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Clinical Investigations

Comparison of Direct Body Composition Assessment Methods in Patients With Chronic Heart Failure

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ABSTRACT

Background: We examined the validity of leg-to-leg bioelectrical impedance analysis (BIA) and near-infrared interactance (NIR) to assess body composition in chronic heart failure (CHF) patients.

Methods and Results: A total of 140 patients with CHF were enrolled in this cross-sectional study between June 2008 and July 2009. Dual energy x-ray absorptiometry (DEXA) served as the reference standard. A priori, desired precision levels were set at $\pm 3.5\%$ body fat and ± 3.5 kg lean body mass. Mean age was 63, 74% were male, and 90% were Caucasian. BIA- and NIR-ascertained percent body fat and lean body mass were highly correlated to DEXA. Mean differences and limits of agreement for NIR were -0.3% $\pm$ 5.1% for percent body fat and 2.9 kg $\pm$ 4.3 kg for lean body mass. Mean difference and limits of agreement for BIA percent body fat was 0.8% $\pm$ 5.8%. BIA lean body mass showed poor agreement with DEXA because of variable limits of agreement across the range of measurement (Pitman's test $P < .0001$).

Conclusions: In patients with CHF, both NIR and BIA accurately measure body fat. However, both methods were imprecise. NIR overestimated lean body mass and BIA was not useful to assess this parameter. Further study is required, including examination of the utility of these field methods in serially assessing body composition. (*J Cardiac Fail 2010;16:867−872*)

Key Words: Bioelectrical impedance analysis, near-infrared interactance, obesity, lean body mass.

Cachexia is a poor prognostic sign in chronic heart failure (CHF) and a central feature of cachexia is weight loss (corrected for changes in fluid status).[1] Serial assessments of body weight or body mass index (BMI) are often used to monitor cachexia. Weight loss alone, however, does not identify the full effect of cachexia on physical function and prognosis.[2] Recently, a consensus panel defined cachexia as at least a 5% loss of edema-free body weight during the previous 12 months or less, plus 3 of the following: decreased muscle strength, fatigue, anorexia, low muscle mass, and biochemical abnormalities characteristic of inflammation, anemia, or hypoalbuminemia.[1] Therefore, implicit in this definition is the need to quantify body composition, and in particular, muscle mass, because muscle is the primary tissue component lost in cachexic patients. There is an additional reason to perform body composition measurements in

patients with CHF. In this population, a higher BMI has been associated with improved survival,[3] a phenomenon known as the "obesity paradox."[4] Recent evidence suggests that the obesity paradox may be explained in part by the inadequacy of BMI to discriminate between muscle and fat tissue.[5] This further underscores the importance of directly measured body composition.

Although dual energy x-ray absorptiometry (DEXA) is considered a valid method for assessing body composition, few heart failure clinics have direct access to DEXA scanning, which can be expensive and requires technical expertise. Direct and convenient measures of measuring body composition using portable devices are now available and may be useful to accurately measure and monitor changes in body fat and lean body mass in the CHF population. The main objective of this study was to examine the concurrent validity of leg-to-leg bioelectrical impedance analysis (BIA) and near-infrared interactance (NIR) compared with DEXA in assessing body composition in patients with CHF. We further characterized whether clinical factors (sex and use of diuretics) affect the accuracy of NIR or BIA when measuring body fat or lean body mass.

Methods

Patient Population

As previously reported,[5] we conducted a cross-sectional study of 140 consecutive patients with systolic and/or diastolic CHF recruited from the University of Alberta Heart Function Clinic between June 2008 and July 2009. The present analysis represents a predefined secondary objective of the original study. Patients ≥18 years of age who were able to provide informed consent and who were clinically euvolemic were included. Patients who were unable to lay flat or who exceeded the 136 kg (300 lb) weight limit for the DEXA scan were excluded. All body composition assessments were performed within the same day during a single scheduled visit. The study was approved by the University of Alberta Health Research Ethics Board.

DEXA

The criterion for assessment of body composition was the 3-compartment DEXA, performed with a Hologic Series Delphi-A Fan Beam X-ray Bone Densitometer with software version 12.4 (Hologic Inc, Bedford, MA). The whole-body fan beam method was used to analyze body composition.[6,7] Three experienced technicians performed all scans in standard fashion. Quality control tests were run every morning using a standard block of tissue-equivalent material, and weekly using a whole body phantom and tissue calibration step phantom. Patients were asked to refrain from drinking more than 500 mL of fluid an hour before their scans.

NIR Interactance

NIR interactance is a method of assessing body composition via light emission using NIR spectroscopy.[8] NIR interactance measured at the biceps of the dominant arm has been validated against the hydrostatic densitometry method.[9] We used a commercial NIR interactance device (portable Futrex 6100, Gaithersburg, MD) to estimate the percentage of body fat and lean body mass. The Futrex 6100 has an estimable body fat range of 3% to 46% and a body mass limit of 227 kg (500 lb).[10] Because NIR cannot differentiate between bone and muscle mass, the lean body mass measurement taken using NIR reflects both of these tissue compartments. After entering the required data (date of birth, sex, weight, and height) of each patient into the device, NIR measurements were performed by placing the Futrex sensor on the upper aspect of the dominant arm for several seconds. The average percent total body fat and lean body mass of 3 consecutive pairs of NIR measurements were recorded. The same investigator (A.O.) performed all NIR measurements.

BIA

BIA measures the resistance of body tissues to the flow of an electrical current. BIA has been validated as a measure of body composition against hydrodensiometry in normal subjects.[11] We used the commercially available Tanita BC 544 Ironman scale (Tanita Corporation of America, Inc, Arlington Heights, IL) to estimate percent total body fat and lean body mass. Contraindications to BIA include internal cardioverter defibrillators and pacemakers; therefore, participants with these devices were excluded from BIA measurement. The Tanita BC554 Ironman has an estimable body fat range of 5% to 75% and weight capacity of 150 kg (330 lb).[12] Lean body mass measurements taken using BIA do not include bone mass. The patients' percent body fat and lean body mass measurements were taken while in a standing position with the electrodes in contact with bare feet and wearing hospital gown and undergarments. The body fat analyzer automatically measures weight and then impedance after entering the patients' sex, age, height, and fitness level (either "inactive" or "athletic"). The average percent total body fat and lean body mass of three consecutive pairs of BIA measurements was recorded.

Statistical Methods

Percent body fat and lean body mass were compared between both field methods and DEXA with paired t-tests, stratified by sex. Partial Pearson's correlation analysis and Bland-Altman plots were performed for the assessment of validity. Sex-specific partial Pearson's correlation coefficients, adjusted for age, were calculated to gauge the degree of agreement between the different devices. Because NIR lean body mass measurements include bone mass, NIR-measured lean body mass was always compared to DEXA-measured lean + bone mass, whereas BIA-measured lean body mass was compared with DEXA-measured lean body mass alone. To test for sex differences, the correlation coefficients were compared using z-tests after applying Fisher's z-transformation to the coefficients.[13,14]

Agreement between each field method and DEXA was assessed in 2 steps according to the recommendations of Bland and Altman,[15] and was performed separately for body fat percentage and lean body mass. In the Bland and Altman method, the mean difference (positive or negative bias) between the 2 measurements (field method − DEXA; y-axis) is plotted as a function of the average of the 2 measurements ([field method + DEXA]/2; x-axis) of each sample. First, Pitman's test of difference was used to make sure that no significant relationship was apparent between the differences of the 2 measurements and the estimated mean value, with a P value > .2 considered not significant. Second, if differences were normally distributed, we calculated the mean positive or negative bias (constant error, reflecting accuracy), standard deviation (SD) (true error, reflecting precision), and limits of agreement (1.96 times the SD of the between-method differences). Where differences were not normally distributed, data were transformed by taking the

natural logs of both methods and back-transformed to antilogs expressed as a ratio to calculate the limits of agreement.[15]

Lohman[16] developed standards for evaluating prediction errors of body composition methods based on empirically derived measurement errors associated with body density as the criterion. The recommended minimum acceptable SD or true error for total percent body fat is ±3.5%,[17,18] and has been used by other investigators.[19,20] In addition, we set the acceptable SD for lean body mass as ±3.5 kg based on Lohmans'[16] standards for evaluating prediction errors. To examine whether use of diuretic medications influenced the accuracy of BIA or NIR, we repeated the analyses in only the subset of patients taking diuretics.

Unless otherwise stated, results are summarized as mean ± SD. A *P* value < .05 was considered to be statistically significant unless otherwise indicated. Statistical analyses were performed with STATA version 10.1 (Stata Corporation, College Station, TX).

Results

Total and sex-specific baseline characteristics are presented in Table 1. As previously reported,[5] mean age was 63 ± 14 years, 74% were male, 90% were Caucasian, and 71% were taking diuretics. Ten women had a total percent body fat of ≥46% by DEXA (the maximum measurable body fat % by NIR) and were therefore excluded, for a total of 130 subjects examined in the primary NIR analyses. Sixty-two patients were excluded from the BIA analysis; 61 had either an internal cardioverter defibrillator or pacemaker (relative contraindications for use of BIA) and 1 had a congenital foot deformity making it impossible to have good contact with the BIA scale, for a total of 78 subjects included in the BIA analyses. Excluded BIA patients had more gastrointestinal disease (40% vs. 26%, *P* = .07), more were taking spironolactone (56% vs. 35%, *P* = .01), had a lower ejection fraction (32% vs. 40%, *P* < .0001), a lower systolic blood pressure (114 mm Hg vs. 123 mm Hg, *P* = .007), a higher urea (8.9 mmol vs. 7.1 mmol, *P* = .03, and a higher N-terminal pro B-type natriuretic peptide (128 pg/mL vs. 60 pg/mL, *P* = .006).

Summary data for each method of estimating body composition are shown in Table 2. In women, BIA-measured percent body fat was significantly different from DEXA. In men, BIA-measured body fat and lean body mass were both significantly different from DEXA measurements. NIR-measured lean body mass was also significantly different from DEXA in men.

Correlations with the Reference

Table 3 shows the partial Pearson's correlation coefficients between DEXA, NIR, and BIA methods. Estimates of both percent body fat and lean body mass from both methods were positively and significantly correlated with DEXA. For the BIA-DEXA correlations for lean body mass, the difference in correlations between men and women achieved statistical significance.

Figures 1 and 2 illustrate Bland-Altman plot analyses and provide the Pitman's test results. With the exception of the

Table 1. Patient Characteristics

	Males (n = 103)	Females (n = 37)
Age, y	62 ± 14	66 ± 13
Caucasian	89.3%	91.9%
Body fat (%)	28.2 ± 7.5	40.7 ± 7.6
Lean body mass (kg)	56.7 ± 9.0	39.0 ± 8.5
Weight (kg)	89.4 ± 20.0	76.2 ± 25.4
Body mass index (kg/m^2)	28.9 ± 5.3	28.8 ± 6.9
New York Heart Association Class		
I	36.9%	37.8%
II	53.6%	48.6%
III	6.8%	13.5%
Current smoker	17.5%	10.8%
Previous smoker	53.4%	56.8%
Diabetes mellitus	28.2%	27.0%
Coronary artery disease	56.3%	43.2%
Hypertension	51.5%	70.3%
Malignancy	11.7%	10.8%
Gastrointestinal disease	26.2%	48.6%
Cerebrovascular disease	15.5%	13.5%
Pulmonary disease	19.5%	37.8%
Kidney function estimated glomerular filtration rate ≥60	65%	52.9%
EGFR 30-60	34.0%	35.3%
EGFR <30	1.0%	11.8%
Dyslipidemia	66.0%	81.1%
Internal cardiac defibrillator or pacemaker	40.8%	48.6%
Left ventricular ejection fraction %	39 ± 17	35 ± 13
Systolic blood pressure (mm Hg)	122 ± 20	118 ± 20
Diastolic blood pressure (mm Hg)	71 ± 10	73 ± 10
Heart rate (beats/min)	71 ± 14	68 ± 10
Serum sodium (mmol/L)	139 (138−141)	140 (138−141)
Serum creatinine	99 (80−117)	93 (74−112)
Urea (mmol/L)	6.8 (5.4−8.8)	7.8 (5.4−10.4)
Hemoglobin (g/L)	141 (134−150)	129 (117−136)
C-reactive protein (mg/L)	1.9 (0.8−3.8)	2.1 (1.0−3.7)
N-Terminal pro B-type natriuretic peptide (pg/mL)	73 (20−212)	89 (50−190)

Values are presented as percentage or mean ± standard deviation except for laboratory values, which are presented as median (interquartile range).

More complete data are available from Oreopoulos et al. The association between direct measures of body composition and prognostic factors in chronic heart failure. Mayo Clin Proc. In press.

BIA-measured lean body mass analysis, in which Pitman's test was significant (*P* = .04), the differences (bias) were not significantly correlated with the average of the field and reference standard measurements. For BIA-measured lean body mass, logarithmic transformation still resulted in limits of agreement that were not uniform across the range of measurements.

Summary statistics for the biases, standard deviations (true error) and limits of agreement are shown in Table 4. Bias estimates (constant error) were generally small for percent body fat and lean body mass, but the limits of agreement between NIR or BIA and DEXA were wider than the desired precision thresholds of ±3.5% for percent body fat and ±3.5 kg for lean body mass.

Sensitivity Analyses

Repeating all analyses in the 100 patients taking diuretic medications yielded similar results for both NIR and BIA methods (data not shown).

Table 2. Body Composition Estimates by Each of the 3 Methods

	Mean	SD	Median	Range	Mean	SD	Median	Range
	Women				Men			
Body fat (%)								
Dual-energy x-ray absorptiometry	40.7	7.6	41.8	17.5−53.5	28.2	7.5	29.3	11.1−43.6
Near-infrared interactance	38.6	5.3	38.67	25.7−45.7	27.6	7.4	27.6	11.1−44.9
Bioelectrical impedance analysis	37.9	9.6	39.2	23.1−50.5	29.5*	7.6	29.8	12.9−44.3
Lean body mass (kg)								
Dual-energy x-ray absorptiometry	39.0	8.5	38.3	26.1−63.0	56.7	9.0	55.3	39.1−85.2
Bioelectrical impedance analysis	40.3*	7.1	39.3	32.9−60.3	59.4*	8.5	58.4	46.4−93.6
Dual-energy x-ray absorptiometry + bone mass	41.6	9.5	40.4	29.8−65.8	59.6	9.3	58.3	41.6−88.8
Near-infrared interactance	42.7	9.0	42.7	31.4−70.0	63.0*	8.0	62.4	40.5−84.6

*Significantly different from dual-energy x-ray absorptiometry measurement $P < .05$ by paired t-test.

Discussion

We examined 2 field methods that can be performed with portable instruments, NIR and BIA, to estimate percent body fat and lean body mass in patients with CHF. The concurrent validity of these 2 methods of measuring body composition compared with the DEXA criterion has not been previously examined in patients with CHF. We found that the measurement of lean body mass and percent body fat using NIR, and the measurement of percent body fat using BIA, have low bias compared against DEXA (ie. are accurate), but have wide limits of agreement (ie, poor precision), indicating that these field methods may yield clinically important discrepant results compared to DEXA in individuals with CHF. For lean body mass, BIA showed lower agreement with DEXA in men compared with women and had variable limits of agreement across the range of lean body mass measurements. The NIR method tended to overestimate the amount of lean body mass by nearly 3 kg. Use of diuretic medication did not affect the accuracy of either method.

We suggest that using accurate and reliable methods to assess body fat and lean body mass in those with CHF, in addition to monitoring changes in body weight, would assist with clinical management given emerging evidence that directly measured body composition is more closely linked to indicators of prognosis[5] and survival in these patients[21] than is BMI. Although accurate and reliable, DEXA is limited in patients over 136 kg (300 lb) and in those who

cannot tolerate the supine position for the duration of the scan. As such, validated field methods may be used as alternative. As cachexia is often a late and unrecognized finding in patients with CHF, we postulate that the use of direct body composition measurement may facilitate the earlier recognition of this poor prognostic indicator. It is acknowledged that no currently available treatments have been proven to reverse cardiac cachexia and improve prognosis.[22] Nevertheless, the earlier identification of cachexia may result in altered dietary recommendations to minimize further weight loss and may trigger a more aggressive approach to maximize medical heart failure treatments. In addition, an accurate and reliable portable field method to measure body composition would be a useful tool for future research studies in the CHF population.

We examined the accuracy and precision of BIA and NIR based upon readings taken from a single visit and it might be more clinically useful to employ such methods to assess serial changes in body composition. When using serial measurements, one might expect that the constant error (overestimation) of lean body mass by NIR would not interfere with monitoring changes; therefore, serial measurements may be more useful than individual measurements for monitoring body composition over time. However, we did not specifically assess repeated measurements and further study would be required to confirm this assumption.

A limitation of BIA, aside from its inaccuracy of lean body mass measurement in CHF, is that it cannot be used

Table 3. Partial Pearson's Correlation Coefficients (r) between DEXA-measured Body Composition and NIR or BIA Methods, Adjusted for Age

	Bioelectric Impedance Analysis			Near Infrared Interactance		
	Women n = 19	Men n = 59	P Value for Sex Differences	Women n = 27	Men n = 103	P Value for Sex Differences
DEXA % body fat	0.74	0.72	0.9	0.72	0.77	0.5
DEXA LBM or LBM + bone mass*	0.96	0.86	0.03	0.92	0.88	0.4

DEXA, dual-energy x-ray absorptiometry; LBM, lean body mass.

All P values $< .001$.

*For DEXA-bioelectrical impedance analysis comparison, LBM measurement was used. For DEXA−near-infrared measurement, lean body mass + bone mass was used.
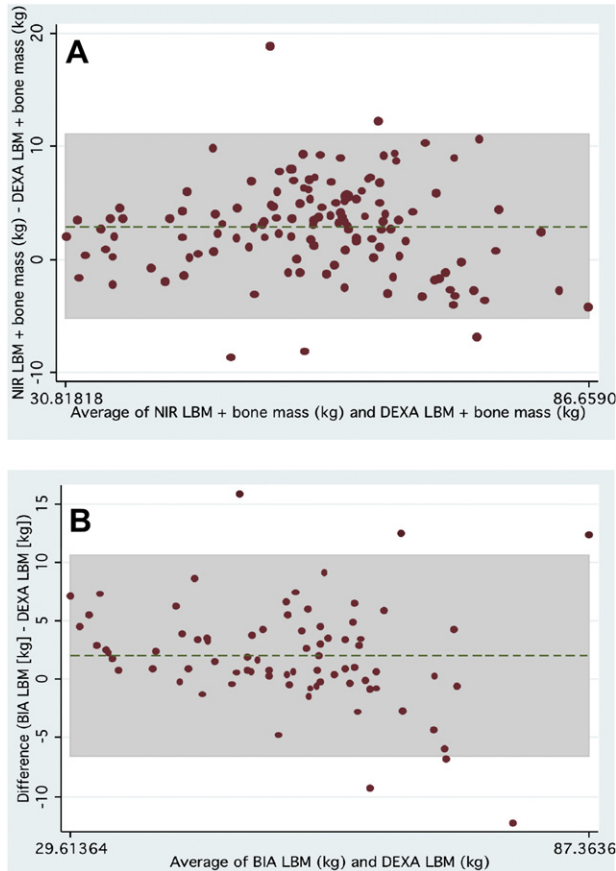
Fig. 1. (A) Bland-Altman plots of differences between DEXA-measured lean body mass + Bone mass and near infrared interactance lean body mass + bone mass in 130 CHF patients. The dashed line is the difference and the shaded area is the 95% confidence intervals for the difference. (B) Bland-Altman plots of differences between DEXA-measured lean body mass and bioelectrical impedance analyses lean body mass in 78 CHF patients. The dashed line is the difference and the shaded area is the 95% confidence intervals for the difference.

Fig. 2. (A) Bland-Altman plots of differences between DEXA-measured percent body fat and bioelectrical impedance analyses percent body fat in 78 CHF patients. The dashed line is the difference and the shaded area is the 95% confidence intervals for the difference. (B) Bland-Altman plots of differences between DEXA-measured percent body fat and near infrared interactance percent body fat in 130 CHF patients. The dashed line is the difference and the shaded area is the 95% confidence intervals for the difference.

in patients with internal cardiac defibrillators or pacemakers, and this excluded 43% of our study population, which limits the use and generalizability of BIA in patients with CHF. A limitation of NIR is its inability to accurately measure body composition in the extremely obese (7% of our study participants). A third potential limitation is that DEXA measurement of lean body mass cannot distinguish between body water and muscle mass. However, ingestion of small fluid volumes (<500 mL) 1hour before the DEXA scan does not bias the estimates of body composition,[23] and we only enrolled and tested patients after they were found to be clinically euvolemic and stable. Finally, other field methods, including air displacement plethysmography, mid arm muscle circumference and skin fold thickness may also be viable techniques for measuring body composition in CHF patients; however, their validity has yet to be assessed in this population.

In conclusion, in patients with CHF, we found that NIR and BIA were accurate methods of assessing body fat percentage
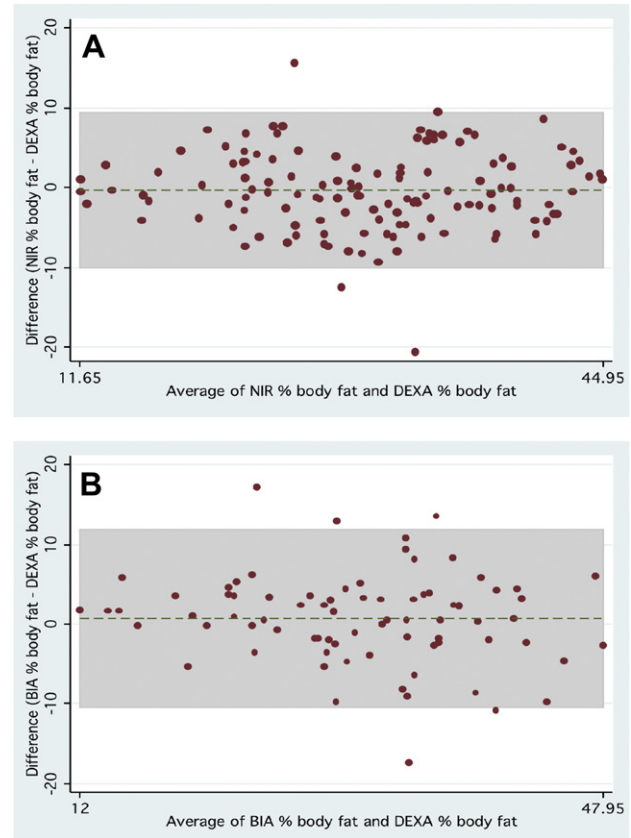
and that NIR is also reasonably accurate for measuring lean body mass. However, both field methods yielded imprecise results. Further research is needed to independently replicate these results and clarify the utility of NIR to measuring body composition changes over time in this population.

Table 4. Biases, Standard Deviations (Error) and Limits of Agreement* (BIA or NIR minus DEXA)

Method	Body Fat (%)			Lean body mass (kg)		
	Bias (Mean)	SD	Limits (±)	Bias (Mean)	SD	Limits (±)
Bioelectrical impedance analysis	+0.8%	5.8%	11.4	+2.0 kg	—	—
Near-infrared	−0.3%	5.1%	10.0	+2.9 kg	4.3 kg	8.4

Note: limits of agreement not calculated for BIA-measured lean body mass due to significant Pitman's test indicating variable limits of agreement across the range of values.

*Limits of agreement calculated as 1.96 × SD (total error) of the differences.

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