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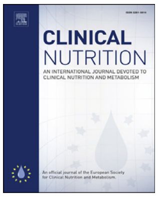

Original article

Validity and reliability of a 4-compartment body composition model using dual energy x-ray absorptiometry-derived body volume

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SUMMARY

Background: Body volume (BV), one component of a four-compartment (4C) body composition model, is commonly assessed using air displacement plethysmography (BodPod). However, dual-energy x-ray absorptiometry (DEXA) has been proposed as an alternative method for calculating BV.

Aims: This investigation evaluated the validity and reliability of DEXA-derived BV measurement and a DEXA-derived 4C model (DEXA-4C) for percent body fat (%BF), fat mass (FM), and lean mass (LM).

Methods: A total sample of 127 men and women (Mean ± SD; Age: 35.8 ± 9.4 years; Body Mass: 98.1 ± 20.9 kg; Height: 176.3 ± 9.2 cm) completed a traditional 4C body composition reference assessment. A DEXA-4C model was created by linearly regressing BodPod BV with DEXA FM, LM, and bone mineral content as independent factors. The DEXA-4C model was validated in a random sub-sample of 27 subjects. Reliability was evaluated in a sample of 40 subjects that underwent a second session of identical testing.

Results: When BV derived from DEXA was applied to a 4C model, there were no significant differences in %BF ($p = 0.404$), FM ($p = 0.295$), or LM ($p = 0.295$) when compared to the traditional 4C model. The approach was also reliable; BV was not different between trials ($p = 0.170$). For BV, %BF, FM, and LM relative consistency values ranged from 0.995 to 0.998. Standard error of measurement for BV was 0.62 L, ranging from 0.831 to 0.960 kg. There were no significant differences between visits for %BF ($p = 0.075$), FM ($p = 0.275$), or LM ($p = 0.542$).

Conclusion: The DEXA-4C model appears to be a valid and reliable method of estimating %BF, FM, and LM. The prediction of BV from DEXA simplifies the acquisition of 4C body composition by eliminating the need for an additional BV assessment.

1. Introduction

The science of body composition measurement is expanding as it plays an important role in disease detection and prevention. Excess fat mass has been associated with orthopedic injury, cardiovascular disease, and other indices of metabolic dysfunction [1–3]. Conversely, inadequate lean mass and bone mineral content have been associated with increased musculoskeletal injury risk in aging and clinical populations, as well as compromised performance in athletes [4,5]. Sophisticated anthropomorphic measures such as percent body fat (%BF), regional adiposity, and fat to lean mass ratio have been demonstrated as more suitable health predictors than the commonly used body mass index (BMI) [6,7]. A variety of methods for assessing whole body composition have been developed to better evaluate each individual's health status, but technology is improving in order to better estimate body tissues.

Common body composition assessment techniques such as skinfold analysis and bioelectrical impedance are based on two-compartment (2C) models, which divide the body into fat mass (FM) and fat free mass (FFM). Such models assume uniform composition of FFM in making anthropomorphic predictions, despite the variation that exists in total body water (TBW), protein

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mass, and bone mineral content (BMC) [8,9]. To compensate for such assumptions, multi-compartment models have been developed to individually assess the varying components of FFM [10]. A four-compartment (4C) model factoring in body mass (BM), body volume (BV), TBW, and BMC is considered by many as the gold standard in body composition [11].

The 4C model measurement, and associated body compartments, is accomplished using a variety of equipment, but also requires considerable time and cost. Dual energy x-ray absorptiometry (DEXA) is used to estimate total body BMC. The gold standard for TBW measurement is the use of deuterium oxide dilution; however, estimates have been shown to be valid when using multifrequency bioelectrical impedance spectroscopy (BIS) [12]. Historically, underwater weighing (UWW) has been the standard method of determining BV based on hydrodensitometry. In recent decades, air displacement plethsmyography (ADP) has replaced UWW as a less invasive and more reliable method of assessing BV [13,14]. Though considered more convenient than earlier methods, ADP requires specialized equipment (BodPod®), tight fitting clothing, and may be highly variable based on subject attire and body hair [15]. Additionally, both ADP and UWW must make assumptions regarding trapped air in the digestive tract or lungs that may compromise validity in certain individuals [16].

Dual x-ray absorptiometry may serve as an alternative method of estimating BV [11,16]. Unlike other displacement techniques, the x-ray attenuations utilized by DEXA exclude internal air voids when analyzing soft tissues, and therefore may provide more accurate volume estimations. One previous investigation from Wilson et al. [11] has suggested that DEXA may be used to determine BV, but the population utilized was small ($n = 11$) and the authors suggested that further validation with a larger sample is necessary. The ability to use a DEXA-derived method for BV estimation may eliminate the need for ADP and/or UWW, reducing the time and cost required to obtain BV and use in a multi-compartment model. Greater testing efficiency would make use of a 4C body composition model more practical in both clinical and laboratory settings. Therefore, the aims of the current investigation were three-fold: 1) to develop a method of deriving BV from standard DEXA tissue measurements; 2) evaluate the validity of using DEXA-derived BV in a 4C body composition model; and 3) determine the reliability of DEXA-derived BV and 4C composition variables, including %BF, FM, and LM.

2. Materials and methods

2.1. Participants

A sample of 127 men and women (Mean ± SD; Age: 35.8 ± 9.4 years; Body Mass: 98.1 ± 20.9 kg; Height: 176.3 ± 9.2 cm, BMI: 31.4 ± 5.5 kg m^{-2}) volunteered to participate in body composition assessments for two separate approved studies (IRB#12-1026, 14-1045). Participant BMIs ranged from normal to obese (BMI:19.9–45.6 kg m^{-2}); with 104 Caucasians, 19 African Americans, and 3 Hispanics. A sample of 100 people was used to develop the coefficients reported in Equation (2); a subsample of 27 was used to cross-validate the equation (Fig. 1). All procedures were approved by the University's Biomedical Institutional Review Board. Prior to testing, all subjects reviewed and signed a written informed consent. In this observational study, subjects were excluded from the study if they were taking medication known to affect hydration status; if they were pregnant or lactating; or if they had undergone weight loss surgery. Subjects reported to the laboratory following a minimum of an eight-hour fast for a single body composition testing session. Additionally, subjects were asked to abstain from caffeine, alcohol, and vigorous exercise at least 24 h prior to the testing session. To evaluate the reliability of testing methods, a sample of participants ($n = 40$) from the original 127 underwent a second session of identical body composition testing at least 7 and no more than 10 days following their initial visit.

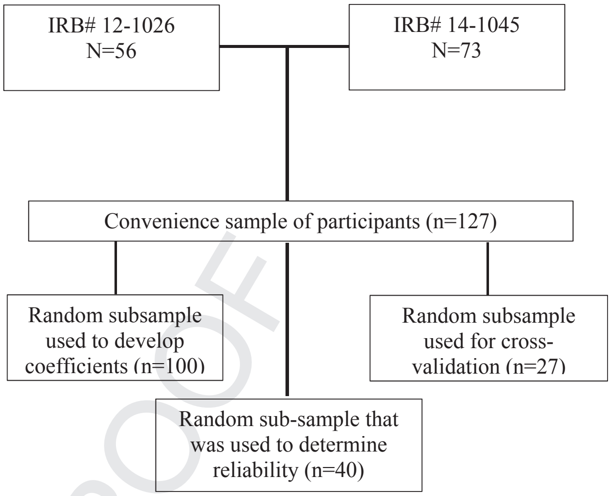

Fig. 1. Flow diagram of participant organization.

2.2. 4-Compartment model

Percent body fat was estimated using a criterion 4C model described by Wang et al. [17].

$$\begin{aligned} &\mathrm{FM}\ (\mathrm{kg}) = 2.748(\mathrm{BV}) - 0.699(\mathrm{TBW}) + 1.129(\mathrm{Mo}) - 2.051(\mathrm{BM});\\ &\%\mathrm{BF} = (\mathrm{FM}/\mathrm{BM}) \times 100;\\ &\mathrm{FFM}\ (\mathrm{kg}) = \mathrm{BM} - \mathrm{FM}. \end{aligned} \tag{1}$$

The model was calculated using traditional measurements of BV from ADP, TBW from bioelectrical impedance spectroscopy (BIS), and total body bone mineral (Mo) from DEXA. A modified 4C model was calculated to determine FM using a DEXA-derived value of BV based on mass measurements found on a standard whole body DEXA report.

2.3. Bioelectrical impedance spectroscopy

Total body water was determined using a multi-frequency BIS (SFB7, ImpediMed, Queensland, Australia) [12]. Estimates were taken after the subject lay supine for a minimum of 5 min. Two single tab electrodes were placed at the distal end of the subject's right wrist and hand and right ankle and foot, with 5 cm between each respective set of electrodes. Measurements were taken while the subject lay supine on the table with a space between their arms and torso and space between their legs. The average of two trials was used to represent TBW. The measurement of TBW from BIS has been shown to be valid against a deuterium dilution method [12]. Based on procedures described by Weir et al. [18], test-retest reliability ($n = 35$) from our laboratory demonstrated intraclass correlation coefficients (model 2,1) were 0.99, standard error of measurement of 0.93 L (1.86% of the mean), with no systematic error between testing days ($p = 0.594$).

2.4. Air displacement plethysmography

Body volume and BM were determined for the traditional equation from ADP using the BodPod® (Cosmed, USA Software V

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