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Utility of ultrasound for body fat assessment: validity and reliability compared to a multi-compartment criterion

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Abstract

Measurement of body composition to assess health risk and prevention is expanding. Accurate portable techniques are needed to facilitate use in clinical settings. This study evaluated the accuracy and repeatability of a portable ultrasound (US) in comparison to a four-compartment criterion for percent body fat (%Fat) in overweight/obese adults. Fifty-one participants (mean $\pm$ SD; Age: 37.2 ± 11.3 yrs; BMI: 31.6 ± 5.2 kg·m⁻²) were measured for %Fat using US (GE Logiq-e) and skinfolds. A subset of 36 participants completed a second day of the same measurements, to determine reliability. US and skinfolds %Fat was calculated using the seven-site Jackson & Pollock equation. The Wang-4C model was used as the criterion method for %Fat. Compared to a gold standard criterion, US %Fat ($36.4 \pm 11.8\%$; $p=0.001$; standard error of estimate [SEE]=3.5%) was significantly higher than the criterion ($33.0 \pm 8.0\%$), but not different than skinfolds ($35.3 \pm 5.9\%$; $p=0.836$; SEE=4.5%). US resulted in good reliability, with no significant differences from Day 1 ($39.95 \pm 15.37\%$) to Day 2 ($40.01 \pm 15.42\%$). Relative consistency was 0.96 and standard error of measure was 0.94%. Although US over-predicted %Fat compared to the criterion, a moderate SEE for US is suggestive of a practical assessment tool in overweight individuals. %Fat differences reported from these field-based techniques are less than reported by other single-measurement laboratory methods and therefore may have utility in a clinical setting. This technique may also accurately track changes.

Keywords

body composition; fat mass; four-compartment model; lean mass; obese; sex; ultrasound biometry

Introduction

The importance of body composition for long term health and risk of chronic disease is expanding (Padwal, *et al.* 2016). It is widely recognized that high body fat is linked with a

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number of health disturbances, such as cardiovascular disease (Rosito, *et al.* 2008), metabolic abnormalities (Smith, *et al.* 2001; Snijder, *et al.* 2004), hypertension (Cassano, *et al.* 1990; Seidell, *et al.* 1991), and sleep apnea (Schafer, *et al.* 2002), among others. Body composition assessment is an important aspect to be integrated within clinical practice as a preventative health approach. Specifically, patient care is shifting toward a more individualized preventative model with the establishment of patient-centered medical homes (Hoff, *et al.* 2012). Measurement of body composition can allow for treatment to be individualized to the patient, is predictive of disease risk, and allows for establishment of optimal nutrition and weight loss goals (Thibault, *et al.* 2012). The obesity epidemic is highlighting the need for accurate assessments of composition as a means for clinical use and has the potential to be integrated into the patient-centered medical home (Jensen 2008). The evaluation of body composition in overweight/obese individuals provides additional challenges when trying to accurately quantify compartments. Despite the obvious increase in body fat in overweight/obese (OW/OB) individuals, excess body fat can also influence the composition of water, mineral, and protein content resulting in inaccurate assessments (Heyward, *et al.* 2004). Previous data suggests that hydration levels are higher in OW/OB men and women (Albu, *et al.* 1989), and relative mineral and protein content in obese are greater than assumed values (Fogelholm, *et al.* 1997). There is also large variability of these compartments among OW/OB individuals (Fuller, *et al.* 1994). Therefore finding accurate field methods to assess body composition in OW/OB individuals is warranted.

Measurement of body composition in a clinical setting is often limited by time, equipment, and expertise. Various techniques to assess body composition are available such as air displacement plethysmography, bioelectrical impedance analysis, and skinfolds, with the majority based upon two-compartment models which divide the body into fat mass and fat-free mass. With advancing technology, accuracy of body composition methods are improving. Multi-compartment models, which assess >3 compartments of the body, reduce the number of assumptions utilized in composition estimation, yielding a more accurate estimate of body composition (Wang, *et al.* 2002). Multi-compartment models are now considered the gold standard for body composition measurement (Heymsfield, *et al.* 2015; Wang, *et al.* 2002). Although multi-compartment models are the most accurate, they require an array of specialized equipment including air displacement plethysmography (ADP), bioelectrical impedance analysis to measure total body water (TBW), and dual energy x-ray absorptiometry (DEXA) to estimate bone mineral to determine a four compartment (4C) model of body composition (Wang, *et al.* 2002).

Due to the potential use of body composition measurement in clinical settings, accurate and portable 'field-based' methods are needed. Traditionally, skinfolds have been widely used as a common field-based method. There are a number of limitations with the skinfold technique, which are compounded in an overfat population (Wagner, *et al.* 1999). Notably, most clinics lack the personnel and time required to complete a skinfold evaluation. Ultrasonography (US), which has been around for decades, has contrasting support for its use as an accurate measurement technique for body composition. It may also potentially address the time limitation with skinfolds, as new software is being developed by a few companies where images can be analyzed in real time and results computed instantaneously. To date, this software is not fully developed or widely available; therefore there is still a time

commitment to analyze the images and compute results. With regards to accuracy, initial investigations by Fanelli and Kuczmarski (1987) suggested that US and skinfolds produced similar measurements. More recently, Leahy et al. (2012) demonstrated that US measures of subcutaneous fat thickness were highly correlated with percent body fat in young healthy adults, when compared to a DEXA criterion. In contrast, our laboratory previously reported a less sophisticated A-mode ultrasound to over-predict body fat in obese subjects, when compared to a multi-compartment criterion (Smith-Ryan, *et al.* 2014). However, to date, we are aware of no previous investigations that have assessed the accuracy of US for percent body fat, in comparison to a multi-compartment criterion body composition method.

Technological advancements have transformed US to a portable, clear-resolution imaging package that is used in a variety of clinics for standard of care practice. Due to the equipment availability and widespread use of US in clinical environments, the ability to accurately assess body composition using US would be a potentially feasible option. Therefore, the purpose of this study was to evaluate the accuracy and repeatability of a portable B-mode ultrasound in comparison to a 4-compartment criterion for percent body fat (%Fat) in overweight and obese adults, as well as evaluate values in men and women, respectively. A secondary purpose was to compare the US to another common field-based method, skinfolds, in overweight and obese adults.

Methods

Subjects

Fifty-one overweight/obese men and women (mean $\pm$ SD; Age: 37.2 ± 11.3 yrs; Height: 173.0 ± 10.1 cm; Weight: 94.7 ± 16.8 kg; body mass index (BMI): 31.6 ± 5.2 kg·m⁻²) volunteered to participate in this study. Descriptive statistics are presented in Table 1. A subset of 36 participants (Age: 38.6 ± 11.2 yrs; Height: 174.2 ± 10.3 cm; Weight: 93.6 ± 16.3 kg; BMI: 31.2 ± 5.1 kg·m⁻²; n=18 men and women, respectively) completed a second day of testing to obtain reliability data. All participants signed an approved informed consent form, in accordance with the Declaration of Helsinki: ethical principles for medical research involving human subjects (Crigger 2000). Eligibility criteria included men and women aged 18–55 years, a body mass index of 25–45 kg·m⁻², and not taking medication that would influence hydration or skeletal muscle mass.

Experimental Design

All participants completed measurements following an 8-hour fast (*ad libitum* water intake was encouraged up to 1h before testing), and abstaining from exercise for a minimum of 24 hours. All body composition tests were performed in the same environment with a consistent ambient temperature, and 24–48 hours apart. For validity comparisons, a 4C model was used as the criterion method, using the equation from Wang et al.(2002). Reproducibility data was obtained on two separate days, at the same time of the morning for both testing periods ($\pm$ 2 hours). All measurements were performed by the same investigator. For both field based measurement techniques body density was calculated; body density is a value of total mass expressed relative to total body volume, based on the assumption that body fat has a density of 0.90 and fat free body has a density of 1.10 (Heyward, *et al.* 2004).

Skinfolds

Skinfold thickness was measured to the nearest millimeter on the subject's right side using a Lange caliper (Beta Technology, Inc., Cambridge, MD). All measurements were taken on the right side of the body while the subject was standing; seven sites were measured in accordance with the International Society for Advances in Kinanthropometry (Kinanthropometry 2001), including the chest, triceps, subscapula, midaxilla, suprailiac, abdomen, and thigh. Thickness measures were taken in duplicate, and completed by the same technician, and used in the seven-site Jackson-Pollock equation to calculate body density for males [Eq. 1] and females [Eq. 2], respectively

$$\text{Males: } \text{Body Density} = 1.11200000 - (0.00043499 \times \text{Sum of Seven Skinfolds}) + (0.00000055 \times \text{Sum of Seven Skinfolds})^2 - (0.00028826 \times \text{Age})$$

(Jackson, et al. 1978); [Eq. 1]

$$\text{Females: } \text{Body Density} = 1.0970 - (0.00046971 \times \text{Sum of Seven Skinfolds}) + (0.00000055 \times \text{Sum of Seven Skinfolds})^2 - (0.00012828 \times \text{Age})$$

(Jackson, et al. 1980). [Eq. 2]

Subsequently, %Fat was calculated according to Siri (1993).

$$\% \text{Fat} = (495 / \text{body density}) - 450. \quad [\text{Eq. 3}]$$

Fat mass (FM; kg) and fat free mass (FFM; kg) were calculated from body mass (BM; kg) and FM values using universal equations (Heyward, *et al.* 2004):

$$\text{FM} = \% \text{Fat} \times \text{BM}; \quad [\text{Eq. 4}]$$

$$\text{FFM} = \text{BM} - \text{FM}. \quad [\text{Eq. 5}]$$

Where FM represents all extractable lipids from adipose and all other tissues, FFM is residual lipid-free chemicals and tissues including water, muscle, bone, connective tissue, and internal organs; %Fat is the amount of FM relative to BM.

Ultrasound Measurements

Measurements were conducted using a portable ultrasound system; NextGen Logiq-e® (GE Healthcare, Wisconsin, USA), using a wide-band linear array probe (12L-RS, 5–13 MHz). All measurements were taken on the right side of the body at the same location of the skinfold measurements and as previously described by Heyward et al. (2004). Specifically, the chest measurement was taken with the probe oriented diagonally at a distance of one-half (for men) and one-third (for women) between the armpit and the nipple. The triceps measurement was taken with the probe placed vertically at the midpoint between the lateral projection of the acromial process and the inferior margin of the olecranon process. For the subscapular thickness, with a diagonal orientation, the measurement was taken just inferior to the scapula. In a vertical position, the midaxillary site was measured below the armpit horizontally from the xiphoid process. The suprailiac measurement was taken just above the iliac crest along the natural cleavage of the skin in a diagonal probe position. The abdomen thickness measurement was taken 3 cm lateral to the belly button with the probe in a horizontal position. Lastly, the thigh measurement, half-way between the inguinal crease and top of the patella, was taken with the probe in a vertical position. Measurements were made by applying a liberal amount of transmission gel to the probe and placing the probe flush against the skin at the specified point. Equal pressure was applied to all sites in order to minimize tissue deformation, with the image captured when the probe became flush with the skin and no layer of gel was visible on the image. Measurements were taken in duplicate by the same technician; a third measurement was taken if two values were not within 10%. In order to compute subcutaneous fat thickness, manual measurement, using the ‘measure’ function within the system, was used to capture fat thickness in cm (Figure 1) just below the skin-facial border. These values were then entered into a custom spreadsheet (Microsoft excel, Microsoft, Redmond, WA); values were first converted to mm and then doubled to mimic a skinfold measurement, and then used in the seven-site Jackson-Pollock equation to calculate body density for males [Eq. 1] and females [Eq. 2], respectively. After calculating body density, %Fat was calculated using the equation by Siri et al. as described above in equations 3–5 (Siri 1993).

Multi-Compartment Criterion

The 4C model requires measurement of separate compartments of the body that are typically estimated from standard assumptions in other 2 and 3C models. With the 4C model, body volume (BV), TBW, and total body bone mineral content (Mo) were measured and then used to estimate FM using the model described by Wang et al.(2002):

$$FM (kg) = 2.748(BV) - 0.699(TBW) + 1.129(Mo) - 2.051(BM). \quad [Eq. 6]$$

%Fat and FFM were then calculated using equations 2 and 3, respectively.

Body volume and BM were determined from air displacement plethysmography using the BodPod (Cosmed, USA Software V 4.2+), which was calibrated prior to each use according to the manufacturer’s guidelines. The subject’s weight (kg) was measured, while wearing a tight-fitting bathing suit or compression shorts and sports bra, to the nearest 0.01 kg using

the device's corresponding scale (Tanita Corp, Tokyo Japan). Two trials were performed for each subject to obtain two BV measurements within 150 mL. Thoracic lung volume was estimated; previous reports have shown that predicted lung volumes are not significantly different than measured volumes, even in obese subjects (Demerath, *et al.* 2002; McCrory, *et al.* 1998).

Total body water was determined from bioelectrical impedance spectroscopy (SFB7, ImpediMed, Queensland, Australia). TBW estimates were taken while the participant laid supine on a table with no contact between the arms, trunk, and legs separated by 30°. Electrodes were placed at the distal ends of the participant's right hand and foot. Prior to analysis, each subject rested for a minimum of five minutes to allow for fluid to settle. The average of two trials within ± 0.05 liters was used to represent each participant's TBW.

Dual energy x-ray absorptiometry (Hologic, Discovery W, Bedford, MA) was used to estimate total bone mineral content (BMC) using the device's default software (Apex V 3.3). BMC was converted to Mo, to be used in the 4C model, using the following equation:

$$\text{Mo} = \text{total body BMC} \times 1.0436 \quad (\text{Wang, et al. 1998}). \quad [\text{Eq. 7}]$$

Statistical Analyses

The accuracy of %Fat estimates (US, skinfolds) were based upon the evaluation of predicted values versus the criterion or actual value from the 4C model by calculating the total error (TE):

$$\text{TE} = \sqrt{\sum \frac{(\text{predicted} - \text{actual})^2}{n}} \quad [\text{Eq. 8}]$$

and

$$\text{CE} = \text{actual} - \text{predicted} \quad [\text{Eq. 9}]$$

Percent body fat scores were analyzed using dependent samples t-tests with Bonferroni adjustments, comparing the 4C criterion with %Fat from US and skinfolds, respectively. These analyses were further evaluated, when split for males and females.

Ultrasound reliability was measured across two days, using a one-way repeated measures analysis of variance. Intraclass correlation coefficient (ICC), standard error of the measurement (SEM), and minimal difference (MD) values were calculated for %Fat. The ICC was calculated in accordance with the following equation (Weir 2005):

$$\text{ICC}_{2,1} = \frac{MSS - MSE}{MSS + (k-1)MSE + \frac{k(MST - MSE)}{n}} \quad [\text{Eq. 10}]$$

All components of the ICC equation were derived from the output of the one-way ANOVA. MSS represents the mean square between subjects, MSE is the mean square error, MST is the mean square between trials/days, k represents the number of trials, and n is the sample size. The SEM for this model was calculated using the following equation (Hopkins 2000):

$$SEM = \sqrt{MSE}. \quad [\text{Eq. 11}]$$

SPSS (IBM Corp, IBM SPSS Statistics for Window, Version 21.0, Armonk, NY), was used to perform validity testing. An alpha level was set at $p = 0.05$. A custom-written spreadsheet (Microsoft excel, Microsoft, Redmond, WA) was used to calculate reliability.

Results

Validity

In comparison to the 4C criterion, the US produced significantly ($p < 0.001$) higher %Fat values ($36.4 \pm 11.8\%$); skinfolds were not significantly different ($35.3 \pm 5.9\%$; $p = 0.836$) (Table 2). For both methods, about 70% of the variance could be explained. The US and skinfolds resulted in 'fairly good' estimates ($SEE = 4.5\%$ Fat) according to Heyward et al. (2004).

When evaluated by sex, US %Fat values were significantly different for females ($p = 0.001$), but not for males ($p = 0.380$), in comparison to the 4C model (Table 2). Skinfolds were not significantly different for men ($p = 0.547$) or women ($p = 0.176$). For men, error values were more acceptable for US ($SEE = 2.4\%$), compared to skinfolds ($SEE = 4.1\%$). For females, the US resulted in fair ($SEE = 3.5\%$) to poor estimates ($SEE = 8.2\%$) of %Fat, with skinfolds producing the most acceptable error rate ($SEE = 2.6\%$).

Reliability

There were no significant differences ($p = 0.734$) between Day 1 ($39.95 \pm 15.37\%$) and Day 2 ($40.01 \pm 15.42\%$) %Fat values for the US. There were also no significant between day differences for men or women (Table 3). Skinfold values were the only method to produce significantly different results from Day 1 ($34.99 \pm 6.04\%$) to Day 2 ($35.62 \pm 5.98\%$). Test-retest values are presented in Table 3. Consistency values were acceptable for both methods with absolute consistency (ICC) values greater than 0.966.

Discussion

Ultrasound is one of few field based tools that can assess total and regional body composition. A number of new ultrasound devices are portable and compact, readily available, and widely used in clinical medicine. In the present study, US produced similar error values as the commonly used skinfold method, but resulted in significantly higher %Fat values than the 4C gold standard. Based on the current results, US may over-predict %Fat in overweight/obese adults, but may still be a useful field-based measurement technique. The skill and time required for US measurement may be less than that required for skinfolds, and US may be more accurate than other commonly used field-based

assessments, such as bioelectrical impedance analysis (Heyward, *et al.* 2004; Moon, *et al.* 2009). Values in the present study were more accurate for men, compared to women, which may be a function of the overall lower adiposity in this sample of men. One previous evaluation contrasts the current results, reporting that US may be superior to skinfolds for measurement of body density in obese individuals (Kuczmarski, *et al.* 1987). However, this previous report utilized an extinct 'advanced diagnostic research' (ADR) US model reducing its generalizability. This previous study also only measured six skinfold sites, excluding the chest and abdominal sites. The addition of those two sites, especially the abdominal fold in the current obese population, may have contributed to the discrepant findings. Additionally, a few recent papers have reported similar validity to the present study when using less sophisticated amplitude (A)-mode ultrasound units (Ripka, *et al.* 2016; Smith-Ryan, *et al.* 2014). These investigations have demonstrated US to underestimate %Fat in young normal weight adults (Ripka, *et al.* 2016), and overestimate in overweight and obese adults (Schoenfeld, *et al.* 2016; Smith-Ryan, *et al.* 2014). Similarly, the B-mode US in the current study provided an overestimation of %Fat in an OW/OB sample.

Despite the variability of precision of B-mode US, it appears to be a reliable method for %Fat measurement, which may provide utility for measurement of body composition in clinical and field-based settings. To date, this is the first investigation that we are aware of that has reported reliability of B-mode US. Previous data from our laboratory have demonstrated good reliability for A-mode US with a standard error of measure of 2.2%Fat in a similar population (Smith-Ryan, *et al.* 2014). The present results demonstrate better reliability with a standard measurement error of 0.94%, which suggests high sensitivity for the potential to detect changes in %Fat in an overfat population. Thus, this portable US may be used to evaluate the effects of a clinical intervention, such as medication, exercise, or diet on %Fat.

Body mass index is still the primary element used to determine health and body 'composition' in the clinic, despite its limitations (Janssen, *et al.* 2004). The lack of time for measurement is understood, but with increasing focus on patient experience and disease prevention in the patient-centered medical home (Hoff, *et al.* 2012), measurement of body composition could play an important role. Dual-energy x-ray absorptiometry has been used in clinical settings, but is costly and often inaccessible for routine care; DEXA may also be less accurate for an overfat population (Williams, *et al.* 2006). In contrast, US is commonly found in a variety of clinics, is portable, non-invasive, and eliminates the concern for radiation found with DEXA. US also allows for segmental and regional evaluation of fat and muscle thickness in regions that may be linked with greater health disparities such as the abdomen and hips, as well as the thigh for detection of sarcopenia (Loenneke, *et al.* 2014). Additionally, although not measured in the present study, US can also be used to accurately measure visceral fat, which is a primary risk factor for cardiovascular disease (Matsuzawa, *et al.* 1995; Ribeiro-Filho, *et al.* 2003).

Males/Females

Due to the varied composition and regional deposition of fat between men and women, sex-specific evaluations are important. Specifically, women have higher body fat levels, the

majority of which remains subcutaneous. In contrast, while lower in overall total body fat, men have a preferential storage of visceral/central fat, which inherently increases risk of metabolic disease (Karastergiou, *et al.* 2012; Karpe, *et al.* 2015). The present study demonstrated that the US may be more valid in men, while over-predicting %Fat in women. Establishing these baseline characteristics of patients, with the ability to track changes over time, may be beneficial for tracking disease risk.

Limitations

In the present study, the same technician completed all of the scans and measurements, thereby potentially masking inter-technician variability which may occur in real world testing. However, unlike the A-mode US, the B-mode US image is clear and likely reduces user error, but due to tissue compression there may be some inter-tester variability, which is not addressed in the present study. Also, to date, there is not a standardized method for measurement of %Fat using US. Additionally, overweight and obese individuals, as measured in the current study, have been suggested to have greater intramuscular fat which may have contributed to the over-prediction of %Fat by interfering with the brightness of the reflection from the US (Nijboer-Oosterveld, *et al.* 2011). Utility of this US in a normal weight population for %Fat measurement has not yet been evaluated against a criterion method, and may provide better estimates. However, O'Neill et al. (2016) recently reported similar %Fat values from predicted multiple regression values in athletes compared to DEXA, which may suggest the error in the present study was a result of higher subcutaneous fat of the participants. Comparison to a multiple compartment criterion, versus DEXA, may also have influenced the error discrepancy.

Summary and Conclusions

When compared to a multi-compartment criterion, the B-mode US resulted in an over-prediction of %Fat in a group of overweight and obese individuals. When stratified by sex, the US proved to be accurate in men, but remained inaccurate in women. When comparing the overestimation of about 3.5%Fat, this is comparable to a number of other more widely accepted body composition techniques, including DEXA and BodPod, neither of which are portable (Heyward, *et al.* 2004; Moon, *et al.* 2009). The repeatability of the US was high, providing potential use as a portable clinical tool. Using %Fat as a clinical outcome and/or tracking in the clinic, rather than body weight or BMI may be a better indicator of disease risk and progression. Future research should evaluate the feasibility of implementing such a tool within a clinic and as a component of a patient centered medical home.

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References

- Albu S, Lichtman S, Heymsfield S, Wang J, Pierson R, Pi-Sunyer F. Reassessment of body composition models in morbidly obese. *Federation of American Societies for Experimental Biology*. 1989; 3:A336.
- Cassano PA, Segal MR, Vokonas PS, Weiss ST. Body fat distribution, blood pressure, and hypertension. A prospective cohort study of men in the normative aging study. *Ann Epidemiol*. 1990; 1:33–48. [PubMed: 1669488]
- Crigger BJ. Declaration of Helsinki revised. *Irb*. 2000; 22:10–11. [PubMed: 11883477]
- Demerath EW, Guo SS, Chumlea WC, Towne B, Roche AF, Siervogel RM. Comparison of percent body fat estimates using air displacement plethysmography and hydrodensitometry in adults and children. *International journal of obesity and related metabolic disorders*. 2002; 26:389–397. [PubMed: 11896495]
- Fogelholm GM, Sievanen HT, van Marken Lichtenbelt WD, Westerterp KR. Assessment of fat-mass loss during weight reduction in obese women. *Metabolism: clinical and experimental*. 1997; 46:968–975. [PubMed: 9258284]
- Fuller NJ, Sawyer MB, Elia M. Comparative evaluation of body composition methods and predictions, and calculation of density and hydration fraction of fat-free mass, in obese women. *Int J Obes Relat Metab Disord*. 1994; 18:503–512. [PubMed: 7920877]
- Heymsfield SB, Ebbeling CB, Zheng J, Pietrobelli A, Strauss BJ, Silva AM, Ludwig DS. Multi-component molecular-level body composition reference methods: evolving concepts and future directions. *Obes Rev*. 2015; 16:282–294. [PubMed: 25645009]
- Heyward, V., Wagner, DR. *Applied Body Composition Assessments*. Human Kinetics; Champaign, IL: 2004.
- Hoff T, Weller W, DePuccio M. The patient-centered medical home: a review of recent research. *Medical care research and review: MCRR*. 2012; 69:619–644. [PubMed: 22645100]
- Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med*. 2000; 30:1–15. [PubMed: 10907753]
- Jackson AS, Pollock ML. Generalized equations for predicting body density of men. *Br J Nutr*. 1978; 40:497–504. [PubMed: 718832]
- Jackson AS, Pollock ML, Ward A. Generalized equations for predicting body density of women. *Medicine and science in sports and exercise*. 1980; 12:175–181. [PubMed: 7402053]
- Janssen I, Katzmarzyk PT, Ross R. Waist circumference and not body mass index explains obesity-related health risk. *The American journal of clinical nutrition*. 2004; 79:379–384. [PubMed: 14985210]
- Jensen MD. Role of body fat distribution and the metabolic complications of obesity. *The Journal of clinical endocrinology and metabolism*. 2008; 93:S57–63. [PubMed: 18987271]
- Karastergiou K, Smith SR, Greenberg AS, Fried SK. Sex differences in human adipose tissues - the biology of pear shape. *Biology of sex differences*. 2012; 3:13. [PubMed: 22651247]
- Karpe F, Pinnick KE. Biology of upper-body and lower-body adipose tissue--link to whole-body phenotypes. *Nature reviews Endocrinology*. 2015; 11:90–100.
- Kinanthropometry TISftAo. *International Standards for Anthropometric Assessment*. National Library of Australia; Australia: 2001. p. 123
- Kuczmarski RJ, Fanelli MT, Koch GG. Ultrasonic assessment of body composition in obese adults: overcoming the limitations of the skinfold caliper. *The American journal of clinical nutrition*. 1987; 45:717–724. [PubMed: 3565298]
- Leahy S, Toomey C, McCreesh K, O'Neill C, Jakeman P. Ultrasound measurement of subcutaneous adipose tissue thickness accurately predicts total and segmental body fat of young adults. *Ultrasound Med Biol*. 2012; 38:28–34. [PubMed: 22104525]
- Loenneke JP, Thibaud RS, Abe T. Estimating site-specific muscle loss: a valuable tool for early sarcopenia detection? *Rejuvenation Res*. 2014; 17:496–498. [PubMed: 25285359]
- Matsuzawa Y, Nakamura T, Shimomura I, Kotani K. Visceral fat accumulation and cardiovascular disease. *Obes Res*. 1995; 3(Suppl 5):645S–647S. [PubMed: 8653544]

- McCrory MA, Mole PA, Gomez TD, Dewey KG, Bernauer EM. Body composition by air-displacement plethysmography by using predicted and measured thoracic gas volumes. *Journal of Applied Physiology*. 1998; 84:1475–1479. [PubMed: 9516218]
- Moon JR, Eckerson JM, Tobkin SE, Smith AE, Lockwood CM, Walter AA, Cramer JT, Beck TW, Stout JR. Estimating body fat in NCAA Division I female athletes: a five-compartment model validation of laboratory methods. *European journal of applied physiology*. 2009; 105:119–130. [PubMed: 18936958]
- Nijboer-Oosterveld J, Van Alfen N, Pillen S. New normal values for quantitative muscle ultrasound: obesity increases muscle echo intensity. *Muscle Nerve*. 2011; 43:142–143. [PubMed: 21082696]
- O'Neill DC, Cronin O, O'Neill SB, Woods T, Keohane DM, Molloy MG, Falvey EC. Application of a Sub-set of Skinfold Sites for Ultrasound Measurement of Subcutaneous Adiposity and Percentage Body Fat Estimation in Athletes. *International journal of sports medicine*. 2016
- Padwal R, Leslie WD, Lix LM, Majumdar SR. Relationship Among Body Fat Percentage, Body Mass Index, and All-Cause Mortality: A Cohort Study. *Annals of internal medicine*. 2016; 164:532–541. [PubMed: 26954388]
- Ribeiro-Filho FF, Faria AN, Azjen S, Zanella MT, Ferreira SR. Methods of estimation of visceral fat: advantages of ultrasonography. *Obes Res*. 2003; 11:1488–1494. [PubMed: 14694213]
- Ripka WL, Ulbricht L, Menghin L, Gewehr PM. Portable A-Mode Ultrasound for Body Composition Assessment in Adolescents. *J Ultrasound Med*. 2016
- Rosito GA, Massaro JM, Hoffmann U, Ruberg FL, Mahabadi AA, Vasan RS, O'Donnell CJ, Fox CS. Pericardial fat, visceral abdominal fat, cardiovascular disease risk factors, and vascular calcification in a community-based sample: the Framingham Heart Study. *Circulation*. 2008; 117:605–613. [PubMed: 18212276]
- Schafer H, Pauleit D, Sudhop T, Gouni-Berthold I, Ewig S, Berthold HK. Body fat distribution, serum leptin, and cardiovascular risk factors in men with obstructive sleep apnea. *Chest*. 2002; 122:829–839. [PubMed: 12226021]
- Schoenfeld BJ, Aragon AA, Moon J, Krieger JW, Tiryaki-Sonmez G. Comparison of amplitude-mode ultrasound versus air displacement plethysmography for assessing body composition changes following participation in a structured weight-loss programme in women. *Clinical physiology and functional imaging*. 2016
- Seidell JC, Cigolini M, Charzewska J, Ellsinger BM, Bjorntorp P, Hautvast JG, Szostak W. Fat distribution and gender differences in serum lipids in men and women from four European communities. *Atherosclerosis*. 1991; 87:203–210. [PubMed: 1854366]
- Siri WE. Body composition from fluid spaces and density: analysis of methods 1961. *Nutrition*. 1993; 9:480–491. discussion 480, 492. [PubMed: 8286893]
- Smith-Ryan AE, Fultz SN, Melvin MN, Wingfield HL, Woessner MN. Reproducibility and validity of A-mode ultrasound for body composition measurement and classification in overweight and obese men and women. *PLoS One*. 2014; 9:e91750. [PubMed: 24618841]
- Smith SR, Lovejoy JC, Greenway F, Ryan D, deJonge L, de la Bretonne J, Volafava J, Bray GA. Contributions of total body fat, abdominal subcutaneous adipose tissue compartments, and visceral adipose tissue to the metabolic complications of obesity. *Metabolism: clinical and experimental*. 2001; 50:425–435. [PubMed: 11288037]
- Snijder MB, Dekker JM, Visser M, Bouter LM, Stehouwer CD, Yudkin JS, Heine RJ, Nijpels G, Seidell JC, Hoorn s. Trunk fat and leg fat have independent and opposite associations with fasting and postload glucose levels: the Hoorn study. *Diabetes Care*. 2004; 27:372–377. [PubMed: 14747216]
- Thibault R, Genton L, Pichard C. Body composition: why, when and for who? *Clin Nutr*. 2012; 31:435–447. [PubMed: 22296871]
- Wagner DR, Heyward VH. Techniques of body composition assessment: a review of laboratory and field methods. *Research quarterly for exercise and sport*. 1999; 70:135–149. [PubMed: 10380245]
- Wang Z, Pi-Sunyer FX, Kotler DP, Wielopolski L, Withers RT, Pierson RN Jr, Heymsfield SB. Multicomponent methods: evaluation of new and traditional soft tissue mineral models by in vivo neutron activation analysis. *The American journal of clinical nutrition*. 2002; 76:968–974. [PubMed: 12399267]

- Wang ZM, Deurenberg P, Guo SS, Pietrobelli A, Wang J, Pierson RN Jr, Heymsfield SB. Six-compartment body composition model: inter-method comparisons of total body fat measurement. *Int J Obes Relat Metab Disord*. 1998; 22:329–337. [PubMed: 9578238]
- Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *Journal of strength and conditioning research/National Strength & Conditioning Association*. 2005; 19:231–240.
- Williams JE, Wells JC, Wilson CM, Haroun D, Lucas A, Fewtrell MS. Evaluation of Lunar Prodigy dual-energy X-ray absorptiometry for assessing body composition in healthy persons and patients by comparison with the criterion 4-component model. *The American journal of clinical nutrition*. 2006; 83:1047–1054. [PubMed: 16685045]

Figure 1.
Subcutaneous fat thickness measured from a B-mode ultrasound. Manual measure function was used to quantify fat thickness at seven different sites.

Table 1

Demographic data for the entire group and for men and women, respectively. (Mean $\pm$ SD).

	Age (yrs)			Height (cm)			Weight (kg)			BMI		
	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD
N=51	20.0–54.0	37.2 $\pm$ 11.3	156.8–194.1	173.0 $\pm$ 10.1	63.4–132.0	94.7 $\pm$ 16.8	25.9–45.6	31.6 $\pm$ 5.2				
Men (n=22)	21.0–53.0	40.4 $\pm$ 10.6	167.7–194.1	182.1 $\pm$ 7.2	76.0–132.0	102.8 $\pm$ 14.2	26.6–40.1	31.0 $\pm$ 4.1				
Women (n=29)	20.0–54.0	34.8 $\pm$ 11.5	156.8–178.2	166.1 $\pm$ 5.4	63.4 – 121.3	88.5 $\pm$ 16.1	25.9–45.6	32.1 $\pm$ 6.0				

Table 2
Validity of the ultrasound and skinfolds compared to the four-compartment criterion.

Sample	Method	Mean	SD	r ²	SEE (%)	TE (%)
All	4C	33.0 ± 8.0				
	Ultrasound	36.4 ± 11.8 *		0.7	3.5	6.9
	Skinfolds	35.3 ± 5.9		0.7	4.5	9.0
Men	4C	26.1 ± 5.8				
	Ultrasound	26.8 ± 4.1		0.6	2.4	3.7
	Skinfolds	29.8 ± 6.0		0.3	4.1	4.3
Women	4C	38.2 ± 5.3				
	Ultrasound	47.4 ± 6.9 *		0.4	4.7	8.9
	Skinfolds	39.0 ± 4.4		0.5	2.6	2.9

* indicates significant difference compared to 4C (p<0.001)

Table 3

Test-retest reliability statistics for B-mode ultrasound total group, ultrasound men only, ultrasound women only, and skinfolds for percent body fat (%Fat) values.

	B-Mode	US-Men	US-Women	Skinfold
p-value	0.734	0.684	0.478	0.013
ICC	0.966	0.939	0.994	0.973
SEM (%Fat)	0.944	0.990	0.905	0.994
MD (%)	2.6	2.7	2.5	2.8