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Section II: Emerging Uses of Bone Densitometry

Relationship Between Dual-Energy X-Ray Absorptiometry Volumetric Assessment and X-ray Computed Tomography−Derived Single-Slice Measurement of Visceral Fat

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Abstract

To reduce radiation exposure and cost, visceral adipose tissue (VAT) measurement on X-ray computed tomography (CT) has been limited to a single slice. Recently, the US Food and Drug Administration has approved a dual-energy X-ray absorptiometry (DXA) application validated against CT to measure VAT volume. The purpose of this study was to develop an algorithm to compute single-slice area values on DXA at 2 common landmarks, $L_{2/3}$ and $L_{4/5}$, from an automated volumetrically derived measurement of VAT. Volumetric CT and total body DXA were measured in 55 males (age: 21−77 yr; body mass index [BMI]: 21.1−37.9) and 60 females (age: 21−85 yr; BMI: 20.0−39.7). Equations were developed by applying the relationship of CT single-slice area and volume measurements of VAT to the DXA VAT volume measure as well as validating these against the CT single-slice measurements. Correlation coefficients between DXA estimate of single-slice area and CT were 0.94 for $L_{2/3}$ and 0.96 for $L_{4/5}$. The mean difference between DXA estimate of single-slice area and CT was 5 cm^2 at $L_{2/3}$ and 3.8 cm^2 at $L_{4/5}$. Bland-Altman analysis showed a fairly constant difference across the single-slice range in this study, and the 95% limits of agreement for the 2 methods were −44.6 to +54.6 cm^2 for $L_{2/3}$ and −47.3 to +54.9 cm^2 for $L_{4/5}$. In conclusion, a volumetric measurement of VAT by DXA can be used to estimate single-slice measurements at the $L_{2/3}$ and the $L_{4/5}$ landmarks.

Key Words: dual-energy X-ray absorptiometry; visceral fat; X-ray computed tomography.

Introduction

Assessment of visceral adipose tissue (VAT) is important because of its metabolically active profile as a pathogenic fat depot *(1)*. It is strongly associated with cardiometabolic disease risks *(2,3)* and can also serve as a leading indicator for the development of metabolic syndrome and type 2 diabetes *(4−8)*. Volumetric measurement of VAT mostly relies on imaging methods, such as X-ray computed tomography (CT) and more recently magnetic resonance imaging (MRI) *(9−13)*. Many investigators use abdominal VAT volume as a measurement endpoint *(14−16)*, whereas others have opted to use single-slice area measurements because of radiation dose and cost concerns *(7,17−19)*.

The selection of the best representative single-slice location for VAT is still a subject of debate *(20−24)* and will remain so when considering the added complication of race, sex, age, and various study endpoints *(25)*. Two distinct landmarks commonly used are the $L_{4/5}$ *(7,12,18,26−28)* and $L_{2/3}$ *(17,19,24)* locations. Other locations have also been

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proposed *(21,29)*, including umbilicus *(5,30)* and 5−10 cm above $L_{4/5}$ *(20,25)*. The selection of a best representative location is not the subject of this study; instead, our focus is the dual-energy X-ray absorptiometry (DXA) measurement of single-slice VAT at the commonly used $L_{2/3}$ and $L_{4/5}$ landmarks.

Recently, the US Food and Drug Administration approved a method, CoreScan[a] (GE Healthcare, Madison, WI), for measuring volumetric VAT using DXA. The technical performance of the DXA VAT measurement has been validated using volumetric CT as the reference standard *(31)*. A single-slice area from a DXA VAT measurement can be implemented using the relationship between CT volume and single-slice VAT measures *(12,21)*. In this study, we use the relationship between single-slice and volumetric measures of VAT from CT to develop equations to compute single-slice measures of VAT from the DXA VAT volume measurements of the same subjects who were used for our VAT volume validation study. To our knowledge, this is the first attempt to develop single-slice VAT from DXA and compare it against CT.

Subjects and Methods

Patient Population and Protocol

The study comprised 124 subjects (61 females and 63 males) who underwent abdominal CT and a total body DXA scan on the same day. Subjects were recruited across 5 age categories (18−30, 31−50, 51−60, 61−80, and 81−90 yr) and 3 body mass index (BMI) categories (normal: 18.0−24.9, overweight: 25.0−29.9, and obese: 30.0−40.0 kg/m^2). Details of CT and DXA acquisition and analysis have been reported elsewhere *(31)*. Briefly, standard total body DXA images were acquired using the Lunar iDXA[a] densitometer (GE Healthcare, Madison, WI), and VAT volumes over the DXA android region were automatically generated with enCORE software version 13.6 (GE Healthcare, Madison, WI). Abdominal CT scans (120 kVp with 5-mm slice thickness) were acquired over 150 mm of the abdomen, starting at the top of the S1 landmark and extending toward the head. A subject-specific threshold in Hounsfield units was used in the CT analysis to identify VAT in the intra-abdominal cavity from the CT image data.

CT Single-Slice Analysis

CT slices at the $L_{2/3}$ and $L_{4/5}$ landmarks were identified from the reconstructed CT 3-dimensional images by counting the vertebrae. After the identification of the CT slice, the subcutaneous fat was removed using a semiautomatic method. A subject-specific threshold developed in previous report *(31)* was applied to the CT slice for the calculation of cross-sectional VAT. This analysis was performed independently by a single operator (XW) at GE Global Research Center (Niskayuna, NY), and an over-read was performed on approximately 10% of the data by a second operator (CED). Data were then transferred to GE Healthcare Lunar (Madison, WI) for equation development and validation.

Relationship Between CT Single-Slice and Volume VAT

Scatterplots between CT single-slice and volume measurements were performed for both $L_{2/3}$ and $L_{4/5}$. Regression analysis was used to examine gender differences and develop relationship between single-slice and volume measures. The linear relationship, in the form of single-slice VAT (cm^2) = a * VAT volume + b, as demonstrated by regression analysis, was applied to DXA VAT volume to derive single-slice values at $L_{2/3}$ and $L_{4/5}$.

Equation Validation

Analyses were performed using $L_{2/3}$ and $L_{4/5}$ VAT for each gender and for both genders combined. The Pearson correlation coefficients between the CT and DXA single-slice VAT were calculated in Excel[b], along with 95% confidence intervals from Fisher Z transformation. Bland-Altman analysis was also performed. Deming regressions of DXA on CT single-slice VAT were performed to detect proportional and constant bias. Analyse-it[b] Method Evaluation version 2.25 (Analyse-it Software, Ltd, Leeds, UK) was used for the Bland-Altman and Deming analysis. A significance level $\alpha = 0.05$ was used for all tests.

Results

Table 1 shows the subjects' characteristics separated by gender. Nine of the study subjects were excluded from the analysis because of defects in the CT scan (metal artifacts, no iliac crest present, and problems with image quality). The remaining 60 female and 55 male subjects were used in this study. The study subjects covered a wide range of age (21−85 yr) and BMI (20−39.7 kg/m^2). The resulting CT VAT volumes ranged from 42 to 3932 cm^3. CT single-slice VAT at $L_{2/3}$ ranged from 3.5 to 372.1 cm^2 and at $L_{4/5}$ from 12.2 to 378.1 cm^2.

Figure 1 illustrates the scatterplot between CT single-slice and volume measures. Single-slice VAT at $L_{2/3}$ (left) was highly correlated with VAT volume, and the relationship was similar for both genders. Single-slice VAT at $L_{4/5}$ (right) appeared to have more noise in the relationship, and there was an obvious gender difference.

Combined gender regression analysis (Table 2) found no gender differences in the $L_{2/3}$ slope and intercept, with the intercept not significantly different from 0 ($p = 0.5$). There was a significant gender difference in slope ($p < 0.001$), but not intercept, for the $L_{4/5}$ analysis. The $L_{4/5}$ intercept of 10.2 cm^2 was statistically significant. One female subject was excluded from the $L_{4/5}$ analysis as

[a]Trademark of General Electric Company.

[b]Excel is a trademark of Microsoft Corporation in the United States and other countries. Analyse-it is a product of Analyse-it Software, Ltd.