Published in final edited form as:

Am J Hum Biol. 2015 July 8; 27(4): 445–457. doi:10.1002/ajhb.22663.

Efficacy of thigh volume ratios assessed via stereovision body imaging as a predictor of visceral adipose tissue measured by magnetic resonance imaging

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Abstract

Objectives—The research examined the efficacy of regional volumes of thigh ratios assessed by stereovision body imaging (SBI) as a predictor of visceral adipose tissue measured by magnetic resonance imaging (MRI). Body measurements obtained via SBI also were utilized to explore disparities of body size and shape in men and women.

Method—121 participants were measured for total/regional body volumes and ratios via SBI and abdominal subcutaneous and visceral adipose tissue areas by MRI.

Results—Thigh to torso and thigh to abdomen-hip volume ratios were the most reliable parameters to predict the accumulation of visceral adipose tissue depots compared to other body measurements. Thigh volume in relation to torso [odds ratios (OR) 0.44] and abdomen-hip (OR 0.41) volumes were negatively associated with increased risks of greater visceral adipose tissue depots, even after controlling for age, gender, and body mass index (BMI). Irrespective of BMI classification, men exhibited greater total body (80.95L vs. 72.41L), torso (39.26L vs. 34.13L), and abdomen-hip (29.01L vs. 25.85L) volumes than women. Women had higher thigh volumes (4.93L vs. 3.99L) and lower-body volume ratios [thigh to total body (0.07 vs. 0.05), thigh to torso (0.15 vs. 0.11), and thigh to abdomen-hip (0.20 vs. 0.15); $p < 0.05$].

Conclusions—The unique parameters of the volumes of thigh in relation to torso and abdomen-hip, by SBI were highly effective in predicting visceral adipose tissue deposition. The SBI provided an efficient method for determining body size and shape in men and women via total and regional body volumes and ratios.

Keywords

Thigh volume; stereovision body imaging; visceral adipose tissue

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Disclosure: The authors have no conflict of interest to declare.

INTRODUCTION

Obesity is a significant public health concern associated with hypertension, dyslipidemia, coronary heart disease, and type 2 diabetes (Kurukulasuriya et al., 2011; Franssen et al., 2011; Logue et al., 2011; Nguyen et al., 2011). In the United States, approximately one-third of the population is overweight (33.3%) and one-third is obese (34.9%) (National Center for Health Statistics, 2013). At present, body mass index (BMI) is the most commonly used technique to assess obesity in populations due to its simplicity. Yet, this method is crude, in that body weight and height only estimate overall obesity, without consideration of the distribution of body fat (Bergman et al., 2011).

Generally, fat depots are classified as subcutaneous and visceral adipose tissue areas (Despres et al., 2008). Within the abdominal area, visceral adipose tissue is the more metabolically active depot due to its associations with escalated risks of cardiovascular disease, diabetes, and metabolic syndrome; whereas, subcutaneous adipose tissue is linked with lower health risks (Despres and Lemieux, 2006; Despres et al., 2008; Fox et al., 2007; Hayashi et al., 2008; Preis et al., 2010). Since visceral adipose tissue is more of a primary concern than is subcutaneous, this research explored the relationships between visceral adipose tissue determined by magnetic resonance imaging (MRI) and body volume measurements estimated by three-dimensional (3D) stereovision body imaging (SBI).

Lower body factors (thigh circumference, thigh fat, leg fat, leg to trunk fat ratio, sagittal abdominal diameter to thigh circumference ratio) have been shown previously to have favorable effects on normal insulin and glucose levels (Goodpaster, Thaete and Kelley, 2000; Snijder et al., 2004; Aasen et al., 2009; Park et al., 2012), metabolic dysfunction (Van Pelt et al., 2005; Heitmann and Frederiksen, 2009; Peppia et al., 2013), and risks of cardiovascular disease (Van Pelt et al., 2002; Heitmann and Frederiksen, 2009; Smith et al., 2005). Higher values of lower body factors have been suggested to exhibit protective effects on health risks associated with obesity-related diseases (Peppia et al., 2013; Park et al., 2012; Heitmann and Frederiksen, 2009). It is predicted that lower body components, such as thigh volume in relation to total body, trunk, or abdomen-hip would be linked negatively with the accumulation of visceral adipose tissue.

To date, instruments that measure regional adiposity, such as dual-energy x-ray absorptiometry (DXA), computed tomography (CT), and MRI, are restricted in field settings due to their bulkiness, cost, and/or radiation exposure. An innovation of this research is the use of a 3D SBI system to collect body measurements in a rapid and inexpensive manner. This device provides a visual presentation and quantitative values of human body size and shape, including volumes of total body, torso (lower neck to top of pelvis), abdomen-hip (smallest point of waist to crotch), and thigh (crotch to top of knee) (Figure 1). Previously, body volume measured via this system showed strong agreement with air displacement plethysmography (ADP) ($R^2 > 0.99$, $p < 0.01$). No significant differences were found between these methods (mean difference -0.17 , $p > 0.05$), indicating the preciseness of this technique (Xu et al., 2009). Also, measurements were highly reproducible, with intraclass correlation coefficient and coefficient of variation values lower than 0.99 and 1.9, respectively (Xu et

al., 2009). In the present research, unique body volume measurements derived via SBI were utilized to assess the association with visceral adipose tissue.

Stereotypically, men accumulate more fat in the abdominal region, which is characterized by an android or apple shape; whereas, women have greater fat deposits in the gluteal-femoral area, and exhibit a gynoid or pear-shaped body type (Haslam, Sattar and Lean, 2006; Cornier et al., 2011). Thus, men and women were assessed by SBI to document precise disparities in their body size and shape. Because central fat depots increase with age, especially for women with postmenopausal status (Haarbo et al., 1991; Reubinoff et al., 1995; Toth et al., 2000; Kanaley et al., 2001), demographics were taken into account for the examination of possible relationships between body volume measurements and obesity measures [overall obesity measures (BMI, percent body fat), abdominal adipose tissue areas (subcutaneous, visceral)].

METHOD AND PROCEDURES

Study Design

A total of 121 non-Hispanic white and Hispanic men (n=67) and women (n=54) made two visits to the University of Texas at Austin SBI laboratory and the MRI Imaging Research Center. Subjects were instructed to fast for 4 hours prior to the visit and avoid excessive perspiration, heavy exercise, and caffeine or alcohol for 10 hours.

Demographic and health history questionnaires were administered at visit 1. Participants were measured for body size and shape by anthropometrics, including height, weight by a scale and a stadiometer; body circumferences (waist, hip) and total/regional body volumes by SBI; and total percent body fat by ADP within 3 hours. At visit 2, MRI scans of the abdominal area were obtained for central obesity assessment within 5 days of the anthropometric measurements.

Subjects

Healthy non-Hispanic white and Hispanic men and women, aged 18 to 65 years with a BMI range of 18.5 to 40 kg/m² were recruited via notices posted online and on bulletin boards, and through word-of-mouth. Prescreening over the phone was performed before the first study visit. Criteria for exclusions were metallic/electronic implants or heavy metal ink tattoos, having known diseases, or being pregnant or breastfeeding. The risks and benefits of the study were explained and informed consents were obtained. The University of Texas at Austin Institutional Review Board approved this study.

Anthropometrics

Participants were measured for weight and height, wearing light clothing and barefoot, by an electronic scale (Tanita, Arlington, IL) to the nearest 0.1 kg and a stadiometer (Health o meter, South Shelton, CT) to the nearest 0.1 cm, respectively. BMI was calculated as weight in kg divided by height in m² and classified as healthy weight (18.5–24.9 kg/m²), overweight (25–29.9 kg/m²), obese class I (30–34.9 kg/m²), or obese class II (35–40 kg/m²). A MyoTape body tape (AccuFitness, Greenwood Village, CO) measured body

circumferences. Waist circumference was measured at the top of the iliac crest across the belly button and hip circumference was assessed at the widest extension of the buttocks. Anthropometric assessments followed standard protocols for anthropometric measurements (National Health and Nutrition Examination Survey III, 1988).

Stereovision Imaging System

A 3D SBI measured body size and shape of the participants (Xu et al., 2009; Lee et al., 2014). The SBI is capable of creating a 3D body image that can be rotated 360 degrees in all directions by employing the techniques of optical triangulation via four cameras and two projectors in front of and behind the subject, respectively (Lee et al., 2014). Four ultrashort throw NEC 575VT LCD projectors (NEC Corporation, Tokyo, Japan) illuminate the subject's body in order to generate artificial texture on the scanned surface, while four pairs of monochromatic CMOS cameras (Videre Design, Menlo Park, CA) capture the body image (Xu et al., 2009). The IEEE 1394 Firewire linked the SBI system to the host computer to transfer the texture pattern of the subject via a video graphics array hub. More detailed information regarding the instrument was reported previously by Xu et al. (2009) (Xu et al., 2009) and Lee et al. (2014).

Subjects were instructed to wear minimal tight underwear and a swimming cap during the assessment. A blindfold was provided to protect the subjects' eyes from the bright light emanating from the projectors. During acquisition, participants posed with their legs slightly spread and arms extended from the torso while holding their breath for one second. A total of ten body scans of 200 milliseconds each was completed for the subjects.

Body volume measurements assessed via SBI included total body, torso (lower neck to top of pelvis), abdomen-hip (smallest point of waist to crotch), and thigh (crotch to top of knee). Figure 1 shows the body image and regional body volumes assessed by SBI according to BMI classification. Subsequently, body volume ratios that reflect upper-(torso/total body, abdomen-hip/total body, abdomen-hip/torso) and lower-body volume ratios (thigh/total body, thigh/torso, thigh/abdomen-hip) were computed. The measurement descriptions of waist and hip circumferences by SBI were identical to the tape measurements. A SBI waist-to-hip ratio measurement was computed by waist circumferences (cm) divided by hip circumferences (cm).

Magnetic Resonance Imaging

The evaluation of abdominal adipose tissue areas was performed using FDA-approved pulse sequences via a MRI 3.0 T General Electric scanner (GE Healthcare, Milwaukee, WI) by a certified MR technician. A 3-plane localizer scan was performed while centering the iliac crest after the subject was positioned on the magnet. A coronal slice was obtained as TR 140, TE 2.1, flip angle 80°, slice thickness 8.0 mm with gap 5.0 mm, FOV 40 × 40, matrix 512 × 93, and bandwidth 62.5 kHz, while centering at the navel. The umbilicus coronal slice was analyzed for assessment of subcutaneous and visceral adipose tissue areas via SliceOmatic 4.3 (Tomovision, Montreal, CAN). Total abdominal adipose tissue area was computed by adding the areas of subcutaneous and visceral adipose tissue. Operation of the MRI scanner and maintenance of all the safety elements were performed only by imaging

research center approved personnel. The term adiposity is defined as the total amount of adipose tissue, including lipids of adipose tissue, bone, nervous tissue and structural lipids from membranes. Thus, the term adipose tissue was used to indicate the fat mass quantified by MRI.

Air Displacement Plethysmography

Percent fat mass and fat-free mass were calculated from body mass, density, and volume, as determined by a BOD POD® body composition tracking system (Life Measurement System, Concord, CA). The body percent fat assessed by ADP was used as an overall obesity measure in this study to compare the relationship with central obesity measures (subcutaneous and visceral adipose tissue) in relation to total and regional body volumes and volume ratios. Moreover, the association between total/regional body volumes and percent body fat, according to BMI classification was explored. Body fat percentage assessed by BOD POD (or ADP) is based on the two-compartment model that the human body is composed of fat and fat-free mass, with the density of fat and fat-free mass are defined as 0.9 kg/L and 1.1 kg/L, respectively (Collins et al., 2004). Participants were instructed to wear minimum clothing and cover their hair with a swimming cap to reduce error variance. Weights were measured by electronic scale and subjects were seated inside the sealed chamber. Under the isothermal conditions, body density was estimated via variations in pressure and body volume. The breathing circuit system measured thoracic gas volume while subjects breathed normally. Five prediction equations (Siri, Schutte, Ortiz, Brožek, Lohman) were available in the BOD POD® software in order to accurately measure body fat percentage for different populations, including the general population (Siri, 1961), African American men (Schutte et al., 1984), African American women (Ortiz et al., 1992), lean and obese individuals (Brožek et al., 1961), and children aged under 17 years old (Lohman, 1986). These prediction equations were based on measurements of body volume and body mass to estimate fat and fat-free mass.

Statistical Analysis

Statistical analyses were performed independently in men and women due to the gender differences in total and regional fat distribution. The normality of the distributions of the variables was examined by the Kolmogorov-Smimov test (Massey, 1951). Overall characteristics of the participants were described as mean and standard error of the mean (Table 1).

The odds ratios (OR) were computed via multinomial logistic regression analysis to predict of the risks of being in the low tertile of visceral adipose tissue versus middle or high, with one standard deviation increases in total/regional body volume parameters (Table 2). Analyses were preceded with no adjustment (model 1); adjusted for age and gender (model 2); adjusted for BMI group (model 3); and adjusted for age, gender, and BMI group (model 4) models in order to accurately explore risks involved while taking age, gender, and BMI into account. Total and regional body volume parameters were converted into Z-scores to compare the study results. The Z-score was computed by subtracting the group mean value from the individual's observed value, and then dividing these subtracted values by the group sample standard deviation.

The intra-participant reliability and the reproducibility of the body measurements assessed via SBI were evaluated by coefficients of variation over ten repeated body scans from a subset of 50 participants. Likewise, the coefficient of variation values were acquired to assure the reliability of the MRI abdominal adipose tissue data via the total abdominal, subcutaneous, and visceral adipose tissue area quantified by two trained researchers that followed standardized protocols. The coefficient of variation was computed as the ratio of standard deviation of the observed value to the mean of the observed values. Values were multiplied by 100 and reported as a percentage.

A one-way analysis of variance (ANOVA) was used to detect mean differences between different gender and BMI groups for demographic parameters and body measurements assessed via traditional anthropometrics, SBI, MRI, and ADP (Table 1 and Figures 2–4). When the results of ANOVA were significant, pairwise comparisons detected where the differences might fall by post hoc analysis of Bonferroni correction. A univariate general linear model analysis also was conducted to explore disparities of total/regional body volumes and body volume ratio parameters among different gender and BMI groups. Line graphs were created to visually examine the associations between body volume parameters and BMI classification (healthy weight, overweight, obese class I and II) (Figure 2).

Age-adjusted partial Pearson's correlation coefficients were used to describe the relationships between total/regional body volumes (torso, abdomen-hip, thigh) and upper/lower volume ratios with a) overall obesity measures (BMI, percent body fat); and b) central obesity parameters (subcutaneous and visceral adipose tissue areas) (Table 3). Scatter plots depicting the R^2 line of best fit were created to investigate linear associations between body fat percentage measured by ADP and total/regional body volumes determined via SBI, as well as visceral abdominal adipose tissue area assessed by MRI and body volume ratios acquired by SBI, according to BMI classification (Figures 3,4).

The level of significance adopted was $p < 0.05$. All statistical analyses were performed by using Predictive Analytics Software Statistics 18.0 (IBM SPSS, Chicago, IL).

RESULTS

Descriptive Statistics

The general characteristics and body measurements of the subjects are shown in Table 1. The mean age, weight, height, and BMI of the overall subjects were 34.4 years, 81.6 kg, 170.3 cm, and 28.0 kg/m², respectively. Among the 121 participants, 35.5% had a healthy weight (n=24, men; n=19, women), 30.6% were overweight (n=23, men; n=14, women), 22.3% exhibited class I obesity (n=14, men; n=13, women), and 11.6% showed class II obesity (n=6, men; n=8, women). The BMI values for men and women in each BMI category did not differ as the group values were 22.3 kg/m² and 22.4 kg/m² in healthy, 27.7 kg/m² and 27.9 kg/m² in overweight, 32.7 kg/m² and 32.8 kg/m² in obese class I, and 37.2 kg/m² and 36.8 kg/m² in obese class II for men and women, respectively ($p > 0.05$). In addition, 65% were non-Hispanic white and 35% were Hispanic. In comparison to men, women possessed greater total abdominal and subcutaneous and less visceral adipose tissue areas, as determined by MRI. Only the difference in subcutaneous adipose tissue was

statistically significant ($p=0.01$). Moreover, a significantly higher percentage of total body fat assessed by ADP, as well as higher thigh volume, stereovision hip circumference, and lower-body volume ratios (thigh to total body, thigh to torso, and thigh to abdomen-hip) measured by SBI were observed in women, as opposed to men ($p<0.01$) (Table 1). In contrast, men exhibited greater total body, torso volumes, and stereovision waist circumference than women ($p<0.01$).

Odds Ratios for Visceral Adipose Tissue Area Tertiles and Total/Regional Body Volumes and Volume Ratios

Multinomial logistic regression analysis was conducted to predict tertiles of abdominal visceral adipose tissue depots assessed via MRI, according to total/regional body volumes and volume ratios measured by SBI. The odds ratios and 95% confidence intervals by one standard deviation increase of each parameter value for increase in visceral abdominal adipose tissue tertile are demonstrated in Table 2. Model 1 was unadjusted, model 2 was adjusted for age and gender, model 3 was adjusted for BMI group, and model 4 was adjusted for age, gender, and BMI group. Regardless of the adjustment for age and gender (model 1 and 2), higher total and regional body volumes (total body, torso, abdomen-hip), as well as upper-body volume ratios (torso to total body, abdomen-hip to total body), were associated with being in a higher visceral adipose tissue area tertile compared to lowest tertile ($p<0.01$).

After adjusting for age and gender (model 2), as well as BMI group (model 3), torso volume and abdomen-hip volume were the strongest variables associated with increased risk for visceral adipose tissue. Among the body volume ratio parameters, the greatest decrease in the risks of having visceral adipose tissue was found with thigh to total body, thigh to abdomen-hip, and thigh to torso volume ratios ($p<0.05$) (Table 2).

However, when the model was adjusted for age, gender, and BMI group (model 4), these associations with visceral adipose tissue were not significant ($p>0.05$). The exceptions were for thigh to torso and thigh to abdomen-hip volume ratios, with the odds ratios for the highest tertile compared with lowest visceral adipose tissue area tertiles being 0.44 and 0.41, respectively ($p<0.05$) (Table 2).

Reproducibility of Body Measurements

The coefficients of variation for body measurements assessed by SBI were 0.89% for waist and 0.36% for hip circumferences; 1.16% for total body, 2.04% for torso, 1.57% for abdomen-hip, and 1.98% for thigh volumes. The coefficients of variation for total abdominal, subcutaneous, and visceral adipose tissue areas evaluated by two trained researchers were 0.69%, 0.83%, and 0.91%, respectively. These strong degrees of agreement assured the reproducibility of the body measurements assessed by SBI and MRI.

Line Graphs of Body Volumes According to BMI Groups

Differences between total and regional body volumes and volume ratios in men and women are illustrated in Figure 2, according to BMI classification. Total and regional body volumes increased, with the exception of thigh volume, in correspondence with increasing BMI classification regardless of gender (Figure 2a). Thigh volume was statistically greater for the

obese class II group, in comparison to healthy and obese class I groups, but not between overweight and obese class II groups (Figure 2a).

Lower-body volume ratios (thigh to total body, thigh to torso, thigh to abdomen-hip) decreased according to BMI groups, specifically from healthy weight to obese class I participants (Figure 2b). No significant differences were observed between obese class I and II participants for lower-body volume ratios (thigh to total body, thigh to torso, and thigh to abdomen-hip) (Figure 2b).

Scatter plots of total/regional body volumes according to overall and central obesity measures

Figure 3 presents scatter plots of total/regional body volumes (torso, abdomen-hip, and thigh) assessed by SBI and percent body fat measured by ADP in men and women, according to BMI classifications. Total body, torso, and abdomen-hip volumes were positively correlated with percent body fat and these relationships corresponded with increasing BMI classification. Thigh volume also showed positive relationships with percent body fat (Figure 3d); however, the correlation coefficients were lower but still significant than that observed for values of other regional body volumes (Figure 3a–c). The scatter plots of visceral adipose tissue assessed by MRI and lower-body volume ratios (thigh to torso and thigh to abdomen-hip) measured by SBI, according to BMI classifications, are illustrated in Figure 4. Lower-body volume ratios showed negative associations with visceral adipose tissue that were stronger in women than men. Respective coefficient correlation values (r) for thigh to torso and thigh to abdomen-hip volume ratios were -0.73 and -0.77 ($p < 0.05$) (Figure 4b,d) for women and -0.44 and -0.46 ($p < 0.05$) for men (Figure 4a,c), respectively. Based on the visual inspection the correlation coefficients values, the scatter plots exhibited greater variations and showed attenuated correspondence with BMI groups in men, as compared to women (Figure 4a,c).

Correlations between Body Volumes and Obesity Measures

Age-adjusted partial Pearson correlation coefficients for overall/central obesity measures with total/regional body volumes and body volume ratios are presented in Table 3. Total and regional body volumes (torso, abdomen-hip) derived from SBI were closely related with overall obesity measures (BMI and percent body fat) and subcutaneous adipose tissue. A significant, but weaker relationship was observed with visceral adipose tissue ($p < 0.01$). In contrast, thigh volume was not related to visceral adipose tissue.

In men and women, the largest negative correlations for visceral adipose tissue were observed with thigh to abdomen-hip volume ratio, clearly followed by thigh to torso volume ratio. Only women showed a significant negative relationship with thigh to total body volume ratio and visceral adipose tissue (Table 3). In addition, upper-body volume ratios, such as torso to total body, abdomen-hip to total body, and abdomen-hip to torso volume ratios, were positively correlated with these obesity measures (Table 3).

DISCUSSION

The primary focus of this paper was to examine the associations between thigh volume ratios assessed by SBI and visceral adipose tissue measured by MRI. The inverse relationships of abdominal visceral adipose tissue with lower-body volume ratios reported in this study suggest that greater volumes in the lower body are more metabolically favorable than those in the upper regions. In addition, decreased visceral adipose tissue was observed with a high thigh volume in relation to abdomen-hip and torso volumes. Thus, this type of fat distribution in the lower body appears to be metabolically advantageous for both men and women.

The current investigation confirmed the favorable associations between lower body factors and accumulation of visceral adipose tissue, even after adjustment for age, gender, and BMI, as the odds ratios were 0.44 for thigh to torso volume ratio and 0.41 for thigh to abdomen-hip volume ratio. It is well established that greater fat deposition in thighs or legs is believed to be a protective factor for obesity-related diseases, such as cardiovascular disease, coronary heart disease, type 2 diabetes (Heitmann and Frederiksen, 2009; Snijder et al., 2003; Seidell et al., 2001; Goodpaster et al., 2000) or longevity/mortality (Lissner et al., 2001; Heitmann and Frederiksen, 2009); whereas, fat depots in the upper portion of the body are more closely linked to those diseases. In the elderly, Snijder et al. (2003) observed that individuals with larger hip and thigh circumferences exhibited a lower risk of type 2 diabetes occurrence (Snijder et al., 2003). The odds ratios for prediction of type 2 diabetes for hip and thigh circumferences were 0.55 and 0.79 in men; and 0.63 and 0.62 in women, when adjusted for age, BMI, and waist circumference (Snijder et al., 2003). In contrast, a larger waist circumference was linked to increased incidence of developing type 2 diabetes (Snijder et al. 2003).

A study by McLaughlin et al. (2011) confirmed that thigh fat behaves as a potential protective factor, as the odds ratios for thigh fat to predict insulin resistance was 0.59, after adjustment of gender and BMI (McLaughlin et al., 2011). Similar findings were observed in college students, with leg (but not arm) fat linked to reduction of cardiovascular risk factors ($p < 0.05$) (Sanchez-Lopez et al., 2013). In comparison, Hoyer et al. (2011) found that neither mid-thigh circumference or subcutaneous thigh adipose tissue depot was related to risk of type 2 diabetes diagnosis among Japanese Americans; the odds ratios for both were only 0.9 (Hoyer et al., 2011) ($p > 0.05$). It is plausible that the accumulation of fat in peripheral regions of the body such as thighs, or legs, may reduce the ectopic fat accumulation in the upper body torso, which are more closely linked with metabolic risks (Manolopoulos, Karpe and Frayn, 2010). Differences in the response rate and introduction of catecholamine-induced lipolysis between gluteal and abdominal fat deposits may explain adverse effects from a physiological point of view (Wahrenberg, Lonnqvist and Arner, 1989). The reported favorable impact of lower-body factors on metabolic health may be related to an undesirable effect of inflammatory cytokines on accumulation in abdominal adiposity. In contrast, peripheral adiposity is negatively associated with systemic inflammation stimulated by cytokines (Manolopoulos et al., 2010; Tchernof and Despres, 2013). Perhaps, changes in peripheral body composition could be explained by a greater proportion of lean (muscle) mass induced by physical activity. However, Wilson et al. (2013) reported that an increased

trunk volume, in comparison, to leg volume, was due to the elevated fat mass in each body segment, as opposed to lean mass (Wilson et al., 2013).

Wang et al. (2007) utilized a Hamamatsu photonic laser scanner to assess body volumes, including total body, trunk, arms, and legs, in class II and III obesity participants (n=8 men, n=23 women). These values were compared to those with a BMI < 35 kg/m² (Wang et al., 2007). Men exhibited greater total body, torso, and arm volumes, as well as torso to total body volume ratio than women; while women had a higher leg to total body volume ratio, irrespective of BMI classifications (Wang et al., 2007). However, no differences were found in leg volume in men and women according to BMI grouping (Wang et al., 2007). The present study identified significantly greater thigh volumes in women, as compared to men. Men showed significantly higher total and upper-body volumes; whereas, women had greater values of lower-body volumes and volume ratios and these findings were consistent across BMI groups between men and women. These results correspond to the previous studies' findings that women are more prone to exhibit a gynoid body shape; whereas men are more likely to have an android body type (Haslam et al., 2006; Ludescher et al., 2009; Cornier et al., 2011).

The research by Wang et al. (2007) also observed that class II and III obese participants showed greater total body, torso, arm, leg (women only) volumes, and torso to total body volume ratio, and lower leg to total body volume ratio, as opposed to subjects with BMI < 35 kg/m² (Wang et al., 2007). Similarly, the current study observed that obesity class II subjects had greater total body, torso, abdomen-hip, and thigh volume, as opposed to other BMI groups including obesity class I, regardless of gender. In addition, thigh volumes in obese class II participants were larger than those in other BMI groups, but not significant compared to class I. This suggests that the changes in the body volume proportions were subtle among moderately and morbidly obese individuals. Greater differences may have been observed if our sample had been expanded in size or included obesity class III participants.

Wilson et al. (2013) utilized a trunk to leg volume ratio that was determined by DXA as a reflection of body shape index (Wilson et al., 2013). A higher value for this measure indicated that the proportion of trunk was greater than the legs, as the upper body volume was divided by the lower body volume. The trunk to leg volume ratio increased across underweight, healthy weight, and overweight participants (1.40, 1.46, 1.57, respectively) (Wilson et al., 2013). This investigation demonstrated that proportions of legs were larger, as compared to trunk volume for underweight individuals, and the proportion of leg volume was smaller than the trunk volume for higher BMI groups. However, no differences were found between the overweight and obese (Wilson et al., 2013). In the current study, upper body volume ratios increased according to the BMI classification, while lower body volume ratios decreased, regardless of gender. These results also conform to Wang et al. (2007) who found that lower-body volume factor (leg to total body volume ratio) decreased as BMI classification increased (Wang et al., 2007). Correspondingly, these suggest that a greater lower body volume may have a beneficial effect on being obese. Thus, as an individual progresses to a higher BMI group, body fat may be more prone to accumulate in the upper body, rather than the lower body region.

Various types of photonic body scanners have been used previously to measure body composition and compare the body size and shape among populations as a means of clinical and field-based epidemiological assessment. The Hamamatsu Bodyline laser Scanner was validated initially in adults and children to measure body volume. It showed less than 3% of error to assess body volume compared to body volume measured by underwater weighing and ADP (Wells et al. 2000). Subsequently, a 3D photonic scanner, [TC]² assessed body circumferences, including head, mid-upper arm, chest, waist, hips, mid-thigh, knee, and calf among Americans, British, and Thai participants (Wells et al. 2008a, Wells, Charoensiriwath and Treleaven 2011, Wells, Treleaven and Cole 2007, Wells, Cole and Treleaven 2008b). Values of body circumference ratios, such as waist-hip, waist-chest, waist-bust, waist-thigh, thigh-arm also were explored according to different gender and age categories, with changes in body size and shape over time (Wells et al. 2007). Finally, a Chang Gung Total Body Scanner explored relationships with BMI, somatotype index and anthropometric data (Liu et al. 2001) in order to develop a health index (Lin et al. 2002, Lin et al. 2004) and chronic disease risk (Chuang et al. 2006). In this research, 3D SBI examined the total/regional body volumes and body volume ratios in terms of risks of visceral adipose tissue accumulation. The affordable cost, portability, relatively small size, and non-invasiveness of the instrument utilized in this research make it ideal for clinical or field base epidemiological studies. Its uniqueness is its ability to quantify visceral adipose tissue in a relatively simple manner, without an elaborate or bulky instrument.

A limitation of this study was the method involved with the percent fat assessment via ADP. If the whole body densities are greater than 1.10 g/ml then negative values of body fat may result. Negative values would suggest violation of the assumption of constant density for the fat free mass. In past studies, negative values of body fat may have been considered as erroneous and perhaps, not published. However, a few studies exist that exhibit these irregular fat estimations. For example, Pollock et al. (1977) found that five runners had less than 2% predicted body fat (from density and Siri's equation). Additionally, in young men, -0.8% and -1.6% body fat have been predicted from fat body densities of 1.102 g/ml (Behnke, 1963) and 1.104 g/ml (Katch and Michael, 1968), respectively. Thus, irregular fat estimates have occurred in lean mesomorphs. It is possible that violation of the assumption of the two-compartment model equations (density constancy of 0.9 kg/L for fat mass and 1.1 kg/L fat-free mass) may have affected the computation of percent body fat in subjects in the current study who were very lean.

In summary, thigh volume in relation to torso and abdomen-hip volume determined by SBI were parameters that estimated the risks of possessing visceral adipose tissue, the metabolically active fat depot. Favorable effects of lower-body components on visceral fat were observed in both men and women, despite gender differences in body size and shape.

Acknowledgments

Supported by: NIH R21 DK081206

This research was supported by grant R21 DK081206 from the National Institutes of Health. Jane J Lee collected the research data and proceeded with data analysis, and composed the initial manuscript. Jeanne H Freeland-Graves served as the primary investigator and prepared the manuscript. M Reese Pepper implemented the study and participated in data collection. Wurong Yu and Bugao Xu developed the three-dimensional stereovision imaging

system and the volume measurement software. Bugao Xu served as one of the Principal Investigators for the NIH grants and provided the training and support for SBI data collection and processing.

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(a) Men, BMI 20 kg/m², healthy weight

(b) Men, BMI 26 kg/m², Overweight

(c) Men, BMI 31 kg/m², obese class I

(e) Women, BMI 30 kg/m², obese class I

(f) Women, BMI 40 kg/m², obese class II

Figure 1.

Total and regional body volumes according to BMI classification assessed by a stereovision body imaging system. Left to right: front of total body volume, back of total body volume, front of torso and thigh volumes, front of abdomen-hip and thigh volumes, and back of abdomen-hip and thigh volumes.

Figure 2. Total and regional body volumes and body volume ratios of men and women assessed by stereovision body imaging, according to BMI classification.

Figure 3.

Scatter plots of total/regional body volumes assessed by stereovision body imaging and percent body fat measured by air displacement plethysmography in men and women, according to BMI classifications.

- (a) Total body volume according to % body fat
- (b) Torso volume according to % body fat
- (c) Abdomen-hip volume according to % body fat
- (d) Thigh volume according to % body fat

Figure 4.

Scatter plots of visceral adipose tissue assessed by magnetic resonance imaging according to lower-body volume ratios measured by stereovision body imaging in men and women, according to BMI classifications.

- (a) Visceral adipose tissue according to thigh to torso volume ratio in men
- (b) Visceral adipose tissue according to thigh to torso volume ratio in women
- (c) Visceral adipose tissue according to thigh to abdomen-hip volume ratio in men
- (d) Visceral adipose tissue according to thigh to abdomen-hip volume ratio in women

Table 1

Subject characteristics and body measurements by gender

Parameters	Gender				p value ^b
	Men (n=67)		Women (n=54)		
	Mean ± SEM ^a	Range	Mean ± SEM ^a	Range	
Demographics					
Age (years)	34.37 ± 1.42	18.6 – 59.8	34.39 ± 1.31	18.5 – 60.6	1.00
Ethnicity (%Caucasian/Hispanic)	65.7/34.3	–	64.8/35.2	–	–
Traditional Anthropometrics					
Weight (kg)	86.26 ± 2.17	59.51 – 129.64	75.89 ± 2.25	47.36 – 126.69	< 0.01
Height (cm)	175.78 ± 0.87	161.29 – 189.48	163.59 ± 0.95	147.32 – 178.82	< 0.01
BMI (kg/m ²)	27.68 ± 0.63	19.10 – 40.30	28.45 ± 0.76	18.61 – 40.07	0.43
Waist (cm)	97.53 ± 1.93	72.70 – 131.20	91.46 ± 2.01	64.50 – 118.11	0.03
Hip (cm)	107.29 ± 1.16	92.10 – 132.20	107.10 ± 1.85	80.50 – 134.00	0.93
Stereovision Body Imaging					
Stereovision waist (cm)	95.21 ± 1.63	73.26 – 127.47	88.46 ± 1.89	65.40 – 115.00	0.01
Stereovision hip (cm)	106.68 ± 1.17	92.17 – 132.36	112.56 ± 1.80	87.19 – 151.07	0.01
Waist-to-hip ratio	0.89 ± 0.01	0.74 – 1.09	0.79 ± 0.01	0.68 – 0.96	< 0.01
Volume (L):					
Total body	80.95 ± 2.19	54.66 – 122.89	72.41 ± 2.34	43.91 – 123.91	0.01
Torso	39.26 ± 1.37	23.59 – 67.70	34.13 ± 1.42	17.90 – 54.50	0.01
Abdomen-hip	29.01 ± 1.19	15.91 – 59.39	25.85 ± 1.16	12.14 – 45.31	0.06
Thigh	3.99 ± 0.15	2.24 – 9.01	4.93 ± 1.17	3.14 – 10.52	< 0.01
Volume Ratio:					
Torso to total body	0.48 ± 0.00	0.39 – 0.58	0.46 ± 0.01	0.35 – 0.59	0.07
Abdomen-hip to total body	0.35 ± 0.01	0.27 – 0.48	0.35 ± 0.01	0.27 – 0.45	0.90
Abdomen-hip to torso	0.73 ± 0.01	0.61 – 0.89	0.75 ± 0.01	0.65 – 0.88	0.04
Thigh to total body	0.05 ± 0.00	0.03 – 0.07	0.07 ± 0.00	0.05 – 0.10	< 0.01
Thigh to torso	0.11 ± 0.00	0.05 – 0.17	0.15 ± 0.01	0.08 – 0.27	< 0.01
Thigh to abdomen-hip	0.15 ± 0.01	0.06 – 0.24	0.20 ± 0.01	0.11 – 0.33	< 0.01
Magnetic Resonance Imaging					

Parameters	Gender				<i>p</i> value ^b
	Men (n=67)		Women (n=54)		
	Mean ± SEM ^a	Range	Mean ± SEM ^a	Range	
Abdominal Adipose Tissue Areas:					
Total (cm ²)	259.15 ± 18.54	20.64 – 652.63	300.56 ± 18.94	56.81 – 544.98	0.12
Subcutaneous (cm ²)	187.50 ± 15.41	13.70 – 514.84	242.62 ± 15.46	35.82 – 458.81	0.01
Visceral (cm ²)	71.65 ± 5.85	2.55 – 188.91	57.94 ± 4.48	8.12 – 137.78	0.08
Air Displacement Plethysmography					
Total body fat (%)	26.00 ± 1.20	9.00 – 49.70	37.18 ± 1.35	16.10 – 53.70	< 0.01

^a Standard error of mean^b Significant level determined by one-way analysis of variance (ANOVA)

Table 2

Logistic regression analysis to predict tertiles of visceral abdominal adipose tissue depots measured by magnetic resonance imaging according to total/regional body volume and volume ratios assessed by stereovision body imaging

Parameters ^a	Tertile of Visceral adipose tissue area ^b					
	Model 1 ^c		Model 2 ^c		Model 3 ^c	
	Low vs. Middle	Low vs. High	Low vs. Middle	Low vs. High	Low vs. Middle	Low vs. High
Volume:						
Total body	3.58** (1.80 – 7.12)	6.98** (3.30 – 14.74)	3.39** (1.65 – 6.94)	6.92** (3.08 – 15.57)	1.94 (0.69 – 5.51)	2.68 (0.90 – 7.94)
Torso	4.37** (2.10 – 9.08)	8.76** (3.95 – 19.47)	3.87** (1.83 – 8.21)	7.75** (3.34 – 17.96)	3.54* (1.08 – 11.62)	5.01* (1.43 – 17.54)
Abdomen-hip	4.93** (2.25 – 10.80)	9.21** (3.98 – 21.31)	4.07** (1.85 – 8.94)	7.50** (3.17 – 17.74)	3.73* (1.10 – 12.63)	4.59* (1.28 – 16.44)
Thigh	1.25 (0.77 – 2.03)	1.44 (0.89 – 2.32)	1.63 (0.92 – 2.90)	2.17* (1.17 – 4.03)	0.75 (0.42 – 1.35)	0.72 (0.40 – 1.30)
Volume Ratio:						
Torso to total body	3.49** (1.84 – 6.60)	6.76** (3.30 – 13.88)	2.99** (1.56 – 5.73)	5.33** (2.51 – 11.29)	2.45* (1.12 – 5.34)	3.19** (1.33 – 7.63)
Abdomen-hip to total body	3.64** (1.87 – 7.09)	6.09** (2.98 – 12.44)	3.06** (1.56 – 6.01)	4.65** (2.23 – 9.70)	2.39* (1.07 – 5.30)	2.65* (1.11 – 6.31)
Thigh to total body	0.46** (0.27 – 0.77)	0.23** (0.13 – 0.42)	0.52* (0.29 – 0.91)	0.31** (0.16 – 0.60)	0.53* (0.30 – 0.94)	0.34** (0.18 – 0.67)
Thigh to torso	0.37** (0.21 – 0.64)	0.17** (0.08 – 0.33)	0.42** (0.23 – 0.75)	0.22** (0.11 – 0.46)	0.47* (0.26 – 0.86)	0.29** (0.14 – 0.61)
Thigh to abdomen-hip	0.33** (0.18 – 0.59)	0.14** (0.07 – 0.29)	0.37** (0.20 – 0.68)	0.19** (0.09 – 0.40)	0.44* (0.23 – 0.84)	0.25** (0.12 – 0.56)

Data on exponential β and 95 % confidence intervals are shown.

^a Determined by stereovision body imaging

^b Determined by magnetic resonance imaging

^c Model 1, unadjusted; model 2, adjusted for age and gender; model 3, adjusted for BMI group; model 4, adjusted for age, gender, and BMI group

* Correlation is significant at 0.05 level (2-tailed)

Correlation is significant at 0.01 level (2-tailed)

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Age-adjusted partial Pearson correlation coefficients between overall/central obesity measures and whole/regional body volumes and body volume ratios assessed by air displacement plethysmography, magnetic resonance imaging, and stereovision body imaging

Table 3

Parameters ^a	Overall Obesity Measure				Abdominal Adipose Tissue Areas ^d			
	BMI ^b		% Body Fat ^c		Subcutaneous		Visceral	
	Men	Women	Men	Women	Men	Women	Men	Women
Volume:								
Total body	0.90**	0.90**	0.82**	0.87**	0.85**	0.85**	0.39**	0.55**
Torso	0.92**	0.92**	0.85**	0.90**	0.87**	0.88**	0.40**	0.64**
Abdomen-hip	0.89**	0.92**	0.85**	0.88**	0.88**	0.89**	0.36**	0.63**
Thigh	0.47**	0.52**	0.46**	0.54**	0.51**	0.48**	0.20	0.09
Volume Ratio:								
Torso to total body	0.74**	0.67**	0.70**	0.70**	0.69**	0.68**	0.36**	0.65**
Abdomen-hip to total body	0.73**	0.74**	0.77**	0.69**	0.75**	0.73**	0.28*	0.67**
Abdomen-hip to torso	0.38*	0.25	0.49**	0.14	0.45**	0.23	0.09	0.14
Thigh to total body	-0.30*	-5.12**	-0.24	-0.46**	-0.19	-0.49**	-0.18	-0.64**
Thigh to torso	-0.45**	-0.61**	-0.39**	-0.60**	-0.35**	-0.61**	-0.26*	-0.67**
Thigh to abdomen-hip	-0.55**	-0.70**	-0.52**	-0.65**	-0.46**	-0.68**	-0.29*	-0.71**

^a Determined by stereovision body imaging

^b Determined by weight in kg divided by height in m²

^c Determined by air displacement plethysmography

^d Determined by magnetic resonance imaging

* Correlation is significant at 0.05 level (2-tailed)

** Correlation is significant at 0.01 level (2-tailed)