Published in final edited form as:

Am J Hum Biol. 2018 January ; 30(1): . doi:10.1002/ajhb.23057.

Use of iDXA spine scans to evaluate total and visceral abdominal fat

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Abstract

Objectives—Abdominal fat may be a better predictor than body mass index (BMI) for risk of metabolically-related diseases, such as diabetes, cardiovascular disease, and some cancers. We sought to validate the percent fat reported on dual energy X-ray absorptiometry (DXA) regional spine scans (spine fat fraction, SFF) against abdominal fat obtained from total body scans using the iDXA machine (General Electric, Madison, WI), as previously done on the Prodigy model.

Methods—Total body scans and regional spine scans were completed on the same day (N=50). In alignment with the Prodigy-based study, the following regions of interest (ROI) were assessed from total body scans and compared to the SFF from regional spine scans: total abdominal fat at 1) lumbar vertebrae L2-L4 and 2) L2-Iliac Crest (L2-IC); 3) total trunk fat; and 4) visceral fat in the android region. Separate linear regression models were used to predict each total body scan ROI from SFF; models were validated by bootstrapping.

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DISCLOSURE STATEMENT

The authors have no conflicts of interest to declare related to this work.

AUTHOR CONTRIBUTIONS

JWB was responsible for the development of the project. JWB, RMB, API, and SBG were responsible for data collection, image analysis, and reliability testing. JWB, API, C-HH, and RMB were responsible for database creation and quality control; C-HH was responsible for all statistical analyses; JWB wrote the manuscript with co-author input; all authors were responsible for data interpretation and approval of the final manuscript.

Results—The sample was 84% female, a mean age of 38.5 ± 17.4 years, and mean BMI of 23.0 ± 3.8 kg/m². The SFF, adjusted for BMI, predicted L2-L4 and L2-IC total abdominal fat (%; Adj. R²: 0.90) and total trunk fat (%; Adj. R²: 0.88) well; visceral fat (%) adjusted R² was 0.83. Linear regression models adjusted for additional participant characteristics resulted in similar adjusted R² values.

Conclusions—This replication of the strong correlation between SFF and abdominal fat measures on the iDXA in a new population confirms the previous Prodigy model findings and improves generalizability.

Keywords

body composition; regional DXA scans; risk prediction; body mass index; visceral fat

INTRODUCTION

Central adiposity, particularly visceral adipose tissue, may be more highly associated with increased risks of type 2 diabetes and cardiovascular disease (Despres, 2007; Farb & Gokce, 2015; Nicklas et al., 2004), as well as some cancers (Donohoe, Doyle, & Reynolds, 2011; Doyle, Donohoe, Lysaght, & Reynolds, 2012; von Hafe, Pina, Perez, Tavares, & Barros, 2004), than body mass index (BMI) or even total body fat. Yet, most clinical entities and large research studies continue to limit body habitus measures to BMI. BMI has several advantages because it is simple to measure, readily available in study populations, built into medical record systems, inexpensive, and is correlated with population-level health outcomes. While BMI was derived as a proxy for total body fat and has the stated advantages, BMI was not meant for use at the individual level, and is not linearly related with body fat across various groups (Gallagher et al., 1996; Whitlock et al., 2009).

Abdominal fat estimated by total body dual energy X-ray absorptiometry (DXA) scan is well-validated against computed tomography (CT) (Clasey et al., 1999; Jensen, Kanaley, Reed, & Sheedy, 1995; Svendsen, Hassager, Bergmann, & Christiansen, 1993) and magnetic resonance imaging (MRI) (Park, Heymsfield, & Gallagher, 2002) and is routinely available on several current DXA models. However, total body scans, which provide body composition results, are not currently evaluated as a standard of care for any indication. Meanwhile, the DXA bone mineral density (BMD) scans at the hip and spine are performed annually on thousands of individuals for osteoporosis screening (O'Malley et al., 2011). Anteroposterior (AP) spine scans in the General Electric Lunar product line provide an auto-generated tissue fat (%) estimate for the image, generally between L1-L4 vertebrae (Bea et al., 2016), which we will refer to as spine fat fraction (SFF).

Due to the limitations of BMI and the lack of total body composition measurements in health care, we recently validated SFF from AP spine scans against abdominal fat from total body scans using the GE Lunar Prodigy DXA scanner among post-menopausal women (GE Lunar Corp, Madison, WI, USA) (Bea et al., 2016). Though DXA scan estimates of fat at the spine and hip have been used to predict total body, trunk, and android fat (Leslie, 2009; Rosenthal & Falutz, 2010; Salamat et al., 2014; Zhang et al., 2007), as noted in our earlier publication which validated the abdominal region specifically (Bea et al., 2016), no prior

studies have included validation of abdominal visceral adipose tissue (VAT), due to the technical limitations of the DXA machine at the time of study. Further, the previous studies utilized older scanner models, limiting generalizability to more modern technology available today.

We sought to expand this work by utilizing a newer DXA model (iDXA, GE Lunar Corp, Madison, WI, USA) and accompanying software (CoreScan) to replicate prior findings in a more diverse population and to add the validation of SFF against total body scan derived VAT. Similar to the Prodigy-based study, we hypothesized that SFF on the iDXA would be well-correlated with previously validated abdominal fat ROIs and trunk fat derived from total body DXA scans (Bea et al., 2016). We further hypothesized that the relationships would be stronger between SFF and VAT due to better alignment of the regions of interest. Evaluating the underutilized DXA images continues to be important to identifying simple and accessible body composition information to better inform disease risks in large populations and to enhance chronic disease management in cost-responsible ways.

METHODS

Study Population

A convenience sample ranging in age and body size (N=50) completed total body scans followed immediately by AP spine scans during a single visit using the GE/Lunar iDXA machine (GE Healthcare Lunar, Madison, WI). The scans were completed during the month of March 2016. The inclusion criteria were good health and age >18yrs. Participants were excluded if they were pregnant, unable to lie down comfortably for 30 minutes, or if they had any metal implants. The University of Arizona Human Subjects Review Committee approved the protocol and all participants provided written informed consent prior to study participation.

Anthropometry

Anthropometric measures were conducted as previously reported (Bea et al., 2016). In brief, height was measured to the nearest 0.1 cm at maximal inhalation using a stadiometer (Schorr Height Measuring Board, Olney, MD) and weight was measured to the nearest 0.1 kg using a calibrated scale (SECA, model 880, Hamburg, Germany). BMI was calculated from height and weight (kg/m^2).

Body Composition

Total Body and AP spine scans were performed by dual energy X-ray absorptiometry (DXA) using the Lunar iDXA narrow angle fan-beam densitometer (GE Lunar Corp, Madison, WI, USA) to assess soft tissue (fat and lean masses, kg) and bone (mass). Subject positioning was standardized according to manufacture guidelines. As previously published, scan mode was determined by subject thickness, DXA calibration was performed daily, and initial lines of demarcations were identified by computer algorithms (Bea et al., 2016). Subsequently, one certified technician inspected all scans and made any necessary adjustments to ensure proper placement of standard demarcation lines. Percent total body fat (TBF) was computed as follows: total fat mass (kg)/total body mass (kg)*100. Percent trunk fat was computed as

follows: $((\text{fat trunk})/(\text{fat trunk} + \text{bone trunk} + \text{lean trunk})) * 100$. All analyses were completed using the iDXA Advance Package equipped with color-fat mapping and visceral fat quantification (CoreScan).

The manufacturer CoreScan software estimated the Visceral Adipose Tissue (VAT) mass and volume within the android region for males or females aged 18 to 90 years with a BMI between 18.5 and 40 kg/m², according to procedures described by Kaul et al (2012). In brief, the android region is the area defined vertically by the pelvis cut line (just above iliac crests) extending upwards to include 20% of the distance between the pelvis and neck cut lines, and horizontally between the arm cut lines. The software algorithms utilize the width of the subcutaneous fat at the lateral margins in the android region and abdominal thickness to estimate total subcutaneous fat for the android region. Subcutaneous fat for the android region is then subtracted from total abdominal fat for the region to estimate VAT. The content that is estimated is the VAT Mass and VAT Volume. (Kaul et al., 2012) The regional percent VAT is computed as: $(\text{VAT fat}/(\text{VAT fat} + \text{VAT lean} + \text{VAT bone}))*100$.

Total abdominal fat ROIs were manually selected on total body DXA scans and estimates of fat (%) and tissue fat (%) were computed by the software for the selected regions. As previously published, MRI validated ROIs were used to estimate total abdominal fat from total body DXA scans based on vertical cut points from lumbar vertebra L2 to L4 (L2-L4) and L2 to the iliac crest (L2-IC) (Bea et al., 2016; Park et al., 2002). All abdominal ROIs from the total body scan, including L2-L4, L2-IC, trunk, VAT are outlined in Figure 1. The SFF area from the AP spine scan, which does not normally appear on a total body scan, has been superimposed on the example total body scan for illustrative purposes. [Figure 1 here].

To replicate the procedures in the Prodigy-based study (Bea et al., 2016), two independent raters manually selected each abdominal ROI on the total body scans two times on a randomly selected subset of the new population (N=20). This procedure allowed for the testing of inter- and intra-rater reliability. To prevent bias, the repeat ROI selection was performed on a different day using separately saved image sets to ensure that none of the prior ROI selection lines of demarcation were available during the second analysis.

The AP spine scan auto-generated a value for tissue fat (%) which was recorded and termed SFF, as previously described (Bea et al., 2016). The technical characteristics of the AP spine scan (i.e., scan length, mode, thickness, zoom) were recorded and evaluated in the analytical models. Scan width was not evaluated in models as the DXA software automatically standardizes the width of the AP spine scan (18cm). Scan length varies based on height; technician-set borders must show a small, but identifiable portion of T12 and extend to the lower edge the L4 vertebrae (Bea et al., 2016). Thus, the AP spine scan height ranged from 17.8 to 21.2 cm (mean: 18.8; standard deviation: 0.87).

Statistical Analysis

Descriptive statistics for the cohort were computed. Intra-class correlation coefficients evaluated inter- and intra-rater reliability related to manually selected ROIs. Pearson correlation coefficients were computed across variables related to body composition and demographics. Participant demographics, body size, AP spine scan technical characteristics,

and SFF were evaluated in separate univariate models for their value in the prediction of abdominal, visceral and trunk fat from the total body DXA. A significance level of 0.10 in univariate analysis was used as the criterion to select any variable for inclusion in the multiple linear regression models as a covariate.

In alignment with the previous Prodigy analysis, multiple linear regression models, including the selected covariates, were then used to predict fat in each of the following ROIs from SFF separately: L2-L4, L2-IC, trunk fat, and VAT on the total body scan. A small portion of the sample returned zero values for VAT (N=6), thus VAT models were repeated with and without individuals with zero values. Exclusion of the zero values for VAT did not change the results, thus the smaller sample size is presented throughout. The optimal model for predicting fat in the ROIs from SFF considered adjusted R^2 , standard error of the estimate (SEE), and Akaike information criterion (AIC). Internal validation of the selected model was completed using the rms package in R and 500 bootstrap samples; potential violation of model assumptions was assessed using model diagnostics, as previously described (Bea et al., 2016). Tissue fat (%) was used in all models because the SFF is reported in that unit and cannot be altered. However, since most investigators are more familiar with fat (%), we evaluated all models using that unit as well. There were no differences between fat (%) and tissue fat (%) models. Therefore, we chose to present tissue fat (%) models only.

RESULTS

The study population (N=50) was 84% female. The average age was 38.5 ± 17.4 years. The mean BMI was in the normal weight range ($23.0 \pm 3.8 \text{ kg/m}^2$) (Table 1). Total body fat was $30.9 \pm 8.9\%$; trunk fat from the total body scan, at $30.1 \pm 10.7\%$, was similar. The percent fat estimates in the total body scan android region and L2-IC ROI were the same (28.8%), while the L2-L4 ROI percent fat estimate was slightly lower (28.3%). The VAT (%) in the android region of the total body scan was substantially and significantly lower (10.4%). The SFF, derived from the regional spine scans, was 18.1%. [Table 1 here]

There were perfect correlations within and between raters for the manually derived measures of fat at L2-L4 and L2-IC for each unit of measure (ICC: 1.00), except for L2-L4 fat mass in grams [ICC: 0.99 (0.98, 1.00)], which was near perfect.

Model Development

The SFF was significantly correlated with VAT, TBF (%), and trunk fat (%) from total body scans ($p < 0.0001$ for all, Table 2). The SFF was also significantly correlated with manually derived abdominal fat (%) in L2-L4 and L2-IC ROIs ($p < 0.0001$ for all, Table 2). Of the many abdominal measures, the L2-L4 and L2-IC ROIs were the most highly correlated (Pearson correlation coefficient, 0.95 for both) with SFF. BMI was significantly correlated with each of the fat measures ($p < 0.0001$), though to a lesser extent. Significant correlations were also seen among other total and regional fat variables ($p < 0.0001$). [Table 2 here]

When SFF was used alone to predict total body scan derived abdominal fat at the L2-L4 and L2-IC ROIs in univariate models, the R^2 value was 0.90 for both L2-L4 and L2-IC

($p < 0.0001$); trunk fat and VAT R^2 values were lower at 0.88 and 0.78 ($p < 0.0001$), respectively. Age, weight, and BMI each met the $p = 0.10$ criterion level and thus were evaluated in the subsequent multiple linear regression models (Table 3). [Table 3 here]

Model 1, with BMI only, had the smallest R^2 and largest AIC compared to other models predicting L2-L4, L2-IC, trunk fat, and VAT. Model 2 included SFF only, model 3 included SFF and BMI, and model 4 additionally included age and weight. The differences between the adjusted R^2 and AIC in the multiple linear regression models were negligible for models 2–4 (Table 4). The SFF was more highly associated with the L2-L4 ROI, compared to other ROIs, whether or not additional variables were included in the models (Adj. R^2 0.90).

Model Validation

In alignment with our previous work, validation analyses with 500 bootstrap samples were conducted on model 3. Overfitting was minimal across all models. The adjusted R^2 was unchanged for ROI L2-L4 at 0.90 and VAT at 0.83 and was minimally changed for L2-IC (0.90 to 0.89) and trunk fat (0.88 to 0.86) post-bootstrapping validation. The regression equations to predict percent fat for each ROI from SFF are provided (Table 5). [Table 4 here] [Table 5 here]

DISCUSSION

As hypothesized, percent total abdominal fat, from any of the ROIs on the iDXA total body scanner, was well correlated with the percent fat derived from regional AP spine scan (SFF). The associations between SFF and L2-L4 fat, L2-IC fat, and trunk fat were somewhat stronger for these regions in the present population versus those of our prior publication, which may be due, in part, to different population demographics (Bea et al., 2016). Compared to our prior analysis of postmenopausal women on the GE Lunar Prodigy DXA machine, this population was nearly 30 years younger, more diverse in terms of race/ethnicity, included both males and females, and participants were normal weight, on average, as opposed to overweight, based on BMI (Bea et al., 2016).

The regression model used for validation herein included BMI along with the SFF value in order to align with the previous publication on the Lunar Prodigy DXA machine. It is important to note, however, that the model that was limited to SFF alone produced adjusted R^2 values equivalent to the model that included BMI for each of these ROIs. Further, the model that included additional covariates only improved the adjusted R^2 a mere one percent for L2-L4 and L2-IC. Thus, SFF can reasonably be used alone to predict total abdominal fat without additional participant information.

Visceral fat (% VAT) is an optional measure available on the iDXA that we were unable to include in our prior analysis using the Prodigy machine. The % VAT was highly correlated with SFF, but the correlation between % VAT and SFF on the iDXA was slightly lower than that of other ROIs, counter to our secondary hypothesis. The lack of a stronger correlation between % VAT and SFF compared to the other ROIs and SFF may also be partially related to the population demographics, especially normal weight status overall. The SFF in the postmenopausal population was 30.2 ± 9.7 (Bea et al., 2016), while the present cohort

demonstrated an average SFF of 18.1 ± 9.7 . It is possible that an overweight or obese population would demonstrate greater agreement between SFF and %VAT. In fact, Suh, Kim, and Lee (2002) found that SFF was a better predictor of VAT directly measured by CT among obese postmenopausal women than among non-obese. Additional research comparing SFF and DXA derived VAT is warranted among larger individuals to further generalize and strengthen these findings, especially given the high prevalence of obesity in the United States and elsewhere (Ogden, Carroll, & Flegal, 2014).

While visceral fat has been proposed as a better predictor of metabolically-related chronic disease risks than overall abdominal fat (Bea & Lohman, 2010), measurement of visceral fat is expensive and not typically available in the clinical setting. This is the first study to show a strong association between DXA derived %VAT and SFF. In addition to our prior study (Bea et al., 2016), the present analysis builds upon the work of others that have estimated total body fat and distribution of fat using regional DXA scans (Leslie, 2009; Rosenthall & Falutz, 2010; Salamat et al., 2014; Zhang et al., 2007). However, our work is focused on abdominal fat and reducing the complexity of the models associating regional and total body scan ROIs to improve the ease of application in the clinical setting. The reason for the focus on abdominal fat is not only due to its implication in metabolically-related chronic conditions, but the fact that commonly used proxies for central adiposity that are auto-generated on DXA, such as trunk fat, include other fatty tissues which may be differentially related to disease risks. For example, breast tissue is included in the trunk fat measure and higher breast density, i.e., *less fatty* breast tissue, has been shown to be associated with higher cancer risk (Peres, 2012).

Though our protocol targeted central adiposity, the trunk measure was provided for comparison across studies. The magnitude of the association between SFF and trunk fat in the present study is similar to that of other studies, including our previous Prodigy-based analysis (present Adj. R^2 0.88 versus 0.78 – 0.94 in other studies) (Bea et al., 2016; Leslie, 2009; Rosenthall & Falutz, 2010; Salamat et al., 2014).

The preponderance of the evidence demonstrating agreement between regional spine scan derived fat and total and regional fat depots across studies indicates SFF readiness for application to chronic disease risk prediction models. Yet the use of SFF to predict or manage chronic diseases remains highly limited. Still, only one study, which was included in our prior publication on SFF, has been used to predict type 2 diabetes, (Leslie, Ludwig, & Morin, 2010), though the same group has explored new ways of using regional scans (spine-hip thickness), to predict type 2 diabetes more recently (Schacter & Leslie, 2015). Given the apparent utility of the existing resource of regional DXA scans across copious clinical sites, the further development of SFF derived prediction models to better identify at-risk patients and target interventions in adiposity related chronic diseases is a simple, yet powerful, advancement that ought to be pursued.

The combination of enhanced analytical capabilities of the iDXA and CoreScan software to yield visceral fat as well as abdominal fat data, and our findings that SFF readings from regional scans are highly correlated with total abdominal, trunk, and visceral fat offers a cost-responsible alternative to total body iDXA scans. Though future economic evaluation

studies are required to quantify cost and benefit parameters, it is evident that cost-efficiencies can be achieved through regional spine scans in the assessment of body composition in both the experimental and clinical setting. It will also be important to evaluate the value achieved from SFF data in terms of the cost of regional spine scans relative to the quality of imaging data required for the experimental or clinical tasks at hand. For instance, is the association ($R^2=0.83$) between BMI-adjusted SFF and measures of visceral fat sufficient for the tasks at hand; and conversely, what is the incremental value of lower-cost regional scans to the estimation of visceral fat (a reasoning that can also be extended to the abdominal and trunk fat measures)? On the risk management side, it will also be important to evaluate the costs of any risk liabilities that may be associated with diagnostic and prognostic predictions made with SFF data serving as proxy estimations for total body scan data.

Strengths and Limitations

The diversity of the present analysis, while replicating previous findings well, improves generalizability by expanding beyond post-menopausal women. The present analysis also expands to a more specific measure of abdominal adiposity, by including VAT, a feature of the iDXA that is more readily available than on the earlier Prodigy model. Further, validation of the new iDXA model herein, coupled with our prior study of the Lunar Prodigy, and that of others using the Lunar DPX and Prodigy models, as well as Norland technology in various regional and total fat validation studies, solidifies the utility of fat measures derived from regional scans. Given that the GE DXA technology is pervasive and maintains a significant proportion of the DXA market share, research and clinical groups will have ample opportunity to replicate these findings across various populations and to test SFF for various risk predictions.

Unfortunately, as noted previously (Bea et al., 2016), the CoreScan software spine fat fraction is derived from the entire area of the AP spine scan, regardless of scan height, and is not adjustable. Only bone values may be adjusted based on ROI selection in the AP spine scan. However, the correlations between SFF and the various measures of abdominal fat evaluated here, including visceral fat, were high, and similar to our previous findings on the Prodigy model (Bea et al., 2016). Considering the strength of both analyses, we maintain that the lack of spine image adjustability is not a major limitation to its application in risk prediction studies (Bea et al., 2016).

In addition, we were unable to compare the DXA derived abdominal ROIs directly to CT or MRI images. We relied on previous validation of the ROIs by gold-standard imaging technology (Park et al., 2002). However, others have shown that manually selected regions of interest on total body scans are reliable for quantifying abdominal fat (Hill, LaForgia, Coates, Buckley, & Howe, 2007).

CONCLUSIONS

The present analysis confirms that spine scans, readily available in clinical settings, provide good estimates of total and visceral abdominal fat. The number of studies demonstrating the agreement between regional spine scan derived fat and total and relevant regional fat depots

across different scanner models and populations indicates that spine fat fraction is ready to be applied to risk prediction models for common chronic diseases, such as diabetes, cardiovascular disease, and several cancers.

Acknowledgments

The research team thanks the participants of this project. The primary support for this project was a University of Arizona Faculty Seed Grant from the Office of the Senior Vice President for Research; additional resources were provided by: University of Arizona Undergraduate Biological Research Program (HHMI grant number 52006942), NIH U54CA143924, NIH HD-074565, and NIH P30CA023074. The funding sources had no role in the design, interpretation, data collection, or decision to publish this study.

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Figure 1. Dual-energy X-ray absorptiometry AP spine scan region overlaid on abdominal fat regions of interest on the total body scan
Yellow: spine scan region overlaid on total body scan; **Blue:** auto-generated trunk fat region; **Purple:** auto-generated android region; **Green:** manually selected lumbar spine L2-L4; **Red:** manually selected lumbar spine L2 to Iliac crest (L2-IC)

Table 1

Demographic and body habitus characteristics of study participants (N=50)

Variable	Mean $\pm$ SD or N (%)
Age	38.5 $\pm$ 17.4
Sex	
Female	42 (84%)
Male	8 (16%)
Race/Ethnicity	
White Non-Hispanic	39 (78%)
Asian	3 (6%)
White Hispanic	8 (16%)
Body Habitus Measures	
Height (meters)	1.66 $\pm$ 0.07
Weight (kg)	63.4 $\pm$ 11.4
BMI (kg/m ²)	23.0 $\pm$ 3.8
Total body fat (%) ^a	30.9 $\pm$ 8.9
Trunk tissue fat (%) ^a	30.1 $\pm$ 10.7
Android tissue fat (%) ^a	28.8 $\pm$ 12.6
L2-L4 tissue fat (%) ^a	28.3 $\pm$ 12.4
L2-IC tissue fat (%) ^a	28.8 $\pm$ 12.4
Visceral fat (%) ^a (N=44)	10.4 $\pm$ 11.6
Spine fat fraction (%) ^b	18.1 $\pm$ 9.7

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

^a total body scan;^b AP spine scan

Table 2

Pearson correlations between fat compartments and participant characteristics (N=50)

Variable	Total body fat (%)	Trunk fat (%)	L2-L4 fat (%)	L2-IC fat (%)	VAT (%)
Total body fat (%) ^a	1.00				
Trunk fat (%) ^a	0.97 ^c	1.00			
L2-L4 fat (%) ^a	0.94 ^c	0.99 ^c	1.00		
L2-IC fat (%) ^a	0.94 ^c	0.99 ^c	1.00 ^c	1.00	
VAT (%) ^a	0.67 ^c	0.78 ^c	0.80 ^c	0.79 ^c	1.00
Spine fat fraction (%) ^b	0.87 ^c	0.94 ^c	0.95 ^c	0.95 ^c	0.88 ^c
Age (y)	0.24	0.24	0.24	0.24	0.34 ^f
Height (cm)	-0.28	-0.25	-0.23	-0.23	-0.07
Weight (kg)	0.50 ^d	0.58 ^c	0.61 ^c	0.61 ^c	0.74 ^c
BMI (kg/m ²)	0.70 ^c	0.77 ^c	0.79 ^c	0.79 ^c	0.84 ^c

IC, iliac crest; L2, lumbar spine vertebrae 2; L4 lumbar spine vertebrae 4; VAT, visceral adipose tissue

^a total body scan^b AP spine scan^c p<0.0001^d p<0.001^e p<0.01^f p<0.05

Table 3

Univariate analysis for the prediction of abdominal fat regions of interest

Variable	L2-L4 fat (%)			L2-IC fat (%)			Trunk fat (%)			VAT(%)		
	Reg coef (SE)	p-value	R ²	Reg coef (SE)	p-value	R ²	Reg coef (SE)	p-value	R ²	Reg coef (SE)	p-value	R ²
Age	0.17 (0.10)	0.09	0.06	0.17 (0.10)	0.09	0.06	0.15 (0.09)	0.09	0.06	0.23 (0.10)	0.02	0.12
Weight	0.67 (0.12)	<0.0001	0.38	0.66 (0.12)	<0.0001	0.37	0.55 (0.11)	<0.0001	0.34	0.77 (0.11)	<0.0001	0.55
Height	-39.9 (24.8)	0.11	0.05	-40.6 (24.8)	0.11	0.05	-37.6 (21.2)	0.08	0.06	-10.95 (24.87)	0.66	0.00
BMI	2.61 (0.29)	<0.0001	0.63	2.59 (0.29)	<0.0001	0.62	2.17 (0.26)	<0.0001	0.59	2.61 (0.26)	<0.0001	0.71
Spine Scan Length	-1.87 (2.05)	0.37	0.02	-1.94 (2.04)	0.35	0.02	-1.89 (1.75)	0.29	0.02	0.13 (2.07)	0.95	0.00
SFF	1.22 (0.06)	<0.0001	0.90	1.21 (0.06)	<0.0001	0.90	1.03 (0.06)	<0.0001	0.88	1.05 (0.09)	<0.0001	0.78

IC, iliac crest; L2, lumbar spine vertebrae 2; L4 lumbar spine vertebrae 4; SFF, spine fat fraction; VAT, visceral adipose tissue

Table 4

Model comparisons for abdominal fat region of interest predictions

Model	# of covariates	L2-L4 fat (%)			L2-IC fat (%)			Trunk fat (%)			VAT (%)		
		R ²	SEE	Adj R ² /AIC	R ²	SEE	Adj R ² /AIC	R ²	SEE	Adj R ² /AIC	R ²	SEE	Adj R ² /AIC
Model1	1	0.63	7.66	0.62/205.6	0.62	7.72	0.61/206.4	0.59	6.90	0.58/195.1	0.71	6.30	0.71/163.9
Model2	1	0.90	4.00	0.90/140.6	0.90	4.05	0.89/141.9	0.88	3.78	0.87/135.0	0.78	5.52	0.77/152.3
Model3	2	0.90	3.95	0.90/140.4	0.90	4.02	0.89/142.1	0.88	3.80	0.87/136.3	0.83	4.88	0.82/142.4
Model4	4	0.91	3.88	0.90/140.4	0.91	3.95	0.90/142.0	0.89	3.71	0.88/135.8	0.86	4.49	0.85/136.8

IC, iliac crest; L2, lumbar spine vertebrae 2; L4 lumbar spine vertebrae 4; SEE, standard error of the estimate; SFF, spine fat fraction; VAT, visceral adipose tissue

Model 1: BMI

Model 2: Spine Fat Fraction

Model 3: BMI + Spine Fat Fraction

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

Table 5

Regression equations for the prediction of each abdominal fat region of interest

Region of Interest	Model 2	Model 3
L2-L4 fat (%)	$6.31+1.22*\text{SFF}$	$0.08+0.36*\text{BMI}+1.11*\text{SFF}$
L2-IC fat (%)	$6.87+1.21*\text{SFF}$	$1.13+0.33*\text{BMI}+1.11*\text{SFF}$
Trunk fat (%)	$11.44+1.03*\text{SFF}$	$8.06+0.19*\text{BMI}+0.97*\text{SFF}$
VAT (%)	$-9.95+1.05*\text{SFF}$	$-30.50+1.18*\text{BMI}+0.69*\text{SFF}$

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