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Original Article

Bioimpedance spectroscopy for the estimation of fat-free mass in end-stage renal disease☆

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SUMMARY

Background & aims: Bioimpedance spectroscopy may provide reliable estimates of fat-free mass in end-stage renal disease patients. We aimed to evaluate the ability of bioimpedance spectroscopy to estimate fat-free mass in end-stage renal disease patients using dual-energy X-ray absorptiometry as a reference.
Methods: Fat-free mass measured by bioimpedance spectroscopy was compared to fat-free mass measured by dual-energy X-ray absorptiometry in 16 end-stage renal disease patients on hemodialysis, 12 undialysed end-stage renal disease patients and 23 control subjects.
Results: Methods were highly correlated for fat-free mass in all subject groups ($r = 0.87$, $P < 0.001$). Mean bioimpedance spectroscopy measures of fat-free mass were not different from the dual-energy X-ray absorptiometry measures in any subject group. Individual comparisons revealed wide limits of agreement between methods in hemodialysis (11.6 to −9.72 kg) and undialysed patients (10.95 to −14.73 kg).
Conclusions: Although bioimpedance spectroscopy estimates of fat-free mass in the end-stage renal disease patient groups were not different from dual-energy X-ray absorptiometry and the methods were highly correlated, there was great individual variability. From these data it is clear that future studies are warranted before bioimpedance spectroscopy can be recommended as a valid clinical tool for assessing fat-free mass in end-stage renal disease patients.

1. Introduction

End-stage renal disease (ESRD) is characterized by a decreased ability of the kidneys to excrete and regulate body water, minerals and organic compounds.[1] Hemodialysis (HD) attempts to manage these symptoms by restoring fluid and electrolyte balance.[1] As a result of HD, shifts from the intracellular fluid (ICF) to the extracellular fluid (ECF) compartment may occur.[1] Loss of lean tissue related to malnutrition and other consequences of renal impairment may also contribute to altered body composition.[1] The prevalence of malnutrition among patients at the initiation of HD has been reported to be as high as 40%.[2] Nutritional status worsens as the disease state progresses, and malnutrition is a significant predictor of morbidity and mortality in ESRD.[3] Accurate and reliable methods to assess body composition are needed to effectively assess the symptoms and severity of the disease, monitor changes in fluid and tissue levels and evaluate the efficacy of therapeutic treatment interventions.

Anthropometric measurements of height, weight and BMI are commonly used to assess nutritional status and estimate body composition.[4] This method is not sensitive enough to identify fluid shifts and malnutrition, because changes that occur at the cellular and tissue levels cannot be evaluated.[5] DXA is capable of evaluating body composition with greater sensitivity and is considered a reference method for estimating FFM, FM and bone mineral content.[6] It is recommended by the National Kidney Foundation's Kidney Disease Outcomes Quality Initiative (K/DOQI) clinical practice guidelines as a valid tool for measuring body composition in ESRD.[2] Factors limiting its utility include the cost of instrumentation, exposure to ionizing radiation, inability to quantify fluid status, non-portability and the need for trained technicians.[2,7]

Abbreviations: BIS, bioimpedance spectroscopy; FFM, fat-free mass; ESRD, end-stage renal disease; HD, hemodialysis; UD, undialysed.

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Bioimpedance spectroscopy (BIS) is a relatively inexpensive, safe and portable method of body composition that has the potential to overcome many of these limitations. BIS devices measure impedance over a spectrum of frequencies and use software to fit the impedance data to the Cole model.[8] The modeled data can be applied to equations for the calculation of ECF and ICF. Estimates of fat-free mass (FFM) can be calculated based on the manufacturer's software. Application of the current over a spectrum of frequencies allows for the differentiation of the ECF and ICF compartments and provides estimates of FFM[9] making this method especially appealing to the renal community. A consensus regarding the use of BIS to evaluate body composition in ESRD and other clinical populations has not been reached. The aim of the present study was to evaluate the ability of the BIS to estimate FFM compared to DXA in ESRD patients.

2. Subjects and methods

Subjects in this analysis were part of a larger study designed to evaluate responses to exercise in patients with ESRD after changing treatments to daily dialysis or transplantation. The analyses presented here are from the baseline data collected on 51 of the study subjects (9 females, and 42 males) aged 21–64 years (45 ± 11) with mean body mass index (BMI) 27.29 kg/m^2. Subjects were recruited into three groups. Group I consisted of 16 ESRD patients treated with HD (25.8 ± 23.4 mo; range: 3–72 mo) who had a mean age of 42.30 ± 14.80 years and a mean BMI of 27.19 ± 5.21 kg/m^2. Group II consisted of 12 undialysed (UD) ESRD patients who had a mean age of 47.68 ± 10.00 years and a mean BMI of 28.83 ± 4.15 kg/m^2. Lastly, group III consisted of 23 healthy control subjects who had a mean age of 45.85 ± 8.40 years and mean BMI of 26.55 ± 4.35 kg/m^2. ESRD patients were recruited from several dialysis centers in the San Francisco Bay area and Minneapolis/St Paul as described by Painter et al. (2010) in the American Journal of Kidney Disease (in press). ESRD patients scheduled for transplant were referred from the University of California at San Francisco and the University of Minnesota. Patients were referred to the study by nurse coordinators and/or physicians. Sedentary healthy control subjects were recruited from kidney donors (>1 year post kidney donation with normal renal function as indicated by estimated GFR) at the University of Minnesota. An attempt was made to match the group of control subjects to the HD and UD patient groups by percentage of women, and age decades, although there were inadequate donors <30 years of age.

The present study was initiated at the University of California at San Francisco, and completed at the University of Minnesota. All testing was performed in the General Clinical Research Center of the respective institutions. Testing was done on a mid-week non-dialysis day, at least 15 h after completion of the dialysis treatment. Subjects were instructed to avoid vigorous physical activity 24 h prior to testing. Due to the duration of testing and the multiple procedures involved in the overall study, a small breakfast was provided to subjects 30–45 min prior to the body composition analysis. Body composition was assessed in all subjects by DXA and BIS. DXA measurements of body composition were taken first, followed by instruction to walk 150 feet and then rest in the supine position for 10 min prior to the BIS measurements. All subjects signed consent documents approved by the Committee on Human Subjects at the University of California-San Francisco and the Institutional Review Board at the University of Minnesota.

2.1. DXA

A DXA whole-body scan was performed using a General Electric Lunar Prodigy scanner (Lunar Radiation Corp., Madison, WI) and provided estimates of FFM calculated according to the manufacturer's software (version 8.8). DXA passes two X-ray energies through the body. The initial energy emitted is known and the final energy is detected after passing through the body. These values are then applied to known body mass attenuation equations and the proportion of FM to FFM is used to determine whole-body composition.[7,10] To help ensure accuracy, subjects were asked to remove all metal items prior to the DXA scan. None of the female subjects were pregnant at the time of examination.

2.2. BIS

BIS measurements of ICF, ECF, and FFM were taken 10 min after the subjects were asked to assume a supine position, using the ImpediMed SFB7 device (ImpediMed Limited, Eight Mile Plains, Australia). BIS measures the body's impedance to an electrical current and based on impedance values, fluid volumes and FFM can be determined.[11] Electrodes were arranged in the traditional tetrapolar configuration, with injection electrodes placed wrist-to-ankle and sensing electrodes placed hand to foot.[12] For patients on HD therapy, electrodes were placed on the side of the body contralateral to the arteriovenous fistula. The ImpediMed SFB7 device made ten measurements at 1-s intervals by applying an electrical current at 256 frequencies ranging from 4 kHz to 1000 kHz. The Cole method of biophysical modeling and the Hanai mixture theory equations using standard resistivity constants were then used to calculate ECF, and ICF.[13] Estimates of FFM were calculated per the manufacture's software.

2.3. Statistical analysis

Data are reported as means ± standard deviation (SD). Comparisons between methods were made in all subject groups (HD, UD and controls) for measures of FFM. For group-level comparisons: A one-way analysis of variance (ANOVA) was used to compare the mean values of subject characteristics and body composition measures between all subject groups, and where ANOVA showed statistically significant differences, post hoc comparisons for unequal variances were made using the Tamhane's test. The Student's paired *t*-test was used to compare mean-level accuracy of BIS within each group and the Pearson's Product Moment Correlation analysis was used to determine the relative agreement between DXA and BIS. To assess the individual variability between the DXA and BIS methods for FFM, the Bland–Altman method[14] was used. The BIS percent differences from the DXA reference value for estimates of FFM were calculated in each individual ESRD patient and control subject. BIS bias was calculated by subtracting the BIS value from the DXA value (DXA–BIS). This bias was evaluated for each subject and also across subject groups, by ANOVA. Correlations between subject characteristics of age, gender and BMI were evaluated for their contribution to the BIS bias in estimates of FFM. To determine if these variables were significant predictors of BIS bias, a general linear model with backwards step-wise model selection was fit to the data. Statistical analyses were performed using SPSS 17.0 for Windows software (SPSS, Inc., Chicago, IL) and statistical significance was set at an alpha value ≤ 0.05. Bland–Altman plots were created using Sigma Plot 10.0 (Systat Software, Inc. Chicago, IL).

3. Results

3.1. Subject characteristics

Mean physical and clinical characteristics of all subjects and each of the groups are summarized in Table 1. No significant differences