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Original article

Accuracy of quantitative magnetic resonance and eight-electrode bioelectrical impedance analysis in normal weight and obese women

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SUMMARY

Background & aims: Quantitative magnetic resonance (QMR) has previously been shown to both overestimate and underestimate average fat mass (FM) in humans. Eight-electrode bioelectrical impedance analysis (BIA) has previously been found biased as well as successfully validated. We report cross-sectional accuracy of QMR and eight-electrode BIA evaluated with air displacement plethysmography (ADP) as reference method.

Methods: Fat mass and fat free mass (FFM) by QMR and eight-electrode BIA were evaluated against ADP as reference in 38 normal weight and 30 obese women. Total body water estimates by QMR and eight-electrode BIA were compared.

Results: Fat mass was overestimated by QMR (1 ± 2 kg, $p < 0.001$) and was underestimated by eight-electrode BIA (1 ± 3 kg, $p = 0.03$, Bonferroni adjusted $p = 0.29$) in normal weight women. Fat mass was underestimated by both QMR (2 ± 2 kg, $p < 0.001$) and eight-electrode BIA (9 ± 3 kg, $p < 0.001$) in obese women. Fat free mass biases were of similar magnitude but in opposite direction to FM biases. Total body water estimates were larger by eight-electrode BIA compared to QMR (1–10 kg).

Conclusions: Fat mass and FFM by QMR were both biased but in opposite directions in both normal weight and obese women. Eight-electrode BIA FM and FFM estimates were imprecise and biased in obese women. Thus, QMR is more precise and more accurate than eight-electrode BIA for estimating body composition in women, but is not accurate enough to be used for individual single assessment of body composition.

1. Introduction

Assessment of nutritional status frequently involves measurement of body composition. Body composition measurements are used e.g. to evaluate dietary treatment for malnutrition and to assess sarcopenia.

Obesity is characterized by both increased fat mass (FM)[1] and increased total body water (TBW), predominantly of the extracellular water (ECW) compartment.[2] Body composition assessment in severe obesity can be a practical challenge, e.g. with risk of exceeding the weight limits of the equipment[3] and also uncertain validity at higher body mass index (BMI).[4] Thus, there is a need for accurate body composition methods in obese subjects.

Quantitative magnetic resonance (QMR) provides excellent precision[5,6] and is a safe and noninvasive method for measuring body composition that is convenient for the subjects.[7] The QMR technique is based on nuclear magnetic resonance.[8] Accuracy of cross-sectional FM measurements in humans by QMR has previously been scarcely evaluated, showing both underestimation of average FM[6,9] as well as overestimation.[5] The FM bias increased with increasing body weight (BW).[5,9]

Bioelectrical impedance analysis (BIA) is based on capacitance and resistance.[10] Impedance methods are quick, but need further evaluation in extreme BMI ranges and abnormal hydration.[4] The trunk contributes minimally to whole body impedance, and whole body composition is mainly predicted by impedance in the limbs.[11] Thus, in whole body BIA measurements changes in impedance are closely related to changes in fat free mass (FFM) in the limbs, while changes of FFM in the trunk are theoretically much

Abbreviations: QMR, quantitative magnetic resonance; BIA, bioelectrical impedance analysis; ADP, air displacement plethysmography; FM, fat mass; FFM, fat free mass; TBW, total body water; ECW, extracellular water; BW, body weight.

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less related to impedance.[10] A segmental approach could possibly improve detection of regional body composition changes, and also contribute to enhanced whole body composition assessment. Previous studies on different eight-electrode BIA equipments have been both successfully validated[12–16] as well as biased.[14]

Air displacement plethysmography (ADP) is a 2-compartment model which fractions the body into FM and FFM,[17] and found reliable for estimation of body density,[18] also in obese subjects.[19] Furthermore, ADP was found reliable and valid for determining body fat percent in adults,[20,21] although slightly biased in lean subjects.[21] Thus, ADP was used as reference method in this study.

This study was a control study to a larger study of pregnant women. The aim of the present study was to evaluate assessment of average FM and FFM by QMR and by eight-electrode BIA against ADP as reference in a group of normal weight and obese women. Additionally, estimates of TBW by BIA and by QMR were compared.

2. Materials and methods

2.1. Study design and population

This study was part of a cross-sectional study aimed at investigating vitamin D status and body composition in normal weight and obese women in Gothenburg, Sweden.[22] Inclusion criteria were 20–45 years of age and BMI of 18.5–24.9 or >30.0 kg/m^2. Inclusion BMI was based on self-reported body height and BW. Exclusion criteria were smoking, pregnancy, non-European descent, severe psychiatric disorder and other diseases or medications known to affect vitamin D status. Forty-four normal weight and 43 obese women were recruited from September 2009 to October 2011. Women lacking some measurement of the 3 body composition methods (QMR, BIA, ADP) were excluded from this analysis, resulting in 38 normal weight women and 30 obese women. Two women in the normal weight group had a BMI <18.5 kg/m^2 when they were measured (17.8 and 18.3 kg/m^2), but exclusion of their data did not change the observed differences between body composition methods. Thus, they were still included. Normal weight women were recruited through postings at public billboards and advertisement in a newspaper. Obese women were recruited from the Obesity Unit at Sahlgrenska University Hospital, Gothenburg, to which they were referred for weight loss treatment. Obese women were also recruited through advertisements in a newspaper. All the measurements took place before the beginning of any weight loss treatment, and all ADP and eight-electrode BIA measurements were performed by the same dietician (Therese Karlsson). The study was approved by the Ethics Committee at the University of Gothenburg, addendum number 402-08. Oral and written information were given to all participants, and written informed consent was obtained from each participant before entering the study.

2.2. Anthropometry

Body height was measured using a stadiometer, to the nearest 0.5 centimeter (cm). Body weight was measured separately by all three body composition assessment methods, see below. Body mass index was calculated based on body height and BW from ADP measurement, where the ADP equipment used whole cm.

2.3. Body composition

Body composition was measured in fasting state, and all 3 methods were measured within maximum 2 h. Bioelectrical impedance analysis was measured after sitting in the ADP or after walking from the previous QMR measurement. Thirty-eight normal weight woman and 19 obese women were measured after fasting over night. Eleven obese women were measured day time after at least 4 h of fasting. Air displacement plethysmography was used as body composition reference method.

2.4. Quantitative magnetic resonance

An equipment using magnetic resonance (EchoMRI-AH by EchoMRI, Houston, TX) was used to measure body composition. The measurement was performed in a box, inside dimensions $L = 198$ cm, $W = 61$ cm and $H = 61$ cm, with a homogeneous low-intensity magnetic field of 0.0065 T. Body weight was measured with Tanita BWB-620, minimum graduation 0.05 kg, maximum weight 200 kg. The subject to be measured was placed in a comfortable position halfway between sitting and lying down. The patient support was moved into the measurement box and the door of copper net was closed. The measurement box was thus shielded from external electric interference. The integration time for one measurement was set to 3 min. The measurement voxel was the entire volume inside the box. Daily, before any measurements were made, a system test was performed to verify that the system was operating within its specifications. During the system test the measurement box contained ten gallons of Canola oil of room temperature (22 ± 1 °C). To further decrease the influence of measurement noise, each examination consisted of four contiguous measurements. Final body composition results were then calculated as the means of the last 3 measurements, with CV 0.3% from these triplicate measurements. The nuclear magnetic resonance signals from fat, free water and muscle mass differ,[8] and multiple linear regression prediction formulas calibrated against canola oil, lean animal tissues and tap water are used to calculate fat, lean mass and free water.[6] Total body water is then derived from the difference between the total amount of protons and the fat found by regression analysis.[8] Consequently, TBW by QMR includes the sum of free water and water in lean mass.[8] The output from a measurement was total fat mass (FM_{QMR}), total lean tissue mass, total water mass ($TBW_{QMRdefault}$) and free water mass. However, lean tissue mass by QMR is not equivalent to non-FM.[8] Therefore, to compare QMR to FFM by ADP, FFM by QMR was calculated as BW minus FM_{QMR}. Total body water by QMR was either based on the values received from the QMR ($TBW_{QMRdefault}$) or calculated as a fraction of FFM by QMR ($TBW_{QMR0.73}$), according to the assumption that the ratio of TBW/FFM is 0.73[23]:

$$FFM_{QMR}\,(kg) = BW - FM_{QMR}$$

$$TBW_{QMR0.73}\,(kg) = 0.73 * FFM_{QMR}$$

2.5. Eight-electrode BIA

Tanita MC-180MA III multi-frequency eight-electrode, Tanita Corporation, was used for BIA measurement. Reported accuracy by the manufacturer is 2%.[24] Subjects were measured in underwear, in a standing position, and were asked to stand barefoot on toe- and heel electrodes and to hold the handgrips with arms hanging down a few centimeters from the hip. The eight-electrode method enables segmental impedance measurement. As ADP reference data does not present segmental analysis, segmental body composition results by BIA were not presented in this study. MC-180MA measured at 5 kHz, 50 kHz, 250 kHz and 500 kHz, current 90 μA or less. Minimum weight graduation was 0.05 kg. Body composition by BIA was calculated from the measured impedance by the manufacturer's proprietary software.[24] Body