A clinically practical approach for screening of low muscularity using electronic linear measures on computed tomography images in critically ill patients

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Abstract

Background: Computed tomography (CT) scans performed during routine hospital care offer the opportunity to quantify skeletal muscle and predict mortality and morbidity in intensive care unit (ICU) patients. Existing methods of muscle cross-sectional area (CSA) quantification require specialized software, training, and time commitment that may not be feasible in a clinical setting. Here, we explore a new screening method to identify patients with low muscle mass.

Methods: We analyzed 145 scans of elderly ICU patients (≥65 years old) using a combination of measures obtained with a digital ruler, commonly found on hospital radiological software. The psoas and paraspinal muscle groups at the level of the third lumbar vertebra (L3) were evaluated by using 2 linear measures each and compared with an established method of CT image analysis of total muscle CSA in the L3 region.

Results: There was a strong association between linear measures of psoas and paraspinal muscle groups and total L3 muscle CSA (R^2=0.745, p<0.001). Linear measures, age and sex were included as covariates in a multiple logistic regression to predict those with low muscle mass, ROC AUC of the combined psoas and paraspinal linear index model was 0.920. Intraclass correlation coefficients (ICC) were used to evaluate intra- and inter-rater reliability, resulting in a 0.979 [95% CI: 0.940-0.992] and 0.937 [95% CI: 0.828-0.978] score respectively.

Conclusions: A digital ruler can reliably predict L3 muscle CSA, and these linear measures may be used to identify critically ill patients with low muscularity, who are at risk of worse clinical outcomes.

Clinical Relevancy Statement

Computed tomography (CT) imaging has been used to quantify skeletal muscle and identify patients with lower than normal muscle mass in intensive care unit (ICU). The conventional method uses a single transverse CT image at the level of the 3rd lumbar vertebra (L3) to determine total muscle cross-sectional area (CSA), which strongly correlates to whole body muscle mass. However, this conventional method is time consuming, requires training and specialized software. As such, this approach is primarily used for research purposes and not clinical practice. Here, we demonstrate the use of a clinically practical approach for screening individuals with low muscularity using linear measures easily obtained from CT images.

Introduction

Patients who have lower than normal skeletal muscle mass at the time of admission into the intensive care unit (ICU) are at an increased risk of mortality[1,2]. Abdominal CT scans obtained during routine hospital care can be used to precisely and specifically measure muscle cross-sectional area (CSA) and determine if the patient falls below established cut-points predicting low muscle mass[3,4]. Current methods utilized in evaluating CT scans for body composition analysis are limited in their clinical use as they require a substantial amount of time (~15-30 min/scan), training and access to specialized software. Rather, targeted measures of specific muscle groups, that can be completed using standard radiological software, may provide an adequate alternative to screening and identifying patients with low muscle mass.

The psoas and paraspinal muscle groups constitute a substantial portion of total skeletal muscle CSA at the level of the 3rd lumbar vertebra (L3). Also, these muscle groups are functionally relevant, and implicated in weight-bearing activity as well as postural control. Low CSA of the psoas has previously been associated with both mortality and morbidity in elderly trauma patients[5–7] and, given the functional role of psoas muscles, atrophy or maintenance of this muscle group may be associated with patient independence following hospital discharge[8]. The erector spinae and multifidus muscles (referred to as paraspinals) may reflect increased time in bed if atrophied[9].

We evaluated the use of a digital ruler (readily available in most hospital radiological software) for linear measurements of the width and length of the psoas and paraspinal muscle groups in the L3 region. These linear measures were compared with muscle CSA measured using an established CT imaging analysis method[4]. We also assessed the capacity for this method to identify patients with lower than normal muscularity and we evaluated the reliability of the linear measures method.

Methods

Study design and patient selection

In this study we examined 149 CT scans acquired in older adult patients (≥65 years old) within 48 hours of admission into a trauma ICU. Additional details on this participant cohort have been presented elsewhere[1]. In the current study, we used these scans to develop the method for linear measures of the psoas and paraspinal muscle groups with the digital ruler. This study was approved by the Institutional Review Board of the University of Texas Health Science Center at Houston and the University of Waterloo Clinical Research Ethics Committee[1].

Skeletal Muscle Analysis using CT imaging

All CT image analyses were performed using sliceOmatic software (version 5.0, TomoVision, Montreal, QC, Canada). The L3 was identified and the total skeletal muscle CSA was measured in the conventional manner as previously described[1,4]. Muscle indices were calculated by dividing total L3 muscle CSA (cm^2) by height squared (m^2). Established cut-points for identifying patients with low muscle indices are: <55.4 cm^2/m^2 for males and <38.9 cm^2/m^2 for females[4].

Linear measures were executed on raw images of a predetermined scan, without any previous markings. A digital ruler was utilized to produce a length measurement corresponding to the widest and longest horizontal and vertical distances, respectively. These 2 measures, in mm, were obtained for each of the muscle groups examined (left and right psoas and paraspinal groups), resulting in a total of 8 measures per scan (Figure 1A). The distance measurement tool in sliceOmatic, or a similar feature in radiological picture archiving systems, determines the measures relative to the size of the patient on the scan (i.e. the length measurements are not affected by aspects such as image magnification or screen resolution). In order to minimize the inconsistencies between analysts, the orientation of each line remained in the horizontal or vertical direction as the scan appears on the screen (Figure 1B), irrespective of the orientation of the patients (i.e. on some scans the individuals did not appear evenly flat on their backs; Figure 1C showcases an example of an improper linear measures spatial orientation). The product of the horizontal and vertical measures was calculated for the left and right sides of each muscle group. The conventional measurement of total L3 CSA was then compared to the sum of the:

1) right and left psoas products,

2) right and left paraspinal products, as well as

3) the sum of 1) and 2).

A detailed step-by-step protocol is included as supplementary material.

Each of these muscle-specific products was divided by height squared (m^2) and termed the linear-based indices. These were then compared with the established L3 skeletal muscle indices (<55.4 cm^2/m^2 for males and <38.9cm^2/m^2 for females[4]). Reliability tests were randomly performed for 10% of scans. Inter-rater reliability was assessed by 2 independent analysts and intra-rater reliability was assessed by the same individual on 2 separate occasions more than one week apart.

Statistics

All statistics were performed using SPSS software (version 24.0, IBM, Armonk, NY, USA). Pearson correlation products and coefficients of determination were used to evaluate the association between the linear measures and muscle CSA obtained using established methods. Multiple logistic regression analysis and receiver operating characteristic (ROC) curves were used to evaluate the utility of linear measures in identifying patients with low muscle index. The multiple logistic regression included the linear-based indices, age, and sex as covariates, all 3 variables are significant predictors of low muscle index in this cohort. Intraclass correlation coefficients (ICC) and coefficient of variation (%CV) were used to assess reliability. For all analyses $p<0.05$ was identified for statistical significance.

Results

Of the 149 scans available, 4 scans were excluded because the border of the psoas muscle could not be definitively identified. Of 145 elderly ICU patients, 83 (57.2%) males, and 62 (42.8%) females. The median age was 79 years (IQR: 72-86 years), median body mass index (BMI) was 25.7 kg/m^2 (22.7-28.3 kg/m^2) (Table 1), and 73.1% of the patients had low muscularity. Using BMI alone, 10 (6.9%) patients were identified as underweight (<18.5 kg/m^2), and 82 (56.6%) were considered overweight or obese (>25.0 kg/m^2). Of these, 10 individuals (6.9%) were classified as sarcopenic obese (using the following criteria: BMI ≥30.0 kg/m^2 and muscle index <55.4 cm^2/m^2 for males or <38.9 cm^2/m^2 for females). The sum of right and left linear measures products for psoas corresponded to 2745.60 ±705.89 mm^2, and 7205.52 ±1654.97 mm^2 for the paraspinal muscles, in men. In women the mean product of psoas measures was 1997.97 ±460.71 mm^2, while the sum of right and left paraspinals products was 5780.49 ±1115.62 mm^2 (Table 2).

Combined products of the psoas and paraspinals are 9951.12 ±2125.83 mm^2 and 7778.47 ±1366.86 mm^2, in men and women respectively (Table 2).

The level of agreement between the linear products and total L3 CSA was assessed using Pearson correlations and coefficients of determination (Table 3). The linear product for psoas and paraspinals strongly associated with total L3 CSA (R^2=0.567, p<0.001, Figure 2A and R^2=0.651, p<0.001, Figure 2B, respectively). The combined psoas and paraspinals linear products relative to total L3 CSA yielded the best coefficient of determination (R^2=0.745, p<0.001, Figure 2C). To assess the ability of our linear measures method to identify patients who have low muscle index, we utilized logistic regression analysis and ROC curves. The ROC AUC produced by a combination of psoas linear-based index, age, and sex was 0.851 [95% CI: 0.783-0.920], while the paraspinal linear-based index with the same covariates was 0.895 [95% CI: 0.838-0.952]. The AUC of a model using combined psoas and paraspinals index, age and sex is 0.920 [95% CI: 0.873-0.968] (Figure 2D). ROC curves and AUC values for each of the linear-based indices without the covariates are shown in the supplementary material (Figure S1 and Table S1, respectively).

We evaluated both the intra- and inter-rater reliability associated with the linear measures (Table 2). Psoas intra-rater ICC was 0.924 [95% CI: 0.768-0.973], while inter-rater ICC was 0.917 [95% CI: 0.716-0.971].. The paraspinals linear product measurement were associated with a 0.994 [95% CI: 0.982-0.998] and 0.926 [95% CI: 0.787-0.974], intra- and inter-rater ICC respectively. When a combination of psoas and paraspinal linear products was evaluated intra-rater ICC was 0.979 [95% CI: 0.940-0.992] and CV was 1.6%. Inter-rater ICC for the combined psoas and paraspinals linear product was 0.937 [95% CI: 0.828-0.978] while the CV was 2.7%.

The conventional method of measuring total L3 skeletal muscle CSA resulted in 0.4% and 1.2% CV for intra- and inter-rater reliability, respectively.

Discussion

Skeletal muscle mass measures are important in ICU and other clinical populations for identification of individuals who may be at risk of poor clinical outcomes[1,2]. Here, we develop a new, expedient screening approach that may be used with most hospital radiological software to screen patients who have CT scans in their medical charts, and identify vulnerable patients and those who may be in an increased need of a rehabilitative or nutrition intervention. Linear measures of the psoas and paraspinal muscles in the L3 region strongly correlate with total L3 skeletal muscle CSA. Combined psoas and paraspinal linear measures, in combination with age and sex as covariates, generated a strong ROC AUC of 0.92 for identification of individuals with lower than normal muscularity. Although the current, conventional method of measuring muscle using CT images provides precise quantification of skeletal muscle CSA, the approach that we have presented may provide a practical screening tool to identify patients with low muscle mass.

Weight, BMI and bioelectrical impedance analysis are common and practical tools that have been used to screen, characterize, and track changes in body size or body composition in the assessment of nutritional status[10]. While these tools are practical, inexpensive and easy-to-use, they lack specificity for the measurement of skeletal muscle. Only 7% were identified as being underweight using BMI in this study, compared with the 73% who had lower than normal muscle based on total L3 skeletal muscle index using CT analysis. CT and MRI scans provide specific and accurate measures of regional and, in rare cases, whole body skeletal muscle mass;

but their utility has been limited in clinical practice because they require training, are expensive, and analysis is time-consuming. The linear measures method that we present provides the opportunity for a simple screening procedure to identify patients with lower than normal muscle mass.

The psoas and paraspinal muscle groups are involved in weight-bearing activity and postural control, respectively, and at the L3 level they constitute a large portion of total muscle CSA; thus, they are considered functionally important muscle groups. In older adult trauma patients, the CSA of the psoas muscle group, albeit at the L4 level, has been used to predict patient independence (and, in contrast, avoidance of assisted living accommodations) following hospital discharge[8]. Also, low psoas CSA in relation to L4 vertebra size is associated with an increased risk of complications during hospital stay[7]. Importantly, low muscularity as determined by measuring psoas CSA using abdominal CT scans recently emerged as a predictor of mortality in elderly trauma patients[5,6]. On the other hand, CSA of the paraspinal muscles, determined using MRI, is reported to decrease following prolonged bed rest in healthy adults[9]. While our work demonstrated that linear measures of the paraspinal muscles yielded less variability and a stronger correlation with total L3 muscle CSA compared with the psoas muscle group, the combined linear measures products of psoas and paraspinal muscles exhibited a stronger correlation and a greater ability to correctly identify patients with low skeletal muscle index values.

Recently, other researchers evaluating the use of practical strategies for measuring psoas area with a digital ruler on CT images obtained in cancer populations have reported mixed results[11,12]. The measurement of psoas area alone as a surrogate of whole body skeletal muscle depletion, and a predictor of adverse clinical outcomes, has been criticized[13]. In our cohort, psoas CSA measured using the conventional CT image analysis method constitutes 11.5 ±3.3% of the total L3 skeletal muscle CSA, whereas the erector spinae and multifidus muscles correspond to 31.2 ±5.6%. Therefore, linear measures of both the psoas and paraspinal muscle groups evaluate a more prominent portion of total L3 muscle CSA. This may perhaps explain why the combined linear measures product of the psoas and paraspinal muscle groups in our study was the strongest indicator of low skeletal muscle index values.

One limitation of the linear measures method is that it does not capture aspects related to muscle quality[3,14]. Muscle attenuation and intermuscular adipose tissue may confound the capability to accurately classify individuals with lower than normal muscle mass. Further research is necessary to establish the amount of error caused due to poor muscle quality. In addition, the generalizability of our findings beyond the cohort examined in this study is yet to be tested. Low muscle mass is an important feature of both cachexia and sarcopenia[15]. It is associated with adverse clinical outcomes in a number of diverse cohorts, including cancer, elderly trauma, and surgical patients[5,16,17]. Future work is needed to better understand the effectiveness of the linear measures method in predicting nutritional, functional and clinical outcomes. Despite these limitations, overall, this new approach may provide a clinically effective screening tool to identify patients who may require nutrition and rehabilitative interventions.

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Abbreviations

AUC – Area under the curve

BMI – Body mass index

CSA – Cross-sectional area

CT – Computed tomography

ICC – Intraclass correlation coefficient

ICU – Intensive care unit

IQR – Interquartile range

ISS – Injury severity scale

L3 – 3rd lumbar vertebra

L4 – 4th lumbar vertebra

MRI – Magnetic resonance imaging

ROC – Receiver operating characteristic

SD – Standard Deviation

95% CI – 95% confidence interval

%CV – Percent coefficient of variation

Supplementary Material

Supplementary detailed protocol, Figure S1, and Table S1 are available with the article online at http://journals.sagepub.com/home/pen.

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Figure Legends

Figure 1: Linear measures, horizontal and vertical, preformed on the right and left psoas and paraspinal muscle groups (A). An example of linear measures analysis preformed on a scan where the patient does not appear flat on their back (B), improper linear measures spatial orientation on the same scan (C).

Figure 2: The association between sums of (A) right and left psoas products, (B) right and left paraspinal products, (C) right and left psoas and paraspinal products, with respect to L3 CSA. The ROC curves (D) represent the discriminative ability of a logistic regression model of linear measures area and age, sex as covariates in predicting low muscle mass.

Table 1: Participant characteristics related to physical and clinical variables.

Participant Characteristics	All Patients (n=145)	Low Muscle Index (n=106)	Normal Muscularity (n=39)
Sex (#, % of the category)			
Males	83 (57.2%)	71 (67.0%)	12 (30.8%)
Females	62 (42.8%)	35 (33.0%)	27 (69.2%)
Age (Median, IQR)	79 years (72-86 years)	80 years (73-86 years)	75 years (68-83 years)
Body Mass Index (Median, IQR)	25.7 kg/m^2 (22.7-28.3 kg/m^2)	24.4 kg/m^2 (21.8 - 27.3 kg/m^2)	28.23 kg/m^2 (25.5-31.2 kg/m^2)
ISS Score (Median, IQR)	18 (14-26)	19.8 (14-29)	17 (13-22)
Mechanically Ventilated (#, % of the category)			
Yes	90 (62.1%)	70 (66.0%)	20 (51.3%)
No	55 (37.9%)	36 (33.0%)	19 (48.7%)
Mechanism of Injury (#, % of the category)			
Motor Vehicle Accident	76 (52.4%)	52 (49.1%)	24 (61.5%)
Fall	55 (37.9%)	44 (41.5%)	11 (28.2%)
Automobile-pedestrian	6 (4.1%)	3 (2.8%)	3 (7.7%)
Other	8 (5.5%)	7 (6.6%)	1 (2.6%)

ICU=Intensive care unit, IQR=Interquartile range, ISS=Injury Severity Scale.

Table 2: Summary of cross-sectional areas determined using the conventional CT image analysis method and linear measures products assessing the right and left psoas and paraspinal muscle groups at the L3 level.

	Men		**Women**	
	Mean	**SD**	**Mean**	**SD**
Skeletal Muscle CSA (cm^2)				
Psoas	16.35	4.93	12.08	4.53
Paraspinals	44.99	11.66	34.01	9.33
Total L3	144.43	31.18	103.62	19.51
Linear Measures Products (mm^2)				
Psoas	2745.6	705.89	1997.97	460.71
Paraspinals	7205.52	1654.97	5780.49	1115.62
Combined Psoas and Paraspinals	9951.12	2125.83	7778.46	1366.86

SD=Standard deviation, CSA=Cross-sectional area.

Table 3: Coefficient of determination of linear measures in relation with total muscle CSA at the L3 level and reliability of linear measures.

	Coefficient of Determination (vs. L3 CSA)		**Intra-rater reliability**		**Inter-rater Reliability**	
	R^2	**P-Value**	**ICC [95%CI]**	**%CV**	**ICC [95%CI]**	**%CV**
Psoas	0.567	P<0.001	0.924 [0.788-0.973]	4.4%	0.917 [0.764-0.971]	5.7%
Paraspinals	0.651	P<0.001	0.994 [0.982-0.998]	1.1%	0.926 [0.787-0.974]	3.8%
Combined Psoas and Paraspinals	0.745	P<0.001	0.979 [0.940-0.992]	1.6%	0.937 [0.826-0.978]	2.7%

CSA=Cross-sectional area, ICC=Intraclass correlation coefficient, %CV=Percent coefficient of variation, 95%CI=95% confidence interval.

Table 4: Multiple logistic regression predicting low muscle index based on linear-based indices, age and sex.

	Logistic Regression Formula	Odds Ratios [95% CI]				ROC AUC [95% CI]	ROC P-Value
		Constant	Sex (0 = Male, 1 = Female)	Age (years)	Linear Index (mm^2/m^2)		
Psoas	2.990-2.999*Sex+0.07*Age-0.007*Psoas	19.890	0.050 [0.015-0.166]	1.072 [1.007-1.141]	0.993 [0.990-0.996]	0.851 [0.783-0.920]	P<0.001
Paraspinals	6.274-3.453*Sex+0.09*Age-0.004*Paraspinals	530.562	0.032 [0.008-0.133]	1.094 [1.019-1.175]	0.996 [0.994-0.997]	0.895 [0.838-0.952]	P<0.001
Combined Psoas and Paraspinals	10.282-4.212*Sex+0.083*Age-0.004*Combined	292000.566	0.015 [0.003-0.079]	1.087 [1.008-1.172]	0.996 [0.994-0.997]	0.920 [0.873-0.968]	P<0.001

ROC=Receiver operating characteristic curve, AUC=Area under the curve, 95%CI=95% confidence interval.

Figure 1

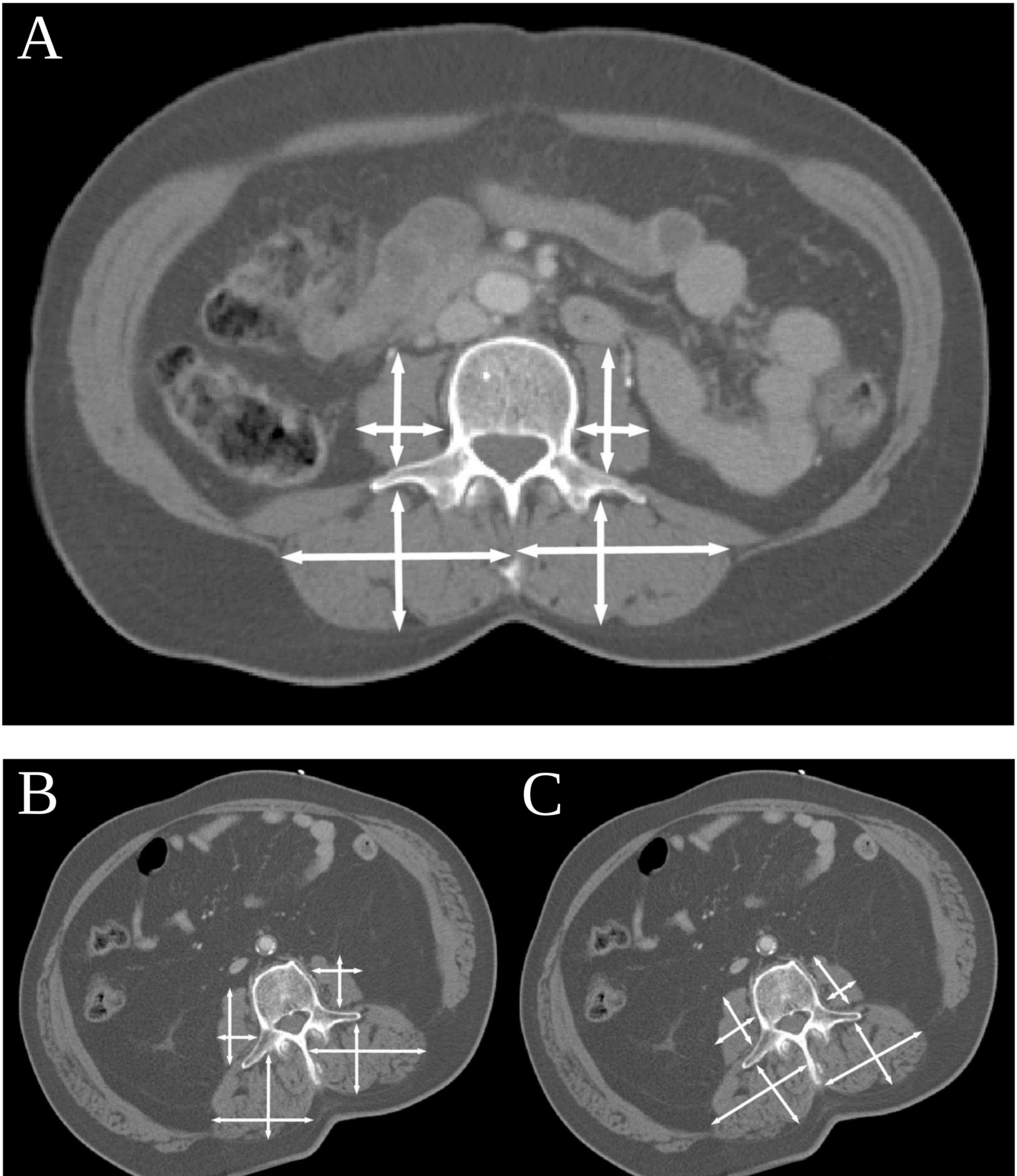
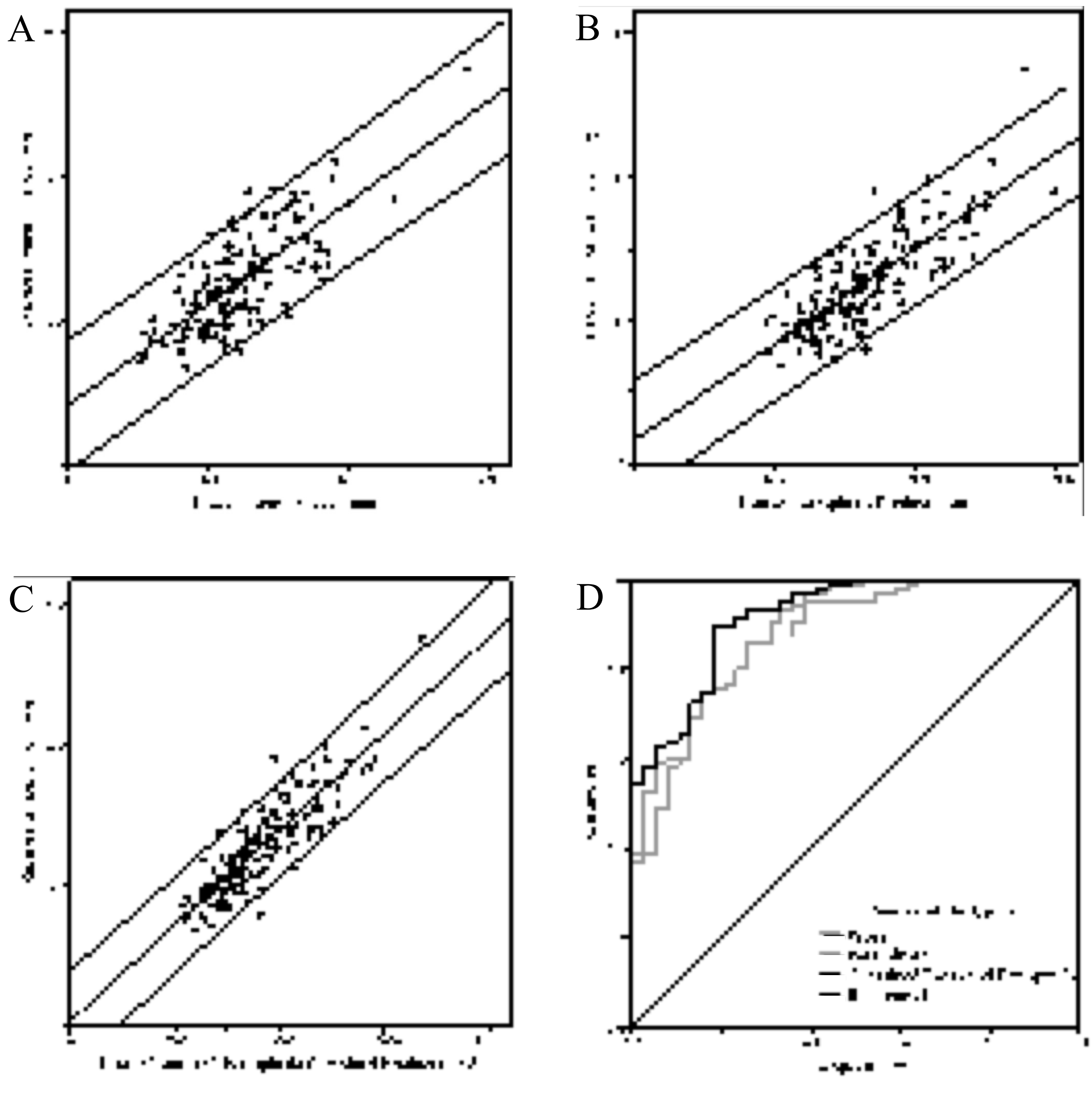


Figure 2

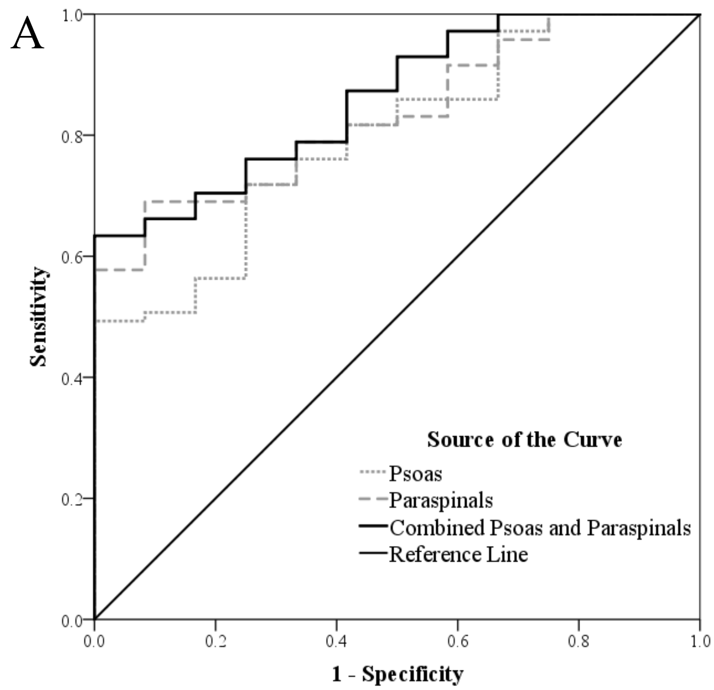


Detailed linear measures protocol

The linear measures may be performed in any software capable of viewing and processing medical imaging files with a built-in digital ruler feature.

1. Land marking of the L3 is performed similar to the strategy employed as part of the conventional method of image analysis. Briefly, first the T12 (vertebra attached to the last rib) or S1 (first vertebra identified within the pelvis) is identified, and images are scrolled inferiorly or superiorly, respectively. Each lumbar vertebra is counted until the L3 level. The CT image with the most prominent transverse processes is used for image analysis (i.e. both transverse processes display visible marrow).
2. Record the relevant identifying information and scan characteristics for future reference.
3. Evaluate the scan for any unusual radiological artifacts or substantial anatomical abnormalities. If present, identify whether it may prevent accurate assessment of the image.
4. Select the digital ruler tool. This ruler must be able to measure the size relative to the dimensions of the patient in the scans, and not simply provide an on-screen distance which may be altered due to aspects such as magnification levels or image resolution.
5. Identify the right and left psoas, as well as the right and left paraspinals (multifidus and erector spinae) (Figure 1A). The paraspinal muscle group measures do not include the quadratus lumborum or latissimus dorsi muscles.
6. Horizontal and vertical measures are performed on each of these 4 muscles (2 per muscle, 8 in total per image). IMPORTANT: Each line should be maintained in the horizontal and vertical direction (i.e. not diagonal) (Figure 1B, C). This step is important for consistent analysis and minimizing variability between analysts.
7. Only the visually identifiable area of the muscles should be measured. In particular, this is important in the area close to the vertebra as it often contains intermuscular adipose tissue (which should not be included in the measure). NOTE: a visual aid that may help illustrate this aspect is to imagine (or roughly "draw" in) a rectangular box around each of the muscles measured; the vertical and horizontal lines of the box thus correspond to the dimensions that will be used for your linear measures.
8. Record the vertical and horizontal measures of each muscle in mm (or cm), on a data collection sheet or digitally.
9. To calculate the products of the linear measures:
    a. Independently multiply the vertical by the horizontal measures of each: right and left psoas and paraspinal muscle groups (i.e. right psoas area (mm^2) = vertical right psoas measure (mm) x horizontal right psoas measures (mm)).
    b. The right and left product values are summed in order to obtain a value representing the total product of the psoas or paraspinals muscle groups.
    c. The psoas and paraspinal products can be further combined (summed) to obtain a single value, which incorporates all 8 linear measures performed on the scan.

Figure S1. Receiver operating characteristic (ROC) curves representing the ability of the linear-based indices to classify (A) men or (B) women who have low skeletal muscle index values.



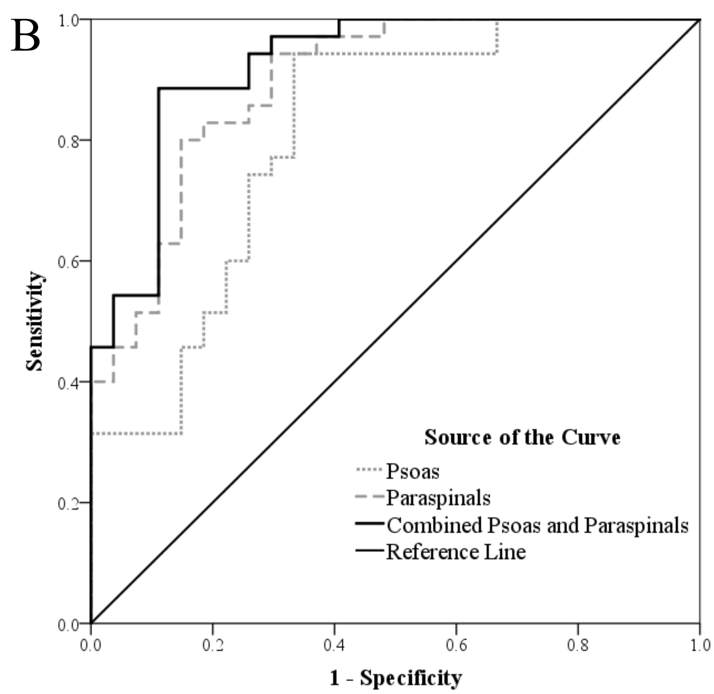


Table S1: Receiver operating characteristic (ROC) AUC values corresponding to the ability of the linear-based indices to classify participants who have low skeletal muscle index values.

	Men		**Women**	
	ROC AUC [95% CI]	**ROC P-Value**	**ROC AUC [95% CI]**	**ROC P-Value**
Psoas	0.796 [0.676-0.915]	P=0.001	0.808 [0.696-0.921]	P<0.001
Paraspinals	0.832 [0.734-0.931]	P<0.001	0.893 [0.814-0.973]	P<0.001
Combined Psoas and Paraspinals	0.860 [0.767-0.953]	P<0.001	0.924 [0.857-0.990]	P<0.001

ROC=Receiver operating characteristic curve, AUC=Area under the curve, 95%CI=95% confidence interval.