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Comparison of CT and Dual-Energy DEXA Using a Modified Trunk Compartment in the Measurement of Abdominal Fat

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The quantification of abdominal fat is a marker of health risk. While dual-energy x-ray absorptiometry (DEXA) is easily applied, it measures overall fat, although abdominal fat may be a better indicator of health risk from obesity. We have evaluated whether a subcomponent of DEXA measurements correlates better with computed tomography (CT) for body fat than those traditionally used. Forty-seven healthy adults (22 M/25 F), aged 54.5 ± 15.8 yr (mean ± SD), with BMI of 27.1 ± 4.6 kg/m^2 participated in a cross-sectional study. Body fat was measured using abdominal CT and DEXA for total fat, trunk fat, and a modified trunk measurement that excludes the chest, termed "lower trunk," and compared. The coefficient of variation for DEXA measurements for trunk, lower trunk, and total body were 1.98, 3.12, and 0.85%, respectively. Mean DEXA for percentage fat ranged from 31.7% to 34.1% for trunk, lower trunk, and total body, compared to 54.2% for abdominal CT ($p < 0.003$ for each pairwise comparison). Lower trunk, whole trunk, and total body DEXA measurements were not different. Measurement of subcomponents of fat content by DEXA is not superior to whole body measurements and remains consistently lower than measurements by CT.

Key Words: Fat; visceral; insulin; resistance; DEXA.

Introduction

Increased abdominal fat is negatively associated with metabolic and cardiovascular health outcomes *(1–9)*. In addition, abdominal or visceral fat has been shown to be independently associated with all components of the metabolic syndrome such that it is a major determinant of the National Cholesterol Education Program Adult Treatment Panel II criteria for this entity *(10,11)*. Having an easy, convenient method to quantify abdominal fat would be desirable for the identification of patients with the metabolic syndrome and who are at risk for diabetes and cardiovascular disease.

Computed tomography (CT) scanning has been considered the gold standard for measurement of abdominal fat but is more time consuming and requires more radiation exposure than dual-energy X-ray absorptiometry (DEXA). DEXA can quantify total fat mass, total fat-free mass, and bone mass, and has been validated against measurement of fat using CT *(12–14)*. Methods for measuring abdominal fat have also been described for ultrasound *(15,16)* and magnetic resonance imaging *(17)* that have been found to identify the metabolic syndrome, but the latter methods have been less commonly used.

The DEXA instrument has the ability to measure body subcompartments for fat mass including the "trunk," which includes the abdomen. We were interested to determine if measurement of body fat in subcompartments, either a trunk or a modified compartment of the trunk (excludes measurements of fat in the chest), correlated better than measuring fat by whole body DEXA or abdominal CT. The lower trunk was selected because it represents the abdominal area thought to best predict cardiovascular disease and includes the cross-sectional area usually measured by CT in the measurement of total abdominal fat. However, this modified lower trunk measurement is not the standard body compartment used for most measurements of abdominal fat.

The specific aim of this study was to compare the measurement of body fat by DEXA in two different abdominal compartments, referred to as trunk and lower trunk, as well as total body fat with abdominal fat measured by CT.

Results

Study Subjects

A total of 47 subjects (22 M/25 F) were recruited. Descriptive statistics for the study subjects are shown in Table 1. The mean age of the subjects was 55 yr (range 24–80). Mean body mass index was 27.1 ± 4.6 kg/m^2.

Repeatability of DEXA Measurements

Figure 1 summarizes the agreement between the repeated DEXA % trunk and lower trunk fat values. For the trunk values, the mean difference in repeated measurements was

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Table 1
Patient Characteristics

	Mean	Range
Age (yr)	54.5 ± 15.8	24.0–80.0
Height (m)	1.7 ± 0.1	1.5–1.9
Weight (kg)	78.7 ± 15.8	46.8–112.2
BMI (kg/m^2)	27.1 ± 4.6	18.3–37.3
Waist circumference (cm)	94.3 ± 15.1	66.3–119.38
Hip circumference (cm)	103.5 ± 10.2	73.7–121.3
W/H ratio	0.91 ± 0.15	0.68–1.48

Results expressed as mean ± SD.
Abbreviations: BMI, body mass index; W/H, waist–hip ratio.

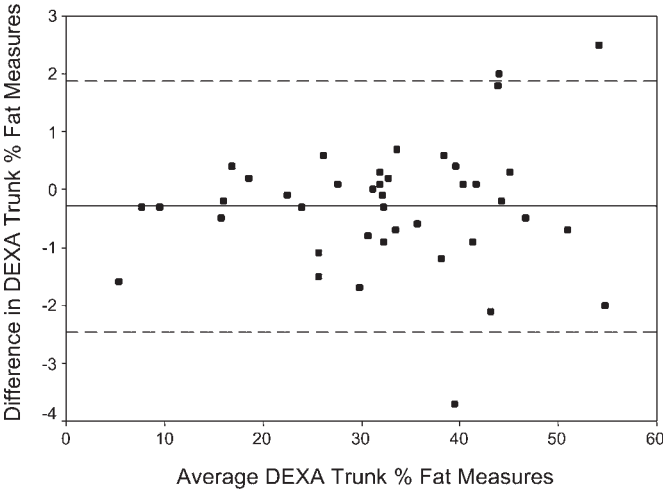

Fig. 1. Bland and Altman plot of repeated DEXA % trunk fat values. Abbreviation: DEXA, dual-energy X-ray absorptiometry.

–0.29% with limits of agreement ranging from –2.46% to 1.88% and for the lower trunk values, the mean difference in repeated measurements was –0.31% with limits of agreement ranging from –3.11% to 2.49%. The coefficient of variation was 1.98% for the DEXA % trunk fat measure and was slightly higher at 3.12% for the DEXA % fat lower trunk measure, but was still acceptable *(18)*. The coefficient of variation was lowest for the DEXA % total fat measure with a value of 0.85%. The intraclass correlation coefficient is greater than 0.98 for each of the DEXA measurement methods.

Measures of % Total Fat

Table 2 summarizes the distribution of the percentage fat measurements using the four different methods. Quantitation of fat on CT of the abdomen was higher than with any DEXA measurement. Trunk, lower trunk, and total % fat by DEXA were similar, but all were significantly lower than abdominal CT measurements of fat ($p < 0.003$) for each pairwise comparison with abdominal CT. The median percentage increase under the CT method relative to the DEXA method is 77%, 72%, and 61% for the trunk, lower trunk, and total fat measures, respectively.

Table 2
Percentage Fat Measurements by DEXA and CT

	Mean	Range
DEXA % trunk fat	31.7 ± 12.5*	4.6–55.4
DEXA % lower trunk fat	33.4 ± 13.1*	5.2–56.7
DEXA % total fat	34.1 ± 11.1*	7.8–56.3
CT % total fat	54.2 ± 14.9	10.9–73.1

Results expressed as mean ± SD.
*Statistically significant at the 0.05 alpha level with $p < 0.003$, compared to CT % total fat, paired *t*-test.
Abbreviations: DEXA, dual-energy X-ray absorptiometry; CT, computed tomography.

Pairwise comparisons among the three DEXA measures suggest that the DEXA measures were more similar relative to the CT measure. The median percentage increase for the DEXA total % fat measures was 8.7% and 3.4% for the trunk and lower trunk % fat measures, respectively. The median percentage increase for the DEXA trunk % fat measures relative to the lower trunk % fat was 0%.

Table 3 shows the correlation of DEXA and CT measurements of fat with weight, hip and waist measurements, body mass index, and waist–hip ratio. Waist, hip, weight, and BMI all generally correlated well with all of the DEXA and CT measurements with correlation coefficients (r) greater than 0.35 for each ($p < 0.05$ for each correlation). One exception was body weight with DEXA % total fat ($r = 0.26$, $p = 0.09$). However, waist–hip ratio did not correlate significantly with DEXA % trunk fat ($r = 0.25$, $p = 0.1$) and correlated with DEXA % lower trunk fat only at a level of $p < 0.05$ ($r = 0.31$). Waist–hip ratio correlated better with CT % total fat ($r = 0.35$, $p = 0.02$).

Effect of Gender on Correlation Between CT or DEXA and BMI

The association between measures for % fat and BMI does not differ significantly for males and females ($p > 0.1$ for each DEXA and CT measure). However, mean BMI is generally higher in men than women at each of the % body fat levels and for each measurement method ($p < 0.002$ for the gender term for each DEXA and CT measure). For each measure, the association between measures of % fat and BMI appear to be curvilinear where BMI remains roughly constant across low levels of % fat and then increases sharply past fat measures greater than 25% ($p < 0.03$ for each quadratic fat term), suggesting that toward the lower end of the % fat scale, there is a poorer correlation with BMI, although the data are sparse and should be interpreted cautiously.

CT and DEXA Measures and BMI as a Function of Age

Age had no impact on the correlation between DEXA or CT measures and BMI when considering age groups of 20–40, 41–60, and 61–80 yr ($p > 0.3$ for each DEXA and CT measure).

Table 3
Correlation of Anthropometric Measurements With Percent Fat as Measured by DEXA and CT

	Weight	Hip	Waist	BMI	Waist–Hip
DEXA % trunk fat	0.53 (<0.001)	0.58 (<0.001)	0.61 (<0.001)	0.72 (<0.001)	0.25 (0.1)
DEXA % lower trunk fat	0.60 (<0.001)	0.53 (<0.001)	0.68 (<0.001)	0.78 (<0.001)	0.31 (0.05)
DEXA % total fat	0.26 (0.09)	0.44 (0.004)	0.39 (0.01)	0.52 (<0.001)	0.14 (0.4)
CT % total fat	0.42 (0.004)	0.42 (0.004)	0.58 (<0.001)	0.61 (<0.001)	0.35 (0.02)

Pearson correlation coefficient shown above with *p* values in parentheses. *p* values less than 0.05 are considered statistically significant.
Abbreviations: DEXA, dual-energy x-ray absorptiometry; CT, computed tomography; BMI, body mass index.

Discussion

Increased abdominal fat mass is associated with multiple disease states including the metabolic syndrome, polycystic ovary syndrome, type 2 diabetes mellitus, and cardiovascular risk *(1,2,19–21)*. Methods that more easily identify high abdominal fat may be used to better understand the individuals at risk for and the pathophysiology of these disorders in a larger population.

The choice of methods for measuring abdominal fat is a compromise among ease of use, cost, and accuracy. Underwater weighing of individuals may be the most accurate method for total fat, but it is certainly not generalizable *(22)*. Anthropometrics are inexpensive, but suffer from a lack of repeatability among a variety of users *(23)*. The choice of methods for evaluating abdominal obesity should lend itself to frequent repeated measures, reproducibility among personnel, and accuracy among subjects of wide age ranges and different genders. Abdominal CT and DEXA measurements for abdominal fat appear to have many of these desirable qualities for measuring abdominal fat. Both CT and DEXA methods have been reported in the literature as viable methods for fat but CT involves more radiation exposure, is more expensive, and takes longer to schedule and perform so is less convenient for the patient *(13)*.

What is unique about our study is the comparison of a modified subsegment of the trunk measured by DEXA, termed lower trunk, with other measures of body fat. We compared abdominal CT measures of fat with a standard trunk measurement, which includes the abdomen and total body fat by DEXA with a more restricted measurement of the abdomen by DEXA. The subjects recruited for the study represented a cohort of healthy, urban, men and women without acute or chronic disease. The age range was specifically broad and evenly distributed for gender. However, the population of subjects is almost entirely Caucasian and may not generalize to other ethnic populations.

The measurements of percentage fat in the total body and abdominal subsegments were reproducible, but, in the end, the DEXA scan results were similar, whether total, trunk, or the newly described "lower trunk" measurements were used. They all gave a consistently lower estimation of fat than abdominal fat measured by CT. This would suggest that trunk or lower trunk measurements by DEXA offer no advantages to measures of total body percentage fat by DEXA. All of the body fat measures correlated with weight, waist, hip, and BMI measures, but less well with waist–hip ratio. There were no gender or age differences in correlation between DEXA or CT measures and BMI. This is especially reassuring in the case of age, as less data are available for efficacy of these measures in older individuals.

Our studies are consistent with previous studies which found CT measurement of body fat exceeded that measured by DEXA. In one such study, Svendsen observed that CT-predicted abdominal fat volume exceeded DEXA-predicted abdominal fat volume by 20% *(12)*. One explanation for this is that CT scanning measures the area of fat tissue, whereas DEXA measures the content of fat mass, fat-free mass, and bone mass. Adipose tissue contains roughly 15% nonfat tissue that would be reported as fat with CT and not with DEXA *(24)*.

Given the limitations of radiation exposure, especially with repeated measures, and the inability to measure some very large subjects with CT because of weight limitations with many CT scanners, DEXA measurements are still preferable for many cross-sectional and longitudinal studies of abdominal fat. However, there appears to be little advantage of using the DEXA % trunk fat or the DEXA % lower trunk fat measurement over DEXA % total fat. It is not obviously clear why this is the case, other than to speculate that in our population the density of fat was so great in the abdomen, compared to the total body, that results were similar. All the measures of abdominal fat by DEXA would have the advantage of being highly reproducible with the current technology. Little is known regarding the sensitivity of these methods to identify changes over time.

In conclusion, DEXA scan consistently measures lower % body fat compared to CT abdominal fat measurements. While trunk or our newly defined "lower trunk" measurement DEXA compartments focused on abdominal fat more than total % body fat, these measures were not significantly different from DEXA % total body fat and offered no other advantage overall or in specific groups for correlation with BMI. Differences in methodology are likely to explain the differences in percentage fat measured by DEXA lower trunk and CT. DEXA measurements still offer the advantage of good repeatability, correlation with standard clinical mea-

surements, including BMI, and are consistent across gender and age categories.

Materials and Methods

Human Subjects

The study was approved by the University of Nebraska Medical Center Institutional Review Board. Men and women from a representative distribution of all ethnic groups ages 19–80, were recruited between 1998 and 2002 from the surrounding community. Pregnant women, patients with chronic disease, and individuals unable to give informed consent were excluded. After obtaining informed consent, subjects had height and weight measures obtained to calculate body mass index (BMI). Waist and hip circumference measurements were taken and a waist–hip ratio was calculated from the data *(25)*. Patients were then scheduled for two studies for the determination of body fat, using an abdominal CT and a DEXA on the same day.

CT Scan for Body Fat

CT studies were performed on all subjects using a General Electric HiSpeed Advantage scanner (General Electric Healthcare, Waukesha, WI). Technical factors included X-ray tube voltage of 120 kVp, 1 cm slice thickness, and 1 s scan time. A single CT image was obtained, centered 1 cm above the iliac crest (roughly the level of the umbilicus). The slice location was determined from a single AP scout scan of the abdomen by a single radiologist. All measurements and calculations were made using the image analysis software of the scanner. The total body cross-sectional area was calculated from the CT image using the image mask function to determine the total cross-sectional area of all fat, soft tissue, and bone in the range of –300 and +2000 Hounsfield Units (HU). Parameters for determination of cross-sectional fat area were selected as the slice area in the range from –250 and –50 HU according to the method of Borkan *(26)*. CT percentage body fat was determined as the cross-sectional fat area divided by the total abdominal cross-sectional area times 100.

DEXA for Body Fat

Whole body composition DEXA was performed on a Hologic QDR 2000 DEXA Scanner, software version 7.20B (Hologic Inc., Waltham, MA). Subjects were scanned by a dedicated technologist. Calibration was performed every morning prior to the first scan using a standard Hologic phantom using the manufacturer's protocol. Each subject was scanned supine and positioned so that all body parts, including both hands, were included in the scan. The fan beam tube and the detector array moved diagonally in a "skewed swath" data acquisition technique to scan the entire patient. Each scan took approx 5 min. In order to estimate reproducibility of the subcompartment measurements, all subjects were scanned twice with the patient moving off and on the DEXA table between scans. Two technologists scanned all subjects. Total body fat and trunk body fat, which is one of six sections recordable by the software (head, trunk, right arm, left arm, right leg, and left leg), were recorded. A third measurement was taken where the trunk section was narrowed by moving the demarcation line between head and trunk inferiorly and the line between the trunk and the legs superiorly. The remaining band of mid-abdomen, halfway between the iliac crests and the inferior costal margin, approx 10 cm thick, was measured and this value was called the "lower trunk measurement" (DEXA-lower trunk) (Fig. 2).

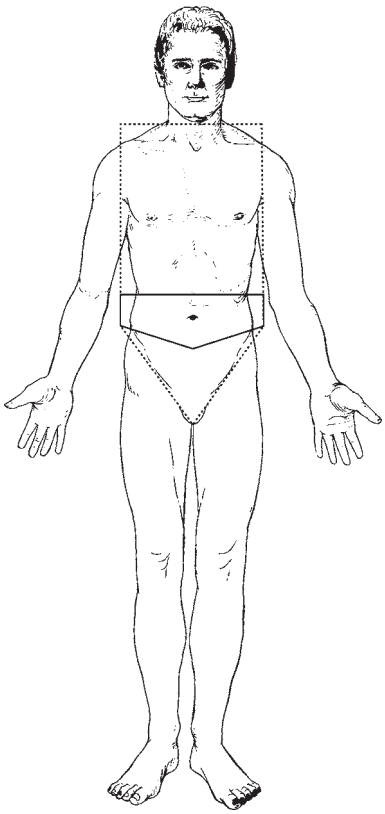

Fig. 2. The figure demonstrates the body compartments analyzed by DEXA for percentage body fat. The traditional trunk measurement involves the body compartments contained within the dashed line. The modified lower trunk compartment is highlighted by the solid line. Abbreviation: DEXA, dual-energy x-ray absorptiometry.

Statistical Analysis

A paired *t*-test was used to compare the mean measures of % fat by CT with the DEXA % trunk fat, DEXA % lower trunk fat, and DEXA % total fat. The association between DEXA measures and BMI or waist–height measures was investigated with descriptive plots. When a linear model was appropriate, correlation coefficients were used to describe the relation between pairs of the variables. Similar analyses were used to correlate CT measures with BMI and waist–height measures.

The repeatability of the DEXA measures was summarized using methods suggested by Bland and Altman *(27, 28)*. Specifically, the average difference between repeated measures was estimated, and the 95% limits of agreement were computed based on a normal distribution. Bland–Altman plots that displayed the difference in the measures by the average value of the repeated measures described the magnitude of the differences seen between repeated DEXA measures. The coefficient of variation was also calculated to describe the agreement between replicated DEXA measures. The coefficient of variation is defined as the standard deviation of within-subject measures relative to the mean of within-subject measures. A random effects ANOVA model was used to estimate the coefficient of variation, as described by Chinn *(29)*, based on natural log transformed data to adjust for increasing variation in repeated measurements relative to the mean of the measurements. The intraclass correlation coefficient was also calculated for the natural log transformed responses based on a random effects ANOVA model. Bland–Altman plots and limits of agreement were also calculated to describe the agreement between DEXA and CT scan measures of total percentage body fat. Linear regression was used to model BMI as a function of age, gender, DEXA, or CT measure, as well as the interaction between age and DEXA or CT measures and the interaction between gender and DEXA or CT measures. Quadratic functions of the CT measure were considered where appropriate. Unless otherwise specified, data are expressed as mean ± standard deviation (SD). A two-sided alpha level of 0.05 was used to define the statistical significance (i.e., a p value <0.05 was considered to be statistically significant). No adjustments were made to the alpha level for the multiple comparisons that were performed.

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