Published in final edited form as:

Am J Hum Biol. 2016 November ; 28(6): 918–926. doi:10.1002/ajhb.22892.

Dual energy X-ray absorptiometry spine scans to determine abdominal fat in post-menopausal women

J. W. Bea^{1,2}, R. M. Blew², S. B. Going², C-H Hsu³, M. C. Lee², V. R. Lee², B.J. Caan⁴, M.L. Kwan⁴, and T. G. Lohman⁵

¹University of Arizona Cancer Center, Department of Medicine, 1515 N. Campbell Avenue, Tucson, AZ 85724-5024, USA

²Department of Nutritional Sciences, University of Arizona, Tucson, AZ, 85721, USA

³University of Arizona Mel and Enid Zuckerman College of Public Health, Tucson, Arizona, 85724, USA

⁴Division of Research, Kaiser Permanente Northern California, Oakland, CA, 94612, USA

⁵Department of Physiology, University of Arizona, Tucson, AZ, 85721, USA

Abstract

Body composition may be a better predictor of chronic disease risk than body mass index (BMI) in older populations.

Objectives—We sought to validate spine fat fraction (%) from dual energy X-ray absorptiometry (DXA) spine scans as a proxy for total abdominal fat.

Methods—Total body DXA scan abdominal fat regions of interest (ROI) that have been previously validated by magnetic resonance imaging were assessed among healthy, postmenopausal women who also had antero-posterior spine scans (n=103). ROIs were 1) lumbar vertebrae L2-L4 and 2) L2-Iliac Crest (L2-IC), manually selected by two independent raters, and 3) trunk, auto-selected by DXA software. Intra-class correlation coefficients evaluated intra and inter-rater reliability on a random subset (N=25). Linear regression models, validated by bootstrapping, assessed the relationship between spine fat fraction (%) and total abdominal fat (%) ROIs.

Results—Mean age, BMI and total body fat were: 66.1 ± 4.8 y, 25.8 ± 3.8 kg/m² and 40.0 ± 6.6 %, respectively. There were no significant differences within or between raters. Linear regression models adjusted for several participant and scan characteristics were equivalent to using only BMI and spine fat fraction. The model predicted L2-L4 (Adj. R²: 0.83) and L2-IC (Adj.R²:0.84)

Corresponding Author: Jennifer W. Bea, PhD, Assistant Professor, Medicine, Assistant Research Scientist, Nutritional Sciences, University of Arizona Cancer Center, 1515 N Campbell Ave., Tucson, AZ 85724-5024, USA, Phone: 520-626-0912, FAX: 520-626-5348, jbea@uacc.arizona.edu.

Disclosure Statement: The authors have declared no conflicts of interest.

Author Contributions: JWB was primarily responsible for project conception and development of overall project plan. JWB, MCL, RMB, VRL, SBG, and TGL were responsible for the data collection and body composition estimates. JWB, MCL, and RMB created the database necessary for the research; C-HH performed the statistical analysis; JWB wrote and formatted the paper with input from all authors; all authors contributed to interpretation of the data; JWB had primary responsibility for final content; all authors approved the final manuscript before submission and none had a conflict of interest with regard to this work.

abdominal fat (%) well; the adjusted R^2 for trunk fat (%) was 0.78. Model validation demonstrated minimal over-fitting (Adj. R^2 : 0.82, 0.83, and 0.77 for L2-L4, L2-IC, and trunk fat respectively).

Conclusions—The strong correlation between spine fat fraction and DXA abdominal fat measures make it suitable for further development in post-menopausal chronic disease risk prediction models.

Keywords

adiposity; body composition; obesity; risk prediction; body mass index

Introduction

Body mass index (BMI, weight/height²) as a predictor of chronic diseases and health outcomes (Bea and Lohman, 2010; Folsom et al., 1993; Michels et al., 1998; Yusuf et al., 2005) has been questioned, largely due to inadequacies in predicting health outcomes in special populations, such as the aged, chronically ill, and minority groups (Bea and Lohman, 2010; Bea et al., 2015; Caan et al., 2006; Gallagher et al., 1996; Henderson, 2005; Jacobson, 2013; Kwan et al., 2014; Whitlock et al., 2009). Body composition, specifically soft tissue, may be a better predictor of metabolic dysfunction, health outcomes, and mortality (Folsom et al., 1993; Krakauer et al., 2004; Michels et al., 1998; Yusuf et al., 2005). Excess abdominal fat, in particular, has been repeatedly implicated in metabolic dysfunction, chronic inflammation, and chronic diseases (cardiovascular disease, CVD; type 2 diabetes, T2DM; and several cancers) and more so than total body fat (TBF) (Bea and Lohman, 2010).

Body composition is not routinely evaluated in health care settings, but hundreds of thousands of dual energy X-ray absorptiometry (DXA) bone mineral density (BMD) scans are performed clinically each year in accordance with osteoporosis screening guidelines (O'Malley et al., 2011). Current Agency for Healthcare Research and Quality (AHRQ) guidelines (2012) recommend that all women 65 years of age, and younger postmenopausal women with risk factors, be screened for low BMD and fracture risk. DXA scanners are also capable of evaluating soft tissue, even though clinical scans tend to be limited to BMD analyses of the most common fracture sites of the spine and hip (AHRQ (2012). Limiting scans in this fashion precludes measurement of total body and regional fat and lean mass. However, spine scans provide a viable region of interest to measure abdominal fat. Abdominal fat estimates, using a variety of anatomical landmarks in the abdominally region of total body DXA scans, have been validated against the gold standard techniques of computed tomography (CT) (Clasey et al., 1999; Jensen et al., 1995; Svendsen et al., 1993) and magnetic resonance imaging (MRI) (Park et al., 2002).

Although the spine specific scans do not span the total abdominal width laterally, the vertical landmarks used to specify regions of interest (ROIs) for abdominal fat on total body scans are present on the spine scans. In addition, other studies have successfully utilized regional DXA scan estimates of the spine and hip to predict whole body composition (Leslie, 2009; Rosenthal and Falutz, 2010; Salamat et al., 2014; Zhang et al., 2007), thus we anticipate an even stronger relationship between abdominal fat by total body DXA and spine fat fraction

from the regional spine scan. Further, regional DXA scan estimates of whole body fat have been shown to out-perform the current clinical estimate of whole body fat, BMI (Leslie, 2009). Estimating abdominal fat from spine BMD scans is simple, accessible, and could provide important body composition data in clinical settings, allowing for enhanced chronic disease risk prediction modeling in large populations.

Our primary aim was to derive and validate abdominal fat estimates from spine scans in post-menopausal women. We hypothesized that the spine scan derived measure of fat would be highly correlated with abdominal fat measures from standard manually selected ROIs from the total body scan, as well as the trunk fat estimate from total body scans provided from the DXA software.

Methods

Study Population

The post-menopausal women who had enrolled in the Bone Estrogen and Strength Training (BEST) between 1995 and 1999 were invited to return for a DXA scan approximately ten years after the conclusion of the primary BEST intervention (Going et al., 2003). The women that responded (N=103) were included in the present study and underwent total body and lumbar spine scans at the same visit. The scans were completed between November 2006 and October 2008. The inclusion criteria and primary outcomes for the BEST Study have been previously published (Going et al., 2003). The parent study and this ancillary follow-up were reviewed and approved by the University of Arizona Human Subjects Review Committee. Written informed consent was obtained from all subjects before study entry.

Anthropometry

Anthropometric measurements were taken using standard procedures (Lohman et al., 1991 (abridged edition)). Participants were wearing lightweight clothing and no shoes. Height (cm) was measured using a stadiometer (Schorr Height Measuring Board, Olney, MD) to the nearest 0.1 cm at maximal inhalation. Weight (kg) was measured using a calibrated scale (SECA, model 880, Hamburg, Germany), accurate to 0.1 kg. The average height and weight from two trials were used to calculate BMI (weight (kg)/height² (m)).

Body Composition

Total and regional body composition were measured by dual energy X-ray absorptiometry (DXA) using the GE Lunar Prodigy (software version 13.60.033) fan-beam densitometer (GE Lunar Corp, Madison, WI, USA). Percent TBF was computed by dividing fat mass (kg) by total body mass (kg) as assessed by total body DXA scan. Percent trunk fat from total body DXA scans represents the percentage of fat in the trunk relative to the other components of the trunk (i.e. % fat trunk = ((fat trunk)/(fat trunk + bone trunk + lean trunk) *100)). Subject positions for total body and spine scans were standardized according to the manufacturer's recommendations, as previously described (Houtkooper et al., 1995). Scan mode was determined by subject thickness, as calculated by BMI-based manufacturer

algorithms. Subjects between 13- 25cm were scanned in “standard” mode (n=98) and subjects > 25cm were scanned in “thick” mode (n=5).

Calibration of the densitometer was checked against a manufacturer supplied standard calibration block daily. Initial scan analysis for bone, TBF, trunk fat, and lean soft tissue, including the placement of baselines distinguishing bone and soft tissue, edge detection, and regional demarcations, was done by computer algorithms. One certified technician inspected all scans, and adjustments were made to the analysis when necessary, ensuring proper placement of standard total body, trunk, and spine scan demarcation lines.

Abdominal fat ROIs for each individual total body scan were manually selected and then evaluated by the integrated software to estimate fat (%) and tissue fat (%) for the selected ROI. Tissue fat (%) is the relative amount of fat in the soft tissue of the ROI excluding bone, whereas fat (%) is the amount of fat relative to all tissues present in the region, including bone. Two MRI validated ROIs on the total body DXA scan were used to estimate abdominal fat using vertical landmarks positioned: 1) immediately superior to lumbar spine vertebra L2 and at the inferior boarder of the lumbar spine vertebra L4 (L2-L4), and 2) immediately superior to lumbar spine vertebra L2 and at the iliac crest (L2-IC) (Park et al., 2002). Figure 1 displays the two abdominal fat ROIs, as well as the area included in the trunk region and anterior/posterior (AP) spine scan only [Figure 1 here].

Two independent raters performed the manual selection of each abdominal ROI on the total body scans. Each rater repeated the manual selection of the ROIs on a randomly selected subset (N=25) to evaluate reliability. The repeat ROI selection and analyses were performed on a different day; no data from the first ROI selection and analyses were available during the repeat ROI selection and analyses to prevent bias.

The AP spine scan, performed the same date as the total body scan, auto-generated a value for tissue fat (%) using the same software noted above; this fat value was recorded and used in analysis as spine fat fraction. The technical characteristics of the spine scan, such as the scan mode, dimensions, thickness, and zoom, were also recorded. The length of the spine scan image is variable and dependent on the height of the subject and the operator's placement of the lower and upper borders, which must include all of the L4 vertebrae and at least some of the T12 vertebrae, respectively. The AP spine scan height ranged from 17.2-21.0 cm (mean 18.7; SD 0.85); scan width was standardized by the DXA software at 18cm.

Statistical Analysis

Descriptive statistics were computed for participant characteristics. Intra-class correlation coefficients were derived to evaluate the reliability of the fat estimates from the manually selected ROIs within and between the two different raters. Pearson correlation coefficients between TBF, regional fat estimates, and other participant characteristics were computed. Univariate analysis was used to assess the value of each participant characteristic (age, BMI, weight, height), DXA scan characteristic (length of the spine scan, mode of the scan) and spine fat fraction for the prediction of standard estimates of abdominal fat (%) by total body DXA (i.e. L2-L4; L2-IC; trunk fat); variables reaching a significance level of 0.10 were

selected for inclusion in multiple linear regression models. Separate multiple linear regression models were derived to predict abdominal fat from the two MRI validated ROIs (L2-L4, L2-IC) on the total body scan using spine scans and participant and DXA characteristics meeting the criteria; similar models were created to predict the automatically generated trunk fat estimate from the total body scan. Adjusted R^2 combined with the standard error of the estimate (SEE) and Akaike information criterion (AIC) were used to select the best model for predicting abdominal and trunk fat. The selected model was then internally validated using 500 bootstrap samples by the rms package in R, including correction of potential over-fitting and calibration. In addition, model diagnostics based on residuals were performed on the selected model to identify any potential violation of the assumptions behind the model. There were no differences between models using DXA derived tissue fat (%) as the dependent variable, as opposed to fat (%), thus only fat (%) models were presented herein.

Results

The women (N=103) were 66.1 ± 4.8 years of age (Table 1). The average BMI was 25.8 ± 3.8 kg/m² and TBF was 40.0 ± 6.6 (%); trunk fat from the total body scan was similar. There were no significant differences between fat from total body scan ROIs L2-L4 and L2-IC (42%). The percent fat in the AP spine image (spine fat fraction) was 30.2 ± 9.7 %. Intra-class correlation coefficients for both manually derived abdominal fat ROI estimates from the total body scan, L2-L4 and L2-IC, were primarily 1.00; the lowest ICC was 0.98 (0.96, 0.99) for the estimate of fat mass (kg) between L2 and IC landmarks within a single rater.

Model Development and Validation

Weight, BMI, and spine fat fraction were significantly correlated with total body scan derived TBF (%), trunk fat (%), and abdominal fat (%) estimates at L2-L4 and L2-IC ($p < 0.0001$, Table 2). Absolute total and regional fat estimates (kg) from the total body scan were similarly correlated with weight, BMI, and spine fat fraction, as well as height ($p < 0.0001$). Total and regional estimates of fat (%) were significantly inter-correlated ($p < 0.0001$).

Univariate predictions of total body scan abdominal fat at L2-L4 and L2-IC from spine fat fraction alone derived from the AP spine scan demonstrated R^2 values of 0.82 and 0.83, respectively ($p < 0.0001$), while total body scan derived trunk fat was 0.75 ($p < 0.0001$). Univariate analyses confirmed the importance of BMI, weight, height, spine scan length, and scan mode for subsequent modeling (Table 3). Since BMI, weight, and height are collinear and BMI was most strongly associated with the abdominal fat regions of interest, only BMI was included in subsequent multiple linear regression models.

Based on both adjusted R^2 and AIC, BMI only (Model 1) had much smaller R^2 and larger AIC than the other models predicting total body scan abdominal fat for L2-L4, L2-IC, and trunk fat (Table 4). Model 3, adjusted for BMI and Spine Fat Fraction, had similar adjusted R^2 to Models 2 (Spine Fat Fraction adjusted only) and 4 (adjusted for BMI, Spine Fat Fraction, scan length, and scan mode). However, Model 3 had an AIC comparable to Model 4, but smaller than Model 2. Therefore, Model 3, with adjusted R^2 /AIC of 0.83/292.51,

0.84/284.64, and 0.78/269.63 for total body scan L2-L4, L2-IC, and trunk ROIs, respectively, was selected for the primary validation of total body scan ROIs. When predicting any of the ROIs (L2-L4, L2-IC, and trunk fat) from the total body scan, overfitting was minimal. Specifically, the adjusted R^2 was 0.82 in the corrected model following bootstrapping procedures for total body scan ROI L2-L4, 0.83 for L2-IC, and 0.77 for trunk fat. Model 2 was secondarily validated by the same procedure. The differences between Models 2 and 3 were very minimal, especially for L2-L4 and L2-IC, approximately 1%. The difference was slightly larger for Trunk Fat (approximately 5%). Table 5 provides the regression equations for both Models 2 and 3.

Discussion

Abdominal fat (%) from either of the abdominal ROIs on the total body scan was highly correlated with the fat estimate (%) from the AP spine scan. The addition of multiple participant and scan characteristics did not significantly improve the estimates, therefore the most parsimonious model, with information typically available to clinicians, was used in the validation models, which performed well.

This is the first study to use the regional spine scan to predict fat in abdomen-specific, MRI validated ROIs on the total body DXA scan (Park et al., 2002). Although others have used regional scans to predict TBF, and even regional fat distribution (Leslie, 2009; Rosenthall and Falutz, 2010; Salamat et al., 2014; Zhang et al., 2007), the models have been more complex, using both hip and spine scans, and the fat distribution estimates have been broad, i.e. trunk (Leslie, 2009; Rosenthall and Falutz, 2010; Salamat et al., 2014), android, and gynoid fat (Zhang et al., 2007), encompassing potentially confounding fatty regions, such as the breast. Our manual ROI selection was designed to be as specific as possible to the abdomen, which has been more strongly implicated in obesity related chronic conditions (Bea and Lohman, 2010). Although we did not compare directly to CT or MRI images, the use of DXA derived abdominal fat as the reference is supported by Hill et al. who found manually selected abdominal ROIs from DXA to be reliably measured (Hill et al., 2007).

Our more parsimonious models were also designed to be more practical, using only BMI and the single regional scan. Although other complex models have demonstrated higher Adj. R^2 values for predicting trunk fat, the variable in common with our study, from regional scans (0.84 - 0.94 compared to 0.78 herein) (Leslie, 2009; Rosenthall and Falutz, 2010; Salamat et al., 2014), our predictions of total body scan abdominal fat from spine fat fraction were well aligned, Adj. R^2 0.83 and 0.84 for L2-L4 and L2-IC, respectively. Auto-generated android fat estimates used to describe fat distribution from total body scans have been similarly correlated with the spine fat fraction from the regional spine scan, as well (Zhang et al., 2007).

Most importantly, early results from the application of spine fat fraction to chronic disease risk prediction are promising. One study applied the spine fat fraction to risk prediction for type 2 diabetes (Leslie et al., 2010). Nondiabetic women aged 40 yrs followed for 5.2 ± 2.6 yrs post-DXA (N=30,252) were at significantly increased risk of diabetes in the highest

quintile of spine fat fraction (>40.4% fat; OR 3.56; 95% CI: 2.67- 4.75), compared with those in the lowest quintile (<21.7% fat). For each standard deviation increase in spine fat fraction from the reference (quintile 1), there was a 43% increase in diabetes risk (Leslie et al., 2010). The mean spine fat fraction in the present study was 30.2%, placing the women in the third quintile of the study by Leslie et al. These results, taken together with the validation of spine fat fraction as a specific surrogate for abdominal fat herein, provide the basis to more confidently apply spine fat fraction to predict risk of obesity-related chronic diseases and cancers, as well as to assess potential deleterious changes in abdominal fat with various treatment strategies.

A discussion of practical measures of abdominal adiposity would not be complete without considering waist circumference measurements (WC). However, WC has not performed consistently in previous fat predictions models. The WC measurement in one study was eliminated in backward stepwise regression predicting trunk fat from regional scans, but remained in TBF prediction models (Salamat et al., 2014). In predicting CT derived abdominal fat, one group found that the combination of DXA derived abdominal fat and WC produced the strongest model (Hill et al., 2007), while another found that WC performed equally as well as DXA-derived abdominal fat when used separately (Direk et al., 2013; Snijder et al., 2002). Unfortunately, spine scans were not available in the CT studies and WC was not available in most regional DXA scan studies, including ours. Ultimately, however, the practicality of readily available spine scans in postmenopausal women may outweigh the burden of anthropometric training and the time required by clinicians to perform routine WC measurements.

The use of spine fat fraction leverages an existing resource without additional effort from personnel, greater patient burden, or the financial burden of upgrading instruments, software, and training. Further, these readily available estimates of abdominal fat may lead to the development of abdominal fat cut-points that better identify patients for early intervention to prevent and manage chronic disease and cancers among post-menopausal women.

Limitations

Use of a single scanner configuration (Prodigy) was a limitation and these analyses should be confirmed with other configurations, such as the iDXA. Of note, GE Lunar is the only DXA manufacturer to presently provide spine fat fraction measurements, thus restricting its use to Lunar-specific settings. However, GE DXA technology represents a significant proportion of the machines currently in use in clinical and research settings and therefore supports substantial opportunities for application of these findings.

The Encore software allows the user to adjust ROI's for analysis of the AP spine scan and to report bone mineral density specific to each selected ROI but, after verifying point typing, this does not affect the percent fat reported, which is derived from the full area of the spine scan image depicted in Figure 1 (yellow box). Nevertheless, the correlation between the spine fat fraction from AP spine scans and the abdominal ROIs from total body scans was high, mitigating concerns related to spine scan ROI adjustment. Visceral fat, which was not available, may be a better predictor of health risks than total abdominal fat (Bea and Lohman, 2010), but is more costly and less practical. Generalizability was limited due to

inclusion of post-menopausal women only, however, post-menopausal women are most likely to receive DXA scans and are a significant segment of the population at risk for obesity related chronic conditions.

The following differences in prior studies also make comparisons with our study challenging: most studies predicted absolute fat mass (kg) (Leslie, 2009; Rosenthal and Falutz, 2010; Salamat et al., 2014), rather than percent fat which is the unit reported in the AP spine image; the inclusion of men (Leslie, 2009; Rosenthal and Falutz, 2010; Salamat et al., 2014; Zhang et al., 2007), which accounted for a large proportion of the variance in studies that did not stratify by sex (Leslie, 2009; Salamat et al., 2014); the presence of various covariates, including the additional regional scan at the hip; and demographic differences, including race/ethnicity (Chinese(Zhang et al., 2007), Iranian(Salamat et al., 2014), and North American(Leslie, 2009; Rosenthal and Falutz, 2010)), although the diversity supports greater generalization.

Conclusions

In spite of increased scan speeds and precision of total body DXA for soft tissue measurements (Krueger and Binkley, 2012), DXA has yet to move beyond osteoporosis screening outside the scientific community. Our data indicate that existing, as well as new, spine scans, commonly available due to osteoporosis screening, can provide a valid and practical estimate of abdominal fat among post-menopausal women. These results should be validated independently across larger and more diverse populations. Further, the DXA-derived spine fat fraction should be evaluated for risk prediction across various obesity-related chronic diseases and cancers.

Acknowledgments

We are grateful to the BEST participants, faculty, and staff for their dedication to this project. This project was supported by NIH AR039559, U54CA143924, P30CA023074, the University of Arizona Undergraduate Biological Research Program: (HHMI) grant number 52006942, and a University of Arizona Faculty Seed Grant provided by the Office of the Senior Vice President for Research. The funding sources had no role in the design, interpretation, data collection, or decision to publish this study.

Grant Sponsorship: This project was supported by NIH AR039559, U54CA143924, P30CA023074, the University of Arizona Undergraduate Biological Research Program: (HHMI) grant number 52006942, and a University of Arizona Faculty Seed Grant provided by the Office of the Senior Vice President for Research.

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Figure 1.

Table 1
Characteristics of the study subjects (N=103)

Variable	Mean $\pm$ SD
Age (y)	66.1 $\pm$ 4.8
Height (cm)	162.7 $\pm$ 6.5
Weight (kg)	68.3 $\pm$ 12.0
BMI (kg/m ²)	25.8 $\pm$ 3.8
Total body fat (%) ^a	40.0 $\pm$ 6.6
Trunk fat (%) ^a	40.7 $\pm$ 7.7
L2-L4 fat (%) ^a	42.0 $\pm$ 9.8
L2-IC fat (%) ^a	42.2 $\pm$ 9.8
Spine fat fraction (%) ^b	30.2 $\pm$ 9.7

Body Mass Index, BMI; L2, lumbar spine vertebrae 2; L4 lumbar spine vertebrae 4; IC, iliac crest.

^a derived from dual energy X-ray absorptiometry scan of the total body

^b derived from dual energy X-ray absorptiometry AP spine scan

Table 2
Associations between fat compartments and participant characteristics by Pearson correlation coefficients (N=103)

Variable	Total body fat (%)	Trunk fat (%)	L2-L4 fat (%)	L2-IC fat (%)
Total body fat (%)	1.00			
Trunk fat (%)	0.96 ^c	1.00		
L2-L4 fat (%)	0.89 ^c	0.96 ^c	1.00	
L2-IC fat (%)	0.90 ^c	0.97 ^c	0.996 ^c	1.00
Spine fat fraction (%)	0.77 ^c	0.86 ^c	0.90 ^c	0.91 ^c
Age (y)	0.01	0.001	-0.001	0.01
Height (cm)	0.15	0.15	0.17	0.16
Weight (kg)	0.69 ^c	0.69 ^c	0.69 ^c	0.68 ^c
BMI (kg/m ²)	0.75 ^c	0.75 ^c	0.73 ^c	0.74 ^c

L2, lumbar spine vertebrae 2; L4 lumbar spine vertebrae 4; IC, iliac crest

^a derived from dual energy X-ray absorptiometry scan of the total body

^b derived from dual energy X-ray absorptiometry AP spine scan

^c p<0.0001

Table 3
Univariate analysis for prediction of selected abdominal fat regions of interest

Variable	L2-L4 fat (%)			L2-IC fat (%)			Trunk fat (%)		
	Reg coef (SE)	p-value	R ²	Reg coef (SE)	p-value	R ²	Reg coef (SE)	p-value	R ²
Age	-0.001 (0.204)	0.99	0.000	0.02 (0.20)	0.94	0.000	0.002 (0.161)	0.99	0.000
Weight	0.56 (0.06)	<0.0001	0.47	0.56 (0.060)	<0.0001	0.47	0.45 (0.05)	<0.0001	0.48
Height	0.25 (0.15)	0.09	0.03	0.24 (0.15)	0.12	0.02	0.18 (0.12)	0.12	0.02
BMI	1.90 (0.17)	<0.0001	0.54	1.91 (0.17)	<0.0001	0.55	1.54 (0.13)	<0.0001	0.57
Spine Scan Length	2.23 (1.12)	0.05	0.04	2.13 (1.13)	0.06	0.03	1.62 (0.89)	0.07	0.03
Scan Mode	8.78 (4.42)	<0.05	0.04	8.69 (4.43)	0.05	0.04	6.20 (3.51)	0.08	0.03
Spine Fat Fraction	0.92 (0.04)	<0.0001	0.82	0.93 (0.04)	<0.0001	0.83	0.69 (0.04)	<0.0001	0.75

L2, lumbar spine vertebrae 2; L4 lumbar spine vertebrae 4; IC, iliac crest

Table 4

Model comparisons for each abdominal region of interest

Model	# of covariates	L2-L4 fat (%)			L2-IC fat (%)			Trunk fat (%)		
		R ²	SEE ^a	Adj R ² /AIC	R ²	SEE	Adj R ² /AIC	R ²	SEE	Adj R ² /AIC
Model 1	1	0.54	6.74	0.54/392.90	0.55	6.72	0.54/392.17	0.57	5.10	0.57/337.64
Model 2	1	0.82	4.28	0.82/298.04	0.83	4.14	0.83/290.43	0.75	3.90	0.75/282.53
Model 3	2	0.83	4.15	0.83/292.51	0.84	4.01	0.84/284.64	0.78	3.65	0.78/269.63
Model 4	4	0.84	4.08	0.83/290.64	0.85	3.93	0.85/282.61	0.80	3.55	0.79/265.76

L2, lumbar spine vertebrae 2; L4 lumbar spine vertebrae 4; IC, iliac crest

Model 1: BMI

Model 2: Spine Fat Fraction

Model 3: BMI + Spine Fat Fraction

Model 4: BMI + Spine Fat Fraction + Length + Mode (all variables with p-value 0.10)

Note: Based on the above table, Model 3 was selected for validation.

^a standard error of the estimate

Table 5
Regression equations for each abdominal region of interest

Region of Interest	Model 2	Model 3
L2-L4 fat (%)	$14.355 + 0.915 * \text{SFF}$	$7.018 + 0.428 * \text{BMI} + 0.793 * \text{SFF}$
L2-IC fat (%)	$14.213 + 0.925 * \text{SFF}$	$7.027 + 0.419 * \text{BMI} + 0.806 * \text{SFF}$
Trunk fat (%)	$19.798 + 0.693 * \text{SFF}$	$10.395 + 0.548 * \text{BMI} + 0.539 * \text{SFF}$

L2, lumbar spine vertebrae 2; L4 lumbar spine vertebrae 4; IC, iliac crest; SFF, Spine Fat Fraction; BMI, body mass index