiodense.

The psoas association may also reflect technical and anatomical factors. The psoas has a well-defined fascial boundary at L3 and is less affected than posterior muscles by degenerative architectural distortion. By contrast, multifidus size can be influenced by segmental degeneration, disuse, and

boundary ambiguity. This does not mean that psoas CSA is a complete marker of trunk function. Recent studies have linked normalized psoas area to early mobility and perioperative events, while multicenter work has associated paraspinal degeneration with surgical outcomes [10, 21]. The broader literature remains heterogeneous, particularly for longer-term patient-reported outcomes [11].

The phenotype restriction is another strength. Coronal-dominant and sagittal-dominant ASD differ in compensatory strategies, muscle loading, and operative correction. By excluding major coronal curves and analyzing an SRS-Schwab type N cohort, we reduced one important source of radiographic heterogeneity. The findings should therefore be interpreted as applying to older women with sagittal imbalance rather than to all forms of ASD.

Radiographic correction did not produce uniform recovery across clinical domains. Improved stride, single-leg balance, stand-up performance, and Locomo-25 suggest gains in mobility and lower-extremity function, whereas unchanged gait speed, grip strength, and two-step outcomes indicate residual limitations. ASD patients use trunk, pelvic, and lower-limb compensation to maintain posture, and these demands change after correction [22–24]. A practical preoperative assessment should therefore combine imaging phenotype with direct testing of gait, balance, strength, and disability. CT or DXA alone should not be used to determine prognosis.

We did not have standardized 2-year CT, so we cannot determine whether extensive fusion caused postoperative paraspinal atrophy, fatty change, or psoas remodeling. Prior studies have demonstrated postoperative muscle changes after lumbar fusion, and metal artifact can impair quantitative CT assessment around long constructs [25]. Prospective studies with harmonized follow-up imaging, standardized rehabilitation exposure, and predefined functional outcomes are needed to evaluate whether changes in muscle phenotype mediate recovery.

Several limitations warrant emphasis. First, the imaging cohort comprised 92 of 121 eligible patients, and complete-case analysis may introduce selection bias. Second, ODI/RDQ data were available for 91 patients and were exploratory. Third, the cohort was restricted to older women at one center, limiting generalizability. Fourth, rehabilitation was not standardized, and SRS-22, Spinal Appearance Questionnaire, trunk endurance, and direct lower-limb strength measurements were unavailable. Fifth, CT attenuation is protocol dependent, CSA was not normalized to body size, and reliability coefficients were not available for the present secondary analysis. Finally, postoperative imaging was unavailable. These limitations are balanced by a phenotype-homogeneous cohort, same-patient comparison of conceptually distinct muscle measures, transparent outcome-specific denominators, false-discovery-rate control, and 2-year objective follow-up.

Conclusion

In older women undergoing correction of sagittal ASD, DXA-derived trunk lean mass correlated with CT-measured psoas size but not with CT muscle attenuation. Quantity and quality metrics are therefore complementary rather than interchangeable. Two-year recovery was clinically meaningful but domain

specific. Multimodal muscle assessment may help characterize preoperative muscle phenotype, but prospective studies with standardized postoperative imaging and rehabilitation are required before these measures are used for prognosis.

Declarations

Author Contribution

Conceptualization: T.O. and H.H.; methodology: T.E. and G.G.; validation: K.O., and T.O.; formal analysis: T.O. and T.E.; investigation: H.H.; writing - original draft: T.O.; writing - review and editing: N.T. and T.O. All authors approved the final manuscript and agree to be accountable for the work.

Acknowledgement

None

Data Availability

De-identified data supporting the findings are available from the corresponding author upon reasonable request, subject to institutional review board approval and applicable privacy requirements.

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Figures

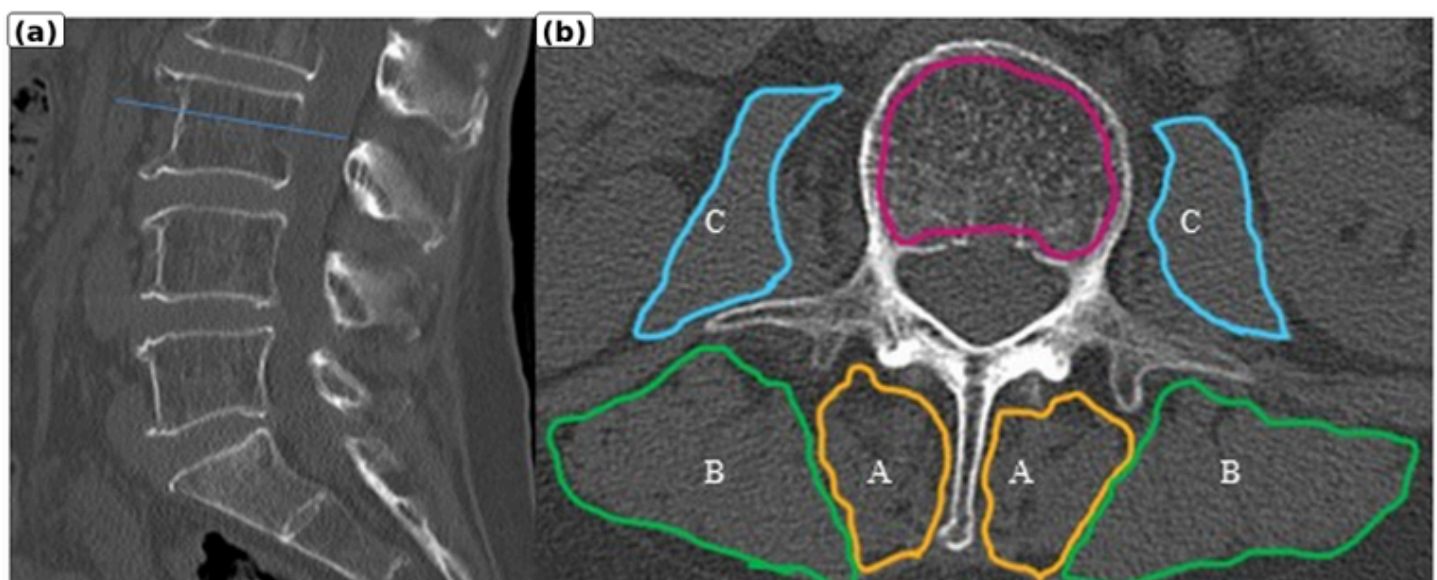


Figure 1

CT measurement protocol. (a) Sagittal CT image showing the measurement level at the superior endplate of L3. (b) Axial L3 image with manually traced regions of interest. A, multifidus; B, erector spinae; C, psoas major. CT cross-sectional area was the area enclosed by the region of interest; CT attenuation was the mean Hounsfield unit value within the region. Bilateral values were averaged

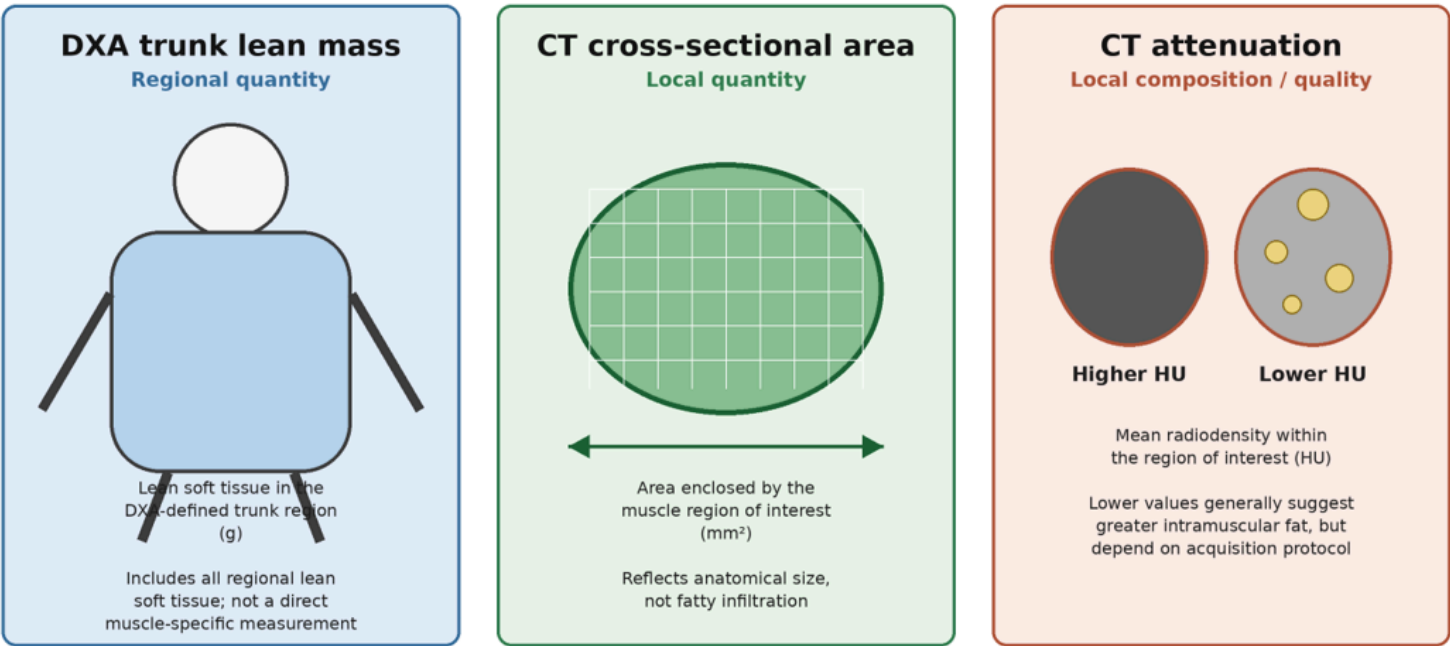


Figure 2

Conceptual distinction among DXA and CT muscle measures. DXA trunk lean mass is a regional lean-soft-tissue quantity measure. CT cross-sectional area is a local anatomical quantity measure. CT attenuation is a local radiodensity measure used as a proxy for muscle composition or quality. The measures are complementary and should not be interpreted interchangeably