Bioelectrical Impedance Analysis (BIA) of the Estimation of Total Body Water and Lean Body Mass in Patients with Renal Failure

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= ***Abstract*** =

Bioelectrical impedance analysis (BIA) was used to determine total body water (TBW) and lean body mass (LBM) in patients with renal failure. The body's electrical resistance (R) was measured by the voltage to current ratio, injecting an 800 μA alternating current with a frequency of 50KHZ and detecting a voltage drop between the wrist and the ankle. Impedance index ($Height^2$/Resistance) compared favorably with TBW measured by deuterium (D_2O) dilution method as the reference, giving the correlation coefficient (r) of 0.966 and standard error estimation (SEE) of 2.71 liter. The index was compared with LBM determined by dual-energy x-ray absorptiometry (DEXA) as the reference, giving r of 0.970 and SEE of 3.00kg. The r of 0.985 and SEE of 2.15kg were found between the reference method. BIA appeared to have a somewhat lower accuracy than those of the reference method. However, it is a useful clinical tool for estimating body composition, because it is easy, rapid and non-invasive. The existing BIA method is based on an extremely simple conductor model of the body. The accuracy may be improved further, based on a more realistic model for the body.

Key Words: Bioelectrical Impedance Analysis (BIA); Total Body Water (TBW); Lean Body Mass (LBM)

INTRODUCTION

Bioelectrical impedance analysis (BIA) is a method used to determine total body water (TBW) and lean body mass (LBM) of the body. In the human body, electrolyte-rich biological

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fluid is much more conductive than fat tissue containing little water. The resistance of the body is mainly determined by water content. BIA is based on the principle that body's resistance is inversely proportional to TBW and that LBM contains 73.4% water. Fat mass can be determined by subtracting LBM from body weight and percent body fat (%BF) can be calculated by the ratio of fat mass to weight multiplying by 100. Having been validated in healthy adults[1-3], the method has become popular to monitor water balance[4-6] and nutritional status[7, 8] in patients. BIA has many advantages over other existing methods because it easy to use, inexpensive, and non-invasive.

In BIA, ECG-type surface electrodes are placed on the skin, through which electrical connections are created between the body and an impedance meter. The meter reads body's resistance by the voltage to current ratio, injecting an harmless alternating current with a ratio frequency into the body and detecting a voltage drop between the wrist and ankle. The terminals of the impedance meter are connected so that a pair of current sources are connected to the outer electrodes placed on the hand and foot, and a pair of voltage detectors are connected to the inner electrodes placed on the wrist and ankle as shown in Fig. 1.

Assuming the body is cylindrical conductor with a uniform cross-sectional area, the body's resistance (R) is a function of the resistivity (ρ), the length (L) and the cross-sectional area of the conductor (A);

$$R = \rho \cdot \frac{L}{A} \quad \cdots\cdots (1)$$

Multiplying the numerator and denominator by L;

$$R = \rho \cdot \frac{L \cdot L}{A \cdot L} \quad \cdots\cdots (2)$$

A·L is the volume of the conductor (V).

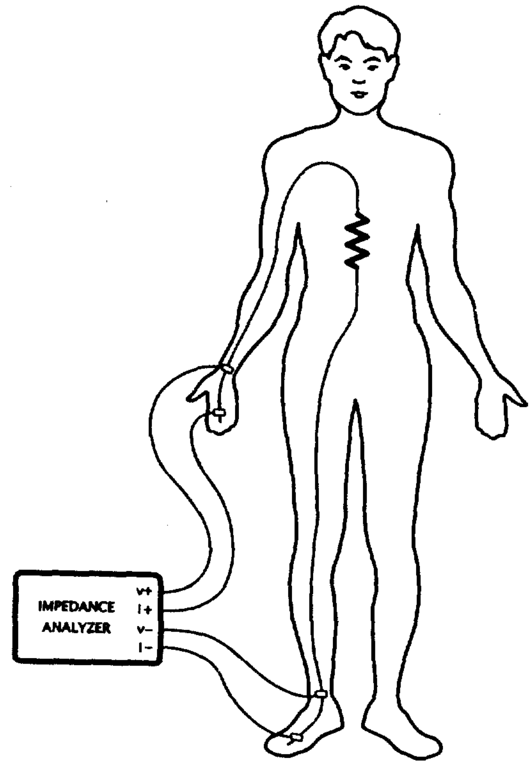

Fig. 1. Schematic diagram of the placement of surface electrode, the interface between the electrode and the impedance meter, and the conductor model of the human body.

Moving R to the right-hand side of the equation and V to the left-hand side produces;

$$V = \rho \cdot \frac{L^2}{R} \quad \cdots\cdots (3)$$

Assuming that TBW or LBM constitutes the volume of the body's conductor mostly, that the length of the conductor is approximated by the height (Ht) in length, and that the resistivity is constant;

$$TBW \propto \frac{Ht^2}{R} \quad \cdots\cdots (4)$$

$$LBM \propto \frac{Ht^2}{R} \quad \cdots\cdots (5)$$

The linear regression analysis can then be employed to determine the best constant coefficients which make Ht^2/R fit TBW determined by the deuterium dilution method or LBM determined by DEXA, and then BIA equations are established. Details of the principle of BIA are available elsewhere[1, 3, 9].

We studied the precision of BIA for estimating TBW and LBM is patients with renal failure in whom the fluid balance varied extensively from normal value. TBW and LBM were determined by deuterium(D_2O) dilution and bromide(*NaBr*) dilution method, respectively, as the reference.

METHODS

1. Patients

Thirty-two hemodialysis patients with renal failure participated in this study. This study was approved by the Institute of Review Board at The Brigham and Women's Hospital. Each patient provided written consent. Each patient participated in this study on the following day after hemodialysis.

2. BIA

For impedance measurement, each patient wore a light gown was rested in a horizontal supine position on a cotton mattress of hospital bed. Four prejellied ECG spot electrodes (Medtronic, Haverhill, MA) were placed on the skin of right hand and foot as described by other[3]. If a patient had an arteriovenous fistula on the right arm, the impedance measurement was made on the left-hand side of the body. Applying alternation current with the amplitude of 800 μA and the frequency of 50kHz across a pair of outer current electrodes placed on the hand and the foot, the meter(RJL system, Model 101A, Clinton Twp, MI) read the resistance of whole body between the inner pair of voltage electrodes placed on the wrist and ankle. Standing height was measured to the nearest 0.5cm; body weight was measured to 0.1kg.

3. D_2O Dilution and DEXA

TBW was determined by intravenously injecting 9ml of 99.9% deuterium oxide. Prior to, and four hours after the injection, blood samples were obtained for analysis. TBW was calculated from the changes in traced concentration. LBM was determined by dual energy x-ray absorptiometry(DEXA) which provided segmental LBM as well as whole body LBM.

4. Statistical analysis

Impedance index(Ht^2/R) determined at various frequencies were compared with TBW and LBM determined by dilution method and DEXA, respectively. The correlation coefficient and standard error of estimation were calculated using a statistical software package, SPSS+/PC(SPSS Inc. Chicago, IL).

Table 1. Patient Characteristics : BMI was Calculated by Weight Divided by Height^2. Total Body Water (TBW) was Measured by D_2O Dilution Method. Lean Body Mass(LBM) was Measured by DEXA. Percent Body Fat(%BF) was Calculated by %BF =(Wt-LBM)/Wt×100. R is Resistance and X is Reactance. Three Patients had their Arteriovenous Fistula on the Right Upper arm and the Rest had the Fistula on the Left Upper arm

N=32	MEAN±SD
Age	54.8±11.2
Ht(cm)	166.3±11.2
Wt(kg)	73.6±17.3
BMI(kg/m^2)	26.4± 4.5
TBW(ℓ)	40.7±10.2
LBM(kg)	47.7±12.0
%BF	34.8± 9.3
Ht^2/R(cm^2/ohm)	51.0±13.4
R50kHz(Ω)	559.7±92.6
X50kHz(Ω)	54.3± 9.5

RESULT

Patient characteristics are shown in Table 1. Mean body weight was 73.6kg(range : 44.6-117.5 kg). Mean TBW was 40.7l(range : 26.7-75.3L) and accounted for 55.3% of body weight. Mean LBM was 47.7kg(range : 32.6-82.5) and accounted for 64.7% of body weight. Percent body fat(%BF) accounted for 30.9% of weight for men and for 38.2% of weight for women.

Fig. 2a shows that the impedance index (Ht^2/R) was favorably compared with TBW measured by deuterium (D_2O) dilution method, giving a correlation coefficient(r) of 0.966 and a standard error estimation(SEE) of 2.71 liter. BIA equation for the prediction of TBW was developed as a function of Ht^2/R;

$$TBW(L) = 0.737 \cdot \frac{Ht^2}{R} + 2.81$$

Fig. 2b shows that the index was compared with LBM determined by DEXA, giving r of 0.970 and SEE 3.00kg. BIA equation of the prediction of LBM was developed as a function of Ht^2/R;

$$LBM(\mathrm{kg}) = 0.867 \cdot \frac{Ht^2}{R} + 3.0$$

Fig. 2c shows TBW determined by D_2O dilution method against LBM determined by DEXA, giving r of 0.985 and SEE 2.15kg. The r and SEE between BIA and reference method was lower than those between the reference methods.

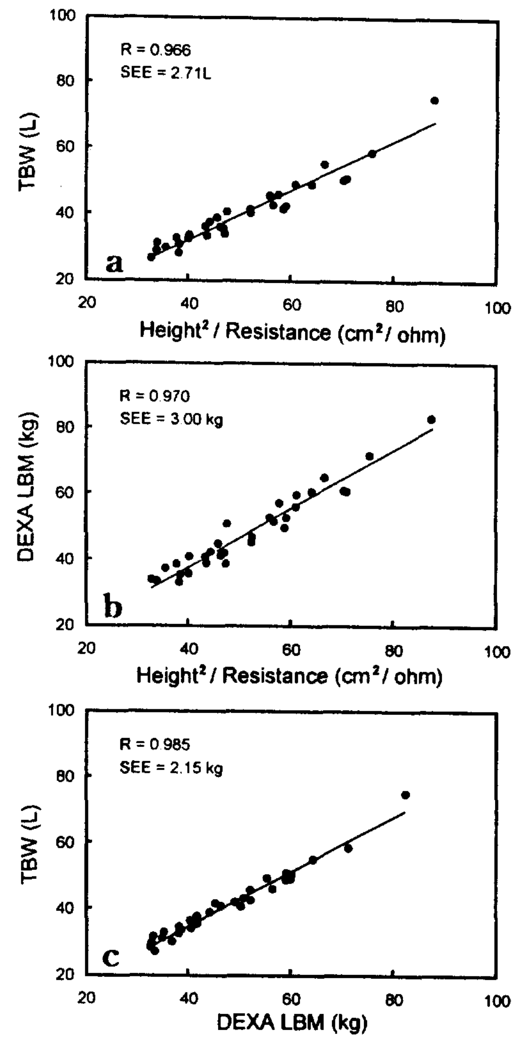

Fig. *2(a) Total body water determined by D_2O dilution method against impedance index (Ht^2/R).*
(b) Lean body mass determined by DEXA against impedance index(Ht^2/R).
(c) Total body water determined by D_2O dilution against Lean body mass determined by DEXA.

DISCUSSION

Any method for the assessment of body composition is based upon assumptions that allow for some types of inherent errors. Wellens et al.[10] compared the accuracy between densitometry, DEXA and D_2O dilution methods, which are widely accepted as the standard method for estimating body composition. For the prediction of LBM in white healthy adults, pairwise regression analysis revealed SEE ranging 1.9-3.1kg among these methods. Our study showed similar precision(SEE=2.15kg) between DEXA and the D_2O dilution method. The precision of BIA(SEE=3.00kg) was somewhat lower than whose of the standards methods.

A major assumption in the BIA method is that the body is modelled as a conductor with a uniform cross-sectional area. Whole body resistance measured between the wrist and the ankle is the serial sum of arm, trunk and leg's resistance. The arm and leg have relatively small cross-sectional areas and thus have high resistances. Thus, R is determined by the resistances from the arm and the leg, largely reflects their conductive mass. The trunk, representing 50% of the body mass, contributes only 10-15% of measured body resistance[11]. Thus there are significant differences in the segmental sensitivity.

It has been reported that BIA underestimates the loss of fluid in peritoneal dialysis patients, while it somewhat overestimates this loss in hemodialysis patients[12, 13]. Other investigators have reported that BIA estimates less than half the volume of ascitic fluid removed from cirrhotic patients[10, 14]. Our study showed that whole body resistance decreased much greater after an intravenous infusion of 0.9% *NaCl* solution than following an intraperitioneal infusion of the same amount of solution[15]. These results indicate that BIA reflects composition of the trunk segment insensitively. Cha et al.[16] modelled the body as a conductor consisting of three serial conductors representing arm, trunk and leg, with the same length but different cross-sectional areas. The residuals between BIA and the reference estimated ($LBM_{Ht^2/R} - LBM_{reference\ method}$) was highly correlated to the ratio of abdomen to wrist cross-sectional area estimated from the circumference measurement, indicating that problems with segmental sensitivity can be greatly reduced.

Impedance techniques can determine water content precisely in homogeneous biological tissues such as blood in a tube with uniform cross-sectional area[17]. The human body is much more complicated than this model in its structure and materials. Nevertheless, the present results showed BIA estimated body composition with the comparable accuracy found in more difficult and expensive methods in patients with disturbed fluid distribution. Further investigation should be made to develop an appropriate conductor model of the complex body in order to improve its accuracy before BIA is widely accepted as a standard method. To do this, we suggest segmental analysis including segmental impedance measurement, composition analysis based on an appropriate conductor model, and then integration of these for the assessment of whole body composition.

In conclusion, impedance index(Ht^2/R) was highly correlated with TBW and LBM measured by D_2O dilution and DEXA, respectively. The precision of BIA appeared to be somewhat lower with respect to the reference methods, because it is easy to use, rapid, non-invasive, inexpensive and applicable at the bedside. The accuracy of BIA may be improved further, based on a more realistic model for the body.

= 국문초록 =

생체 전기 임피던스를 이용한 말기 신부전증 환자에서의 체수분량 및 제지방량

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생체전기임피던스(BIA)는 체수분량(TBW)과 제지방량 (LBM)을 측정하는 방법으로서 투석 환자에게 적용

되어 왔다. 신체의 전기 저항(R)은 인체로 흘려준 전류와 전압의 비율로 결정되는데, 이때 사용되는 전류는 800μA 크기의 50KHZ 주파수를 가진 교류전류를 인체내로 흘려주고 손목과 발목에서 전압차를 측정하였다. 임피던스 지수(신장2/저항)와 중수 희석법(D_2O)으로 산정한 TBW의 관계를 통계학적으로 계산한 결과 이들 사이에는 연관계수(Correlation Coefficient, r) 0.966과 오차(Standard Error Estimation, SEE) 2.7 ℓ가 존재하였다. 임피던스 지수를 이중 에너지 X선 법(DEXA)으로 구한 LBM과 연관 관계에서 r은 0.970 SEE는 3.0kg으로 나타났다. DEXA법과 D_2O법 사이에는 r=0.985와 SEE=2.15kg이 존재하였다. BIA방법은 표준의 방법으로 사용되는 DEXA나 D_2O에비하여 정밀도가 다소 낮은 것으로 나타났다. 그러나 BIA는 인체에 유해하지 않고 쉽고 빠르게 체조성을 측정할 수 있어 유용한 임상 도구로 사용 될 수 있다. 현재 널리 사용되고 있는 BIA방법은 인체를 단순한 원기둥으로 가정하고 있으며, 보다 실질적인 인체 모델에 기초한 BIA 방법은 정밀도를 높일 수 있다.

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