A Comparison of Six Equations to Predict Fat-Free Weight with Bioelectrical Impedance Technique in HONG KONG MALE UNIVERSITY STUDENTS

透過香港男大學生的研究比較生物抗阻法中六題公式對純體重的預測

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摘要

本研究主要透過86名年齡由19至24歲的男性大學生，比較生物抗阻法和皮摺量度法在測量人體脂肪比率上的結果。測試內容包括：身高、體重、電阻、抗阻、腹部皮脂、胸部皮脂、肩胛皮脂。結果顯示，只要使用合適的方程式計算，在量度香港男性大學生的脂肪比率上，生物抗阻法是一個可靠而準確的方法。

Abstract

The main purpose of the present study was to compare existing multiple regression BIA equations with the skinfold technique in male university students. The subjects in this study were 86 male university students aged 19-24 years. Body height, body weight, electrical resistance, electrical impedance, abdominal fold, chest fold, and subscapular fold were measured. Test-retest reliability within 7 days period of bioimpedance measurements was 0.93. Simple linear regression showed that body weight (BW) was the most significant predictor of fat-free weight (FFW) ($r = 0.92$; SEE = 2.10 kg). When BW and electrical resistance index were used in combination to predict FFW in the combined group, the multiple R increased to 0.95 with the SEE value decreased to 0.81 kg. The addition of height, electrical impedance, electrical resistance, body mass index and age to the prediction model contributed less than 1% additional variance and reduced the SEE value to less that 0.03 kg. The BIA equation of Oppliger (1991) was the most accurate equation when used in Chinese population. To conclude, BIA was a reliable and valid measurement in assessing FFW in Chinese male university students provided that an appropriate population-specific equation (Oppliger, 1991) was chosen.

Introduction

Obesity is defined as a body weight that exceeds by more than 20% of the desirable level for a given age, gender, and skeletal frame (National Institute of Health, 1985), or excess of body fat at which health risks begin to increase (U. S. Department of Health and Humun Services [USDHHS], 1988). Obesity is a serious health problem that reduces life expectancy and threatens quality of life. Obese individuals have a higher risk of coronary heart disease, hypertension, diabetes, and possibly certain cancers (USDHHS, 1988). The prevalence of obesity is lower in young children than in adults in the US population, and the prevalence increases throughout childhood and adolescence (Freedman et al., 1987; Gortmaker, Diets, Sobol, & Wehler, 1987; Lohman, Groing, Slaughter, & Boileau, 1989). Therefore, there is a necessity for accurate assessment of the body composition of all age groups in laboratory and field settings in order to track the prevalence and incidence of obesity.

In laboratory setting, there are two kinds of measurements on body composition: direct and indirect methods. Direct measurement of body composition can only be made from analyses on cadaver. Indirect laboratory methods such as densitometry (Akers & Buskirk, 1969), computed tomography (Borkan et al., 1982), electrical conductivity (Presta, Segal, Gutlin, Harrison, & Van Itallie Gutin, 1983; Segal, Gutin, Presta, Wang, & van Itallie, 1985), body water by isotope dilution

(Lohman, 1981; Schoeller et al., 1980) are valid methods of assessing body composition. However, these laboratory methods are expensive, time consuming and inappropriate for large-scale field testing. Anthropometric methods using various combinations of skinfolds (SKF) and circumference (Katch & McArdle, 1973) and biolectrical impedance analysis (BIA) (Eckerson, Housh, & Johnson, 1992) are used in field studies to measure body composition because they are reliable, inexpensive, portable and provide immediate results.

Lohman (1992) stated that there was a great need to develop equations specific to given populations, especially for BIA. There is little information on the BIA measurement to ethnic groups other than the United States and Europe. Asian populations make up a substantial proportion of the world's population but there is a lack of body composition data on them. Limited researches of BIA in the Chinese population was one of the reasons to conduct the present study.

Within the last several years there had been increasing interests in the use of bioelectrical impedance analysis (BIA) for determining body composition. The salient features of this technique were that it was portable, rapid, noninvasive, and required only the placement of four electrodes on well-defined landmarks. Studies had suggested acceptable to high reliability and validity of BIA in the general population (Lukaski, Bolancheck, Hall, & Siders, 1986), normal adults (Lukaski et al., 1985; Segal et al., 1985; Van Loan & Mayclin, 1987), obese adults (Kushner et al., 1990) and children (Houtkooper et al., 1989). However, the equations used to estimate body composition currently supplied by the manufacturer of one of the most commonly used impedance analyzers (RJL Systems) had resulted in errors that were unacceptable when validated against values obtained from underwater weighing (Lukaski, Bolonchuk, Hall & Siders, 1986; Oppliger, Nielsen & Vance, 1991; Ross, Leger, Martin & Roy, 1989; Van Loan & Mayclin, 1987). These findings were observed for individuals of average fatness as well as for those at the extremes of the body composition distribution. Therefore, several new equations had been derived in an attempt to improve the accuracy of BIA for estimating body composition characteristics.

The purpose of this study was to compare existing multiple regression BIA equations with the skinfold technique in male university students.

Materials and Methods

Subjects

The subjects in this study were 86 Chinese male university students aged 18-24 years. Informed written consent was obtained from each subjects prior to initiating the testing protocols. The testing order followed was 1) body height and body weight, 2) BIA, and 3) SKF.

Body Height and Weight Measurements

Measures of body height and body weight were obtained using a Detecto beam-balance scale to nearest 0.5 cm and 0.1 kg respectively. The subjects were instructed to stand in an erect posture centred on the platform with heels together and looking forward.

BIA Measurement

Electrical resistance, electrical reactance and electrical impedance values were measured with the subject lying supine using an impedance analyser (Biodynamics, 3rd version, Biodynamics Corporation, 1988) with a tetrapolar surface configuration. The current electrodes were placed on the dorsal surface of the right hand and right foot at the distal metacarpals and metatarsals, respectively. The detector electrodes were placed on the right pisiform prominence of the wrist and between the medial and lateral malleolus of the right ankle. A standard current of less than 1 mA at 50 kHz was passed through the body and then electrical resistance, electrical reactance and electrical impedance were recorded twice after about 2-minute interval between each measurement. Between trials, the electrodes were removed and then replaced for the second trial. The lowest observed resistance value was used as representative of an individual to predict the body composition of that subject. To avoid interobserver error, one investigator made all BIA measurements. As described by the manufacturer, to ensure accurate test results, the subjects were requested not to consume alcohol within 24 hours of taking the test, and not to exercise or eat for four hours before taking the test. There were totally six BIA equations for comparison in the present study and they were shown in Table 1.

Table 1. Bioelectrical impedance equations used in validation

Equation Number	Reference	Equation	r	SEE (kg)	Nature of Subject
1	Biodynamic	N/A	0.97	1.30	Young adults
2	Lukaski (1986)	FFW = 5.214 + 0.827 (RI)	0.98	2.51	Normal adults
3	Oppliger (1991)	FFW = 1.949 + 0.701 (BW) + 0.186 (RI)	0.98	1.89	Lean adults
4	Segal (1988)	FFW= 9.33285 + 0.00066360 (HT^2) - 0.02117 (R) + 0.6284 (BW) - 0.12380 (AGE)	0.95	2.47	Subjects with wide range of fatness
5	VanLoan & Mayclin(1987)	FFW = 17.7868 + 0.00085 (HT^2) + 0.3736 (BW) - 0.02375 (R) - 0.1531 (AGE)	0.98	3.13	Normal adults
6	Kushner & Schoeller (1986)	FFW = ((0.396 (RI) + 0.143 (BW) + 8.339) / 1.04) / 0.73	0.99	1.66	Obese and non-obese subjects

The r and SEE values were reported in the original studies.

Skinfold Measurement

All skinfold measurements were taken using Harpenden (John Bull British Indicators, Ltd., London, England) skinfold calipers calibrated to exert a constant pressure of 10 g/mm*. The Harpenden skinfold calipers were used to measure SKF thickness at three standardized sites (Harrison et al., 1988): pectoral, subscapular, and abdominal. The descriptions for the specific sites used in the Jackson et al. (1978) equations were as follows: (a) abdominal-fold was taken vertically 2 cm lateral to the umbilicus; (b) pectoral-fold was taken 1/2 the distance between the anterior axillary line and nipple; and (c) subscupular-fold was taken on diagonal line coming from the vertical border, 1-2 cm below the inferior angle. Each site was identified and marked with a surgical marking pen. Two measurements were taken at each site and if the difference between the two was greater than 0.5mm, a third measurement was taken. The average of the two acceptable measurements was used as the representative value for each site. To reduce inter-observer error, the same researcher performed all SKF measurements.

Reliability of bioimpedance Measurement

Test-retest reliability of bioelectrical impedance measurement was also performed. 30 subjects were required to return to the laboratory on the two different days within a 7-day period for an additional measurement of resistance in order to find out the reliability coefficient.

Statistical Analysis

The SKF and BIA percentage of body fat values were compared using the Pearson product-moment coefficient correlation. A paired samples t-test was used to determine if there was a significant difference in the FFW means of the SKF and BIA methods. A stepwise multiple regression analysis was also applied to the data to assess which combination of variables best estimated FFW. Body weight (BW), height squared/ resistance (RI), height (HT), impedance (IMPED), resistance (RESIST), reactance (REACT), body mass index (BMI), and age (AGE) were entered as possible predictors. The 0.05 level of significant was used for all data analyses.

Results

The descriptive characteristics of the subjects were presented in Table 2. The mean value for FFW determined by SKF was 59.67± 5.74 kg (range = 48.67 - 76.10 kg).

Table 2. Descriptive characteristics of Subjects (N = 86)

Variable	X	SD	Range
Age(yr)	21.15	1.21	19.00 - 24.00
Height(cm)	174.35	6.55	153.70 - 188.50
Weight(kg)	65.16	6.64	52.20 - 85.00
Reactance(ohms)	61.71	6.46	51.00 - 87.00
Resistance(ohms)	500.30	52.45	405.00 - 651.00
Impedance(ohms)	504.13	52.51	408.99 - 654.65
% body fat by SKF	7.23	3.09	2.63 - 14.91
Fat-free weight(kg)			
1. SKF	60.39	5.80	49.20 - 76.99
2. EQ1	57.75	5.61	43.91 - 73.19
3. EQ2	56.07	6.48	39.02 - 72.69
4. EQ3	59.07	5.74	47.55 - 75.10
5. EQ4	57.27	5.65	45.26 - 72.56
6. EQ5	52.89	4.42	42.30 - 64.65
7. EQ6	38.65	3.50	29.89 - 48.17

Table 3 presented the results of the validation analyses for the BIA estimations of FFW. Generally, the validity coefficients were relatively high, ranged from r = 0.76 for EQ2 to r = 0.95 for both EQ3 and EQ4, and all were significant at $p < 0.05$ (Table 3). The validity coefficient value for EQ1 (r = 0.90), EQ2 (r = 0.76), EQ3 (r = 0.95), EQ5 (r = 0.93), and EQ6(r = 0.85) were all lower than the correlation coefficients reported in the original derivation studies (Table 1) except EQ4 (r = 0.95) which was identical to the value reported in the original investigation.

Table 3. Validations of bioelectrical impedance equations used to estimate fat-free weight

Comparison	t-value	Mean difference	r	SEE(kg)
EQ1 vs SKF	9.54	2.64	0.90	2.55
EQ2 vs SKF	9.29	4.32	0.76	3.80
EQ3 vs SKF	7.24	1.32	0.96	1.70
EQ4 vs SKF	16.77	3.12	0.96	1.73
EQ5 vs SKF	30.56	7.50	0.94	2.05
EQ6 vs SKF	52.55	18.32	0.85	3.04

The standard error of estimate values for all of the six BIA equations in the present study were also reported in Table 3. The SEE values ranged from 1.81 kg for EQ3 to 3.73 kg for EQ2. The values for EQ1 (SEE = 2.55), EQ2 (SEE = 3.73), and EQ6 (SEE = 3.01) were higher than the SEE reported in the original cited studies. In contrast, EQ3 (SEE = 1.81), EQ4 (SEE = 1.83), and EQ5 (SEE = 2.10) resulted in having lower standard error of estimate. Test-retest reliability coefficient for a single measurement of resistance on the two different days within a 7-day period was 0.93.

Simple linear regression showed that body weight (BW) was a significant predictor (r = 0.93, $P < 0.01$) of FFW (SEE = 2.10 kg). In contrast, the variable of resistance index (RI), (used in EQ2, EQ3, and EQ6) was moderately correlated with FFW (r = 0.76, $P < 0.01$), but resulted in a SEE value of 3.73 kg. Results of multiple regression analysis indicated that BW accounted for the majority of the variance (R* = 0.87) in the prediction of FFW. The variance of RI in predicting FFW was 0.58 which was lower than that of BW. The variances of height (HT), impedance (IMPED), resistance (RESIST), reactance (REACT), body mass index (BMI), and age (AGE) was in descending order followed by BW and RI. When BW and RI were used in combination to predict FFW, the multiple R and the variance (R*) increased to 0.95 and 0.90 respectively with SEE decreased to 1.81 kg. The addition of HT, IMPED, RESIST, REACT, BMI, and AGE to the prediction model contributed to less than 1% additional variance and reduced the SEE to less than 0.03 kg (1.81 to 1.78).

Discussion

The results of this study indicate that combined BW and RI can accurately predict FFW in Chinese male university students. BW has the highest correlation coefficient with FFW (r = 0.93). This result is expected since FFW accounts for the majority of the total BW in lean individuals (mean and SD of % FFW of the subjects in this study = 91.67 ±5.55 %) (Eckerson et al., 1992). It implies that those BIA equations with large correlation coefficient (> 0.6) between BW and FFW are mostly used for lean individuals as shown in the equation of Oppliger (1991) and the newly developed equation in this study. Therefore, choosing an BIA equation of similar levels of fatness is important for accurate estimation of FFW. These results imply that BIA equation is population-specific just like SKF equation. Houtkooper et al. (1989), Lukaski et al. (1985), and Eston et al. (1993) showed a high correlation coefficient (r > 0.94) between RI and FFW. The hypothesis that bioelectrical impedance measurements can be used to determine total body water or FFW is based on the principle that the impedance of a geometrical system is related to conductor length and configuration, its cross-sectional area, and signal frequency (Lukaski et al., 1985). Using a constant signal frequency and a relatively constant conductor configuration, bioelectrical impedance to the flow of current can be related to the volume of the conductor (Lukaski et al., 1985). Bioelectrical impedance is based on the equation, $V = pS^2/R$ (Nyboer, Bango & Nims, 1943), in which the conductive volume (V) is assumed to represent total body water, stature (S) is taken as an estimate of the length of the conductor, the whole body resistance (R) is measured between a wrist and ipsilateral or contralateral ankle using four surface electrodes, and the specific resistivity (p) is assumed to be constant. However, it is apparent that the application of this equation to the human body is limited in principle, because it assumes a conductor of homogeneous composition and fixed cross-sectional area and a uniform current density distribution (Baumgartner, Chumlea & Roche, 1990). These assumptions are not met when human body is considered as a conductor (Baumgartner et al., 1990). The cross-sectional area of the body is not constant, and the parts with the smallest cross-sectional areas will primarily determine the resistance (Smith, 1987). Stature is not the actual length of the conductor (Baumgartner et al., 1990). The specific resistivity (p) is unknown and will not be a constant for all individuals, but will vary depending upon the amounts and distributions of particular tissues and fluids (Baumgartner et al., 1990). Besides the above discrepancies, one more important reason for such disagreement may be due to the physiological differences in race between Chinese and Caucasian. That may be why RI only shows a moderately high correlation coefficient (r = 0.76) with FFW in the present study.

EQ1, developed by Biodynamic Corporation (1989), shows the lower r value (0.90 vs 0.99) and the higher SEE value (2.55 vs 1.30 kg) when compared to the original study. There are significant differences (P < 0.01) of the FFW means between EQ1 and the criterion method utilized in this study (SKF) using paired samples t-test. These results confirm the findings of several previous investigations (Lukaski et al., 1986; Oppliger et al., 1991; Ross et al., 1989; Van loan et al., 1987) that the equations supplied by the manufacturer (RJL Systems) produced results that were unacceptable when compared to UWW. However, Biodynamic body composition analyzer shows a very high level of immediate test-retest correlation coefficient (r =0.99) and relatively high reliability correlation coefficient (r = 0.93) of resistance measurement.

EQ2, Lukaski (1986), reports the lowest r value (0.76) and the highest SEE value (3.73 kg) among the six BIA equations in this validation study. These results are very similar to the values reported in a previous validation study by Jackson et al. (1988). In their study, FFW derived from EQ2 resulted in a SEE value of 4.9 kg and a validity coefficient of r = 0.79. These results were in contrast to the original derivation study that reported the r and SEE value of 0.98 and 2.51 kg respectively. The reason for such differences between the original and the present studies may due to the fact that EQ2 does not include BW as a predictor in assessing FFW since BW correlates highest, accounts for 87% of the variance, with FFW in the present study.

The results of the validation analysis (Table 3) indicate that EQ3, Oppliger (1991), is the most accurate equation in estimating FFW among the six BIA equations. Moreover, the distribution of FFW estimated from EQ3 (X ±SD = 59.07 ± 5.74 kg) is very similar to the actual distribution (X± SD = 59.67 ±5.74 kg). The SEE value (1.81 kg) is lower than the value (1.89 kg) reported by Oppliger et al. (1991) while the validity coefficient (r = 0.95) found in the present study is similar to the reported value (r = 0.98). The high accuracy attained by applying EQ3 is likely due to the fact that it is derived from lean adolescent males (mean and SD of % FFW = 92.00 ± 5.62 %) and includes BW (the highest correlated predictor in the present study) as an independent variable. In the present study, the % FFW of the subjects (mean and SD of % FFW = 91.67 ± 5.55 %) are more similar to the subjects used by Oppliger et al. (1991) to derive EQ3 than those from the studies used to derive the other BIA equations (EQ1, EQ2, EQ4, EQ5, and EQ6).

Ross et al. (1989) who reported that both Segal (1988), EQ4, and VanLoan & Mayclin (1987), EQ5, resulted in means and standard derivations that were not significantly different from FFW values obtained from UWW both before and after a 10-weeks diet and exercise regimen in 17 healthy adult males. In the present study, EQ4 and EQ5 significantly underestimate FFW by 2.39 kg and 6.78 kg and result in a SEE value of 1.83 kg and 2.10 kg respectively. These results are in contrast to the findings of Ross et al. (1989). Besides, these equations include the variables of RESIST and HT instead of RI as predictors in estimating FFW. The multiple R of combined RESIST and HT is 0.78 and the SEE value is 3.61 kg in this study. These results are in contrast to those reported by Segal et al. (1988) who found that the multiple R of RESIST and HT was 0.94 and the SEE value was 2.47 for normal adults. The reason for such disagreements may be due to the use of different kinds of subjects (slightly obese vs lean) in the two studies.

EQ6, Kushner& Schoeller (1986), significantly underestimate FFW by 4.98 kg with a SEE value of 3.04 kg. The results for EQ6 are in contrast to those of Kushner et al. (1986) who examined the validity of BIA to detect changes in FFW in obese individuals and found that the equation in predicting FFW was not significantly different to the values derived from deuterium-isotope dilution. The equation of Kushner and Schoeller (1986) is characterized by small coefficients for BW and large regression coefficients for RI. However, the present study indicates that BW accounts for 87% of variance which outweigh the effect of RI (58% variance) in predicting FFW. That is why EQ6 is not accurate enough in estimating FFW in this study. Besides, once again, using different kinds of subjects in the above two studies may contribute to the disagreement (obese vs lean).

Summary

This study shows that BW has the highest correlation with the FFW as predicted by BIA in Chinese male university students. The reason for this phenomenon is that FFW accounts for the majority of the total BW in lean individuals. When BW is used in combination of RI, the multiple R and SEE values significantly improved ($R = 0.95$, $SEE = 1.81$; $p < 0.01$). Since EQ3, Oppliger (1991), included these two variables in the equation, it shows the highest R value and lowest SEE value.

Conclusions

The present study shows that BIA is a valid and reliable measurement in assessing fat-free weight in Chinese male university students provided that an appropriate population-specific equation (Oppliger, 1991) is chosen. In practical usage, the BIA equation of Oppliger (1991) can be accurately applied to Chinese male university students.

Recommendation

One of the limitations in the present study is using skinfold technique as the criterion method. Further research involving the BIA equations with Chinese male university students using underwater weighing or any other acceptable criterion method is needed before BIA can be used to estimate body composition in this population. Besides, validating other Chinese population such as Chinese females, Chinese children and Chinese elderly are highly recommended because at that time, one can developed a generalized equation for a wide range of Chinese subjects instead of using so many different equations for different subjects.

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