Bioelectric impedance phase angle and body composition[1–3]

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ABSTRACT The use of bioelectric impedance phase angle for predicting body composition was determined in 53 males and 69 females 9–62 y of age. The phase angle describes the amount of reactance (X_c) in a conductor relative to the amount of resistance (R). Bioelectric resistance (R) and reactance (X_c) were determined for the whole body and separately for arm, leg, and trunk. Weight, stature, and skinfold thicknesses were measured. Body composition was determined from densitometry. Phase angles for the trunk (ϕ_t), leg (ϕ_l), and whole body (ϕ_w) had significant ($p < 0.05$) negative correlations with percent body fat (%BF) in each sex, and positive correlations with fat-free mass (FFM) in males. In multiple regression analyses, ϕ_t was associated significantly with %BF after controlling for age, mean skinfold thickness, and weight/stature^2 in each sex. Bioelectric phase angle for the trunk may be useful for predicting %BF in clinical and survey research. *Am J Clin Nutr* 1988;48:16–23.

KEY WORDS Body composition, bioelectric impedance, fat-free mass, percent body fat, skinfold thickness

Introduction

The principles of bioelectric impedance have been established for > 40 y (1–4) but methods for estimating components of body composition from bioelectric impedance, specifically total body water (5), intracellular and extracellular water (6), and fat-free mass (7), are comparatively recent. The availability of accurate, phase-sensitive electronics has increased interest in the use of bioelectric impedance to estimate body composition in the fields of human nutrition (8, 9), human biology (10), physiology (11, 12), and sports medicine (13, 14). Bioelectric impedance (Z), measured in ohms, is the square root of the sum of the squares of resistance (R) and reactance (X_c), or

$$Z^2 = R^2 + X_c^2 \tag{1}$$

and it is frequency dependent. Bioelectric resistance is the pure opposition of a biological conductor to the flow of an alternating electric current whereas reactance is the resistive effect due to capacitance produced by tissue interfaces and cell membranes. Capacitance, or the storage of electric charge by a condenser, causes the current to lag behind the voltage, creating a phase shift. This shift is quantified geometrically as the angular transformation of the ratio of reactance (X_c) to resistance (R), or the phase angle (ϕ). The geometrical relationships among impedance, resistance, reactance, phase angle, and frequency of an electrical current are illustrated in **Figure 1**. At very low frequencies (f_l) the capacitive component of the system is effectively an open circuit so that reactance is equal to zero and the measured impedance (Z) is purely resistive (R_o). As the frequency increases, reactance (X_c) increases in proportion to resistance causing the phase angle to open until a maximum is reached at a critical frequency (f_c) specific to the system. Beyond the critical frequency the reactance begins to decrease in proportion to resistance with increasing frequency and at very high frequencies (f_h) the capacitive component is essentially short circuited so that the measured impedance is purely resistive once again (R_∞).

Most biologic systems are highly conductive and the phase angle at the critical frequency is small (15). Several early investigations focused on the associations of phase angles with physiological variables, such as basal metabolic rate (1, 2), but little is known about the sources of variation in phase angles among individuals. Theoretically, variation among individuals in phase angles at a fixed frequency could be due to differences in the capacitative behavior of their tissues associated with variability in cell size, membrane permeability, or intracellular

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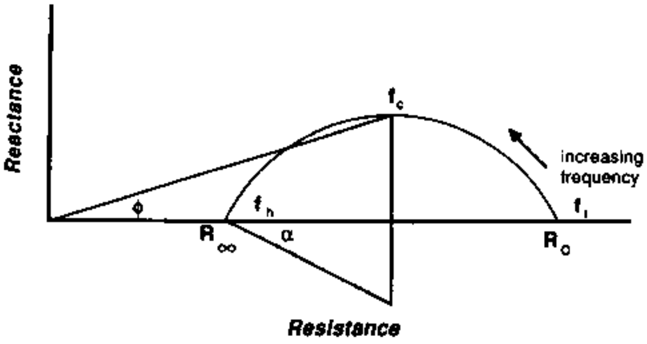

FIG 1. Impedance plot illustrating the relationships between resistance (R), reactance (X_c), and phase angle (ϕ). The phase angle for a biological conductor is maximum at a critical frequency (f_c).

composition or associated with differences in the distribution of body fluids among individuals, which may affect the amount of shunting of the current through the interstitial spaces (15).

To date, bioelectric studies of body composition have used measurements of bioelectric resistance in combination with stature squared (S^2) as an index of total body water or of fat-free mass (FFM). The theoretical basis for this use is Ohm's Law, which relates the volume of a cylindrical conductor to its length squared divided by its impedance, or

$$V = \rho L^2/R \text{ (5)} \tag{2}$$

Reactance has been ignored, perhaps because it is very small (< 2%) in proportion to resistance in the total impedance for most biologic conductors and because resistance is a better predictor of impedance than reactance (7). Also, the association of the phase angle with body composition has not been studied. The purpose of this study was to explore the use of measurements of reactance and phase angle for predicting body composition.

Materials and Methods

Study population

The study population consisted of 53 white males, ages 9–62 y, and 69 white females, ages 9–58 y. Twenty-four of the males and 24 of the females were < 18 y of age. These normal individuals were not selected by any criteria relating to their body composition. Individuals in the population ranged from very lean (< 5% body fat [%BF]) to obese (> 50%BF). Although there were significant differences between the sexes for mean levels of percent body fat, the adults (age > 18 y) were significantly fatter than the children (age < 18 y). The study population is described in **Table 1**.

Bioelectric impedance

Bioelectric impedance measurements were taken on the right side of the body for the arm, trunk, leg, and whole body using a BIA 101 impedance analyzer (RJL Systems, Detroit, MI). This device utilizes a four-electrode arrangement that eliminates electrode polarization and measures the resistance and reactance of a conductor to injection of an alternating electric current at 800 μA and 50 kHz. The measurements were taken at ~0930 h, after each participant had fasted for at least 12 h and with the bladder empty. The electrodes were attached using electrode cream and tape. All impedance measurements were taken with the participant supine, the arms relaxed at the sides but not touching the body, and thighs separated. The calibration of the impedance analyzer was checked daily against a 400 Ω precision resistor.

The locations used for placement of the source and receiving electrodes were described previously in detail (16). Briefly, for whole-body measurements the electrodes were placed on the anterior surface of the foot and ankle and on the posterior surface of the hand and wrist. For measurement of the leg, one pair of electrodes was placed at the standard locations on the foot and ankle and the other pair of electrodes was placed on the anterior midline of the proximal thigh with the measuring electrode in the same plane as the gluteal crease and the source electrode 5 cm proximal to the measuring electrode. Trunk impedance was measured by placing one pair of electrodes on the proximal thigh at the same locations used for measurement of the leg but with the source and receiving electrodes reversed and the other pair of electrodes on the sternal notch and the anterior midline of the neck. Impedance of the arm was measured by attaching one pair of electrodes at the standard locations on the hand and wrist and the other pair on the anterior surface of the shoulder with the measuring electrode over the midpoint of a line between the acromial process and the axilla and the source electrode 5 cm medial to this midpoint.

Measurements for the trunk were taken at midrespiration during quiet breathing in all participants. The need to standardize trunk impedance measurements with respect to respiration was demonstrated by data recorded at maximum inspiration and maximum expiration for a subsample of nine participants. Maximum inspiration produced an increase in resistance of ~4.8% over the resistance of the trunk measured at midrespiration. Maximum expiration decreased trunk resistance by ~1.2%. The phase of respiration did not affect reactance.

Anthropometry

All anthropometry data were collected following standardized procedures closely similar to corresponding techniques in the Airlie Consensus Report (17). All measurements were made by two observers and the means of paired measurements were used in the analyses. Stature was measured to the nearest 1.0 cm using a stadiometer. Weight was measured to the nearest 0.1 kg on a beam-balance scale. Skinfold thicknesses were measured to the nearest 0.2 mm with calipers at the triceps, subscapular, and lateral calf sites.

Densitometry

Estimates of %BF and FFM were derived from body density estimated from underwater weight corrected for lung residual volume. Each participant's underwater weight was measured by use of a steel chair suspended from a frame by four load cells into a tank of water at 35 °C. Underwater weights were recorded to the nearest 0.002 kg from a digital display with a microprocessor attached to the load cells. Each participant was weighed underwater 10 consecutive times and the mean of the last three weights were used to compute body density. Residual volume was measured on land to the nearest 0.01 L by a nitrogen-washout method with a Gould Model 2180 comput-

TABLE 1
Distributions of body composition variables by sex and age*

	Age			
	Male		Female	
	> 18 y (n = 29)	< 18 y (n = 24)	> 18 y (n = 44)	< 18 y (n = 25)
Weight (kg)	83.32 ± 12.33	48.53 ± 13.10	64.67 ± 15.52	48.32 ± 13.32
Stature (cm)	181.44 ± 6.79	159.73 ± 13.91	164.74 ± 5.99	155.88 ± 12.91
MSK (mm)	10.14 ± 1.38	7.87 ± 1.48	13.62 ± 1.43	10.46 ± 1.47
BD (g/cm^3)	1.047 ± 0.016	1.051 ± 0.021	1.030 ± 0.021	1.037 ± 0.015
%BF	22.74 ± 7.16	17.80 ± 9.91	30.75 ± 9.74	23.86 ± 7.00
FFM (kg)	63.72 ± 6.46	39.63 ± 11.20	43.71 ± 5.93	36.53 ± 9.62

* $\bar{x}$ ± SD.

erized spirometer. Previous studies (18, 19) showed that residual volumes measured on land are not consistently different in either magnitude or direction from residual volumes measured with the participant in the water and calculations of %BF are not altered by > 1.5%. The %BF was computed from body density with Siri's equation (20) with corrections for variation in the density of fat-free tissues with age and sex for individuals < 25 y of age (21). FFM was calculated as the product of body weight and 100 − %BF.

Statistical methods

Phase angles for the whole body and for each body segment were calculated in radians by the formula

$$\phi = \text{atan}\,(X_c/R) \tag{3}$$

and converted to degrees by multiplying by 57.297. S^2/R was computed as an index of FFM. Mean skinfold thickness (MSK), an index of subcutaneous adiposity, was calculated as the average of the natural logarithms of the subscapular, triceps, and lateral calf skinfold thicknesses. Weight (kg) divided by stature (m) squared (W/S^2) was calculated as an index of total body adiposity. Children were defined as participants < 18 y of age and adults were defined as participants > 18 y. Mean phase angles for the sexes and for the age groups were compared using t tests. Correlations were computed between resistance, reactance, and phase angles and age, %BF, FFM, MSK, and W/S^2. Age-adjusted or partial correlations controlling for age were also calculated between phase angles and %BF, FFM, MSK, and W/S^2. %BF and FFM were regressed separately for each sex and age group on age, S^2/R, W/S^2, MSK, and phase angles to determine the strength of the associations of phase angles with fat and fat-free components of body composition after adjustment for alternative bioelectric and anthropometric indices. Regressions also were computed with the age groups and sexes combined using dummy-coded variables (0, 1) for sex and including variables for interactions between sex, age, and phase angles (22).

Results

Statistics describing the distributions within each sex by age group (< 18 y vs > 18 y) for phase angles of the total body and of each segment are presented in **Table 2.** There were no statistically significant differences ($p > 0.05$) among the sex and age groups for phase angles; although the trunk, leg, arm, and whole-body phase angles tended to be consistently larger in the males than in the females. Also, phase angles for the trunk tended to be larger in the children than in the adults and had significant ($p < 0.05$) negative correlations with age in each sex (males, $r = -0.44$; females, $r = -0.42$). Phase angles for the trunk were larger and more variable than for the arm or leg in each sex and age group.

By definition, phase angle is positively associated with reactance and negatively associated with resistance. Therefore, variation among phase angles measured at a fixed frequency could be interpreted to some extent from the associations between resistance and reactance within and between body segments. Correlations between body segments for resistances or reactances are shown by sex in **Table 3** for children and in **Table 4** for adults. Resistances for the arm and the leg had strong, positive correlations ($r > 0.70$) with resistances for the whole body in both sexes and age groups, and resistances for the arm were correlated highly with those for the leg. Resistances

TABLE 2
Bioelectric phase angles (degrees) for body segments by age and sex*

	Children		Adults	
Body segment	ϕ	CV%	ϕ	CV%
Trunk				
Male	11.17 ± 2.16	19.34	10.46 ± 2.75	26.29
Female	10.13 ± 1.63	16.09	8.66 ± 2.26	26.10
Leg				
Male	7.98 ± 1.02	12.78	8.16 ± 1.52	18.63
Female	7.57 ± 0.82	10.83	7.25 ± 1.11	15.31
Arm				
Male	6.27 ± 0.85	13.56	7.38 ± 1.12	15.18
Female	5.66 ± 1.32	23.32	6.38 ± 1.65	25.86
Whole body				
Male	6.25 ± 0.68	10.88	7.01 ± 0.88	12.55
Female	6.21 ± 0.65	10.47	6.31 ± 0.69	10.94

* $\bar{x}$ ± SD.

TABLE 3
Matrix of correlations between body segments and the whole body for measurements of bioelectric resistance or reactance by sex in children*

Body segment	Resistance or reactance†			
	Trunk	Leg	Arm	Whole body
Trunk		0.66	0.56	0.39
		(0.76)	(0.70)	(0.49)
Leg	0.40		0.84	0.89
	(0.51)		(0.86)	(0.84)
Arm	0.44	0.85		0.82
	(0.57)	(0.59)		(0.87)
Whole body	0.22‡	0.92	0.89	
	(0.49)	(0.90)	(0.72)	

* Correlations not in parentheses are for boys; correlations in parentheses are for girls.

† Correlations above diagonal are for reactance with reactance; correlations below diagonal are for resistance with resistance.

‡ Not statistically significant, $p > 0.05$.

for the trunk, however, were not correlated significantly with whole body resistances in the boys or with the arm, leg, or whole-body resistances in the men or in the women. Similarly, reactances for the arm and the leg had strong, positive correlations with reactance for the whole body in all four groups, and reactances for the arm were correlated highly with those for the leg. Reactances for the trunk generally were not correlated strongly with reactances for the whole body, arm, and leg, and the correlation for reactance in the trunk and reactance in the whole body was not statistically significant in the men.

Correlations between resistance and reactance within each body segment are shown in **Table 5** by age group and sex. Resistance and reactance were significantly, positively correlated ($p < 0.05$) for the whole body and for the body segments in the boys and the girls but they were not significantly correlated in the women for the arm or in the men for the trunk, leg, or arm. These correlations suggested that bioelectric impedance for the whole body was principally associated with impedance in the extremities. Resistance and reactance in the trunk were independent to some extent of resistance and reactance in the rest of the body especially in the adults. Also, resistance and reactance were independent of each other to a degree in all segments of the body in the men.

Correlations of resistance and reactance with %BF from densitometry are shown in **Table 6** for each sex and age group. Resistance for the trunk was significantly and positively correlated with %BF in the boys, the men, and the women. Reactance for the leg had a significant negative correlation with %BF in the men and whole-body reactance was significantly and negatively correlated with %BF in both the men and the women.

Age-adjusted correlations among body composition

TABLE 4
Matrix of correlations between body segments and the whole body for measurements of bioelectric resistance or reactance by sex in adults*

Body segment	Resistance or reactance†			
	Trunk	Leg	Arm	Whole body
Trunk		0.60	0.70	0.31‡
		(0.72)	(0.66)	(0.59)
Leg	0.25‡		0.49	0.85
	(0.17)‡		(0.70)	(0.95)
Arm	0.34‡	0.80		0.43
	(0.04)‡	(0.67)		(0.61)
Whole body	0.10‡	0.94	0.91	
	(−0.08)‡	(0.88)	(0.85)	

*Correlations not in parentheses are for men; correlations in parentheses are for women.

† Correlations above diagonal are for reactance with reactance; correlations below diagonal are for resistance with resistance.

‡ Not statistically significant, $p > 0.05$.

TABLE 5
Correlations between resistance and reactance within each body segment and for the whole body by age group and sex

Body segment	Children	Adults
Trunk		
Male	0.62	0.35*
Female	0.74	0.50
Leg		
Male	0.73	0.27*
Female	0.63	0.71
Arm		
Male	0.76	0.22*
Female	0.55	0.20*
Whole body		
Male	0.76	0.38
Female	0.56	0.71

* Not statistically significant, $p > 0.05$.

TABLE 6
Correlations of resistance and reactance for body segments with %BF

	%BF			
	Children		Adults	
Body segment	Male	Female	Male	Female
Trunk				
Resistance	0.67*	0.17	0.56*	0.44*
Reactance	0.15	−0.13	−0.24	−0.19
Leg				
Resistance	0.25	0.12	−0.28	−0.02
Reactance	−0.10	−0.19	−0.53*	−0.29
Arm				
Resistance	0.34	0.11	−0.10	0.05
Reactance	0.09	−0.04	−0.21	−0.27
Whole body				
Resistance	0.23	0.05	−0.30	−0.17
Reactance	−0.05	−0.08	−0.54*	−0.33*

* Statistically significant, $p > 0.05$.

TABLE 7
Matrix of age-adjusted correlations among body composition variables and bioelectric impedance phase angles by sex*

	%BF	FFM	W/S^2	MSK	S^2/R	ϕ_t	ϕ_l	ϕ_a	ϕ_w
%BF		—	0.67	0.66	—	−0.74	−0.59	−0.29	−0.46
FFM	−0.38		0.48	—	0.89	—	—	—	—
W/S^2	0.42	0.51		0.77	0.44	−0.57	−0.41	—	−0.26
MSK	0.62	—	0.55		—	−0.65	−0.39	−0.28	—
S^2/Z	−0.34	0.91	0.40	—		—	—	—	—
ϕ_t	−0.57	0.37	—	−0.52	0.33		0.79	0.46	0.61
ϕ_l	−0.39	0.49	—	—	0.41	0.76		0.55	0.87
ϕ_a	—	0.49	0.38	—	0.44	0.61	0.82		0.53
ϕ_w	−0.34	0.50	—	—	0.52	0.54	0.84	0.81	

* Males below diagonal, females above diagonal. Nonsignificant correlations ($p > 0.05$) not shown.

and bioelectric variables are shown in **Table 7** by sex. S^2/R was correlated strongly with FFM and had small but significant positive correlations with W/S^2 in each sex. %BF was not correlated significantly with S^2/R in the females and the correlation in the males was small ($r = -0.34$). Age-adjusted correlations of phase angles for the trunk, leg, and the whole body with %BF were significant and negative in the males. Phase angles for all three segments and for the whole body had significant negative correlations with %BF in the females. Phase angles were not correlated significantly with FFM or S^2/R in the females; however, the corresponding correlations, although small, were significant ($p < 0.05$) and positive in the males. In the females the magnitude of the age-adjusted correlation of %BF with ϕ_t ($R = -0.74$) was slightly greater than the correlations of %BF with W/S^2 ($R = 0.67$) or MSK ($R = 0.66$). In the males the correlation of %BF with ϕ_t ($r = -0.57$) was slightly greater than that of %BF with W/S^2 ($r = 0.42$) but slightly less than that with MSK ($r = 0.62$). Age-adjusted correlations for ϕ_t and MSK in each sex also were significant (males, $R = -0.52$; females, $R = -0.65$).

Results of regressions of %BF on age, MSK, W/S^2, and ϕ_t are shown in **Table 8**. Age, MSK, and W/S^2 were forced into the regression in that order and phase angles for the trunk, leg, arm, and whole body were allowed to enter using a stepwise algorithm. Age and MSK accounted for a significant ($p < 0.001$) portion of the variance in %BF in both sexes (males, $R^2 = 0.44$; females, $R^2 = 0.45$). W/S^2 did not add significantly to the total R^2 after accounting for variation from age and MSK. ϕ_t was the only bioelectric variable to be entered in the predictions of %BF and explained statistically significant ($p < 0.001$) portions of the variance in %BF after controlling for age, MSK, and W/S^2 in both sexes (males, $R^2 = 0.10$; females, $R^2 = 0.15$). In the males the full equation including age, MSK, W/S^2, and ϕ_t explained 55% of the variance in %BF with a root mean squared error (rmse) of ~6%. In the females the corresponding equation explained 60% of the total variance in %BF with rmse of ~5%. The interaction terms were not statistically significant.

The contribution of phase angles to explanation of variance in FFM also was evaluated using similar regression methods. Age and S^2/R explained 92% of the variance in FFM in the males (rmse = 4.6 kg) and 83% in the females (rmse = 3.7 kg) but the inclusion of phase angles in the regressions did not add significantly to the prediction of FFM after controlling for age and S^2/R. Again, the interaction terms were not significant.

The slopes of the regression of %BF on age, MSK, and ϕ_t were not significantly different between the sexes (Table 8). Therefore, the groups were combined and %BF was regressed on sex (coded 0 for females, 1 for males), age, and ϕ_t. The regression equation explained 55.8% of the total variance in %BF in the sample with an rmse of 6.2%. In contrast, sex, age and ϕ_w explained only 31.5% of the total variance with an rmse of 7.8%. A regression equation controlling hierarchically for sex, age, MSK, W/S^2, and ϕ_t explained 61% of the total variance

TABLE 8
Results of regression of %BF from densitometry on age, MSK, W/S^2, and ϕ_t

Independent variable	Coefficient*	Change in R^2	F
Intercept	23.69 ± 8.21		
Age (y)	−0.14 ± 0.10	0.07	3.31
MSK (mm)	0.73 ± 0.34	0.37	34.27†
W/S^2 (kg/m²)	0.49 ± 0.36	0.01	0.53
ϕ_t (°)	−1.54 ± 0.53	0.10	6.96†
Total $R^2 = 0.55$			
SEE = 5.99%			
Intercept	41.14 ± 8.44		
Age (y)	−0.06 ± 0.06	0.05	2.85
MSK (mm)	0.46 ± 0.24	0.40	37.39†
W/S^2 (kg/m²)	−0.01 ± 0.38	<0.00	<0.00
ϕ_t (°)	−1.96 ± 0.46	0.15	18.01†
Total $R^2 = 0.60$			
SEE = 5.08%			

* $\bar{x} \pm$ SD.

† Statistically significant, $p < 0.001$. SD, standard deviation of coefficient.

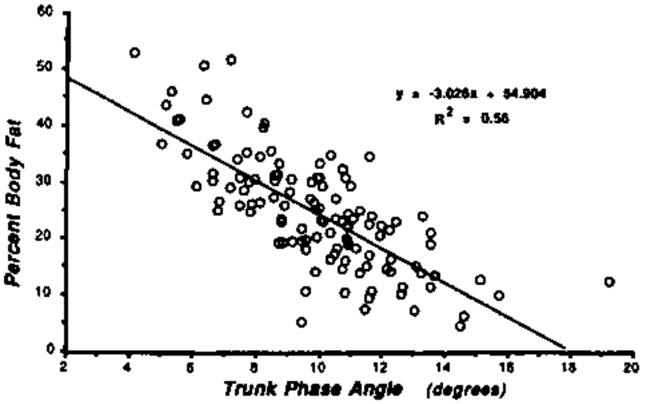

FIG 2. Plot of percent body fat from underwater weighing by bioelectric phase angle for the trunk, including males and females ages 9–58 y (n = 122).

in %BF with an rmse of 5.5%. In this equation ϕ_t explained a statistically significant portion of the residual variance in %BF ($R^2 = 0.05$, $p < 0.001$) after these other variables were controlled for.

The unadjusted relationship of %BF to ϕ_t is illustrated in **Figure 2** for the total sample. Although a straight regression line has been fitted to the data, the true relationship between ϕ_t and %BF may be nonlinear due to theoretical minima for %BF (essential fat) and for reactance. A polynomial regression model using ϕ_t and ϕ_t^2 provided a significantly better fit than the linear model ($F = 8.7$, $p < 0.01$), but the improvement was small (increment in $R^2 = 0.03$).

Figure 3 shows a plot of reactance versus resistance for the trunk at the fixed frequency of 50 kHz with regression lines describing the average association within high (> median) vs low (< median) groups for %BF. The slope (±SD) of the regression for the low %BF group (0.26 ± 0.77) was significantly greater than the slope (0.10 ± 0.58) for the high %BF group ($p < 0.05$). Reactance was significantly higher ($p < 0.005$) in the low %BF group (mean ± SD, 15.4 ± 4.4 Ω) than in the high %BF group (13.3 ± 3.7 Ω) and resistance was significantly lower ($p < 0.001$) in the low %BF group (mean ± SD, 76.5 ± 13.2) than in the high %BF group (90.7 ± 21). The mean (±SD) ϕ_t in the low %BF group (11.3 ± 2.1°) was significantly higher than that in the high %BF group (8.4 ± 2.0°). Considerable vertical as well as horizontal displacement was evident in the plot, suggesting that the sources of variation in ϕ_t among participants with differing body composition are complex.

Discussion

This study shows that %BF can be predicted from measurements of the bioelectric phase angle of the trunk and that prediction equations using conventional anthropometric indices of adiposity can be improved by the addition of trunk phase angle. In previous studies, the estimation of %BF from bioelectric impedance was limited by the accuracy of the estimation of FFM, where %BF was calculated as 100 (weight − estimated FFM)/weight. Direct regressions of %BF on S^2/R produced low R^2s and large errors of estimation; the addition of S^2/R to equations using anthropometric measurements improved predictions of %BF only marginally (10). In contrast, phase angles do not add appreciably to the prediction of FFM after age and S^2/R are controlled for.

It is clear from the theory of bioelectric impedance that the length of the conductor squared divided by its longitudinal impedance is proportional to the volume of the conductor so it is not surprising that S^2/R is an accurate index of total body water and of FFM (5, 7). The high correlations of whole-body resistance with resistances in the arm and the leg but not in the trunk support the hypothesis of Settle et al (23) that the association between S^2/R and TBW and FFM may be fortuitous and not due to a direct relationship.

Explanation of the association between phase angle and %BF in this study is more difficult because there may be multiple causes of variation in phase angle within a biological conductor that are difficult to separate when the frequency of the current cannot be varied (15). The correlations among body segments for resistance and reactance indicate that the bioelectric properties of the trunk are different from those of the arm and the leg, a fact that is obscured by the measurement of whole-body impedance. In addition, the correlations between resistance and reactance within body segments suggest that the bioelectric properties of men may differ from those of women and children in all body segments. Resistance for the trunk was significantly and positively correlated with %BF except in the girls whereas reactance for the trunk tended to be uncorrelated or negatively correlated with %BF. Mean resistance was significantly higher in the high %BF group than in the low %BF group whereas mean reactance was significantly lower. As a result, correlations between ϕ_t and %BF were significantly negative

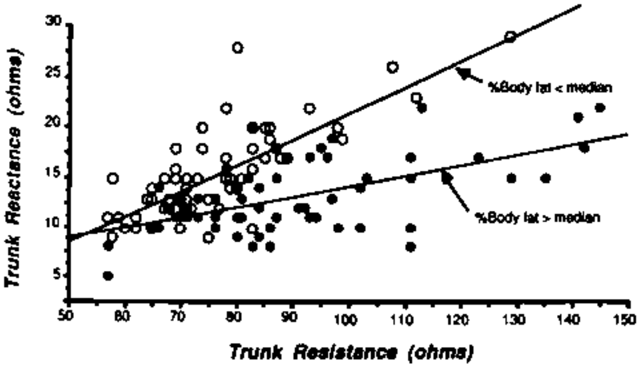

FIG 3. Plot of reactance by resistance for the trunk, including males and females ages 9–58 y (n = 122). Regression lines have been fitted for groups with percent body fat greater than and less than the sex-specific medians. (Median %BF in males = 21%; median %BF in females = 27%.)

and mean ϕ_t was higher in the low %BF group than in the high %BF group. The multiple regression analyses indicated that ϕ_t accounts for a significant portion of variation in %BF that is independent of sex, age, mean thickness of subcutaneous adipose tissue, and body mass. It is possible that the ϕ_t is affected by the volume of intraabdominal adipose tissue. Also, ratios of phase angles for body segments might be used to index adipose tissue distribution.

Theoretically, increased extracellular fluid could produce increased shunting of the current, which would be observed as decreases in both resistance and reactance for a fixed frequency. Increased subcutaneous and intraabdominal fat as well as interstitial fat in muscle could reduce cell wall and tissue interface permeability, producing increases in both reactance and resistance (15). Disproportionate changes in resistance and reactance and, consequently, changes in the observed phase angles may be the net result of the combination of these factors. The percentage of total body water in fat-free tissues decreases (24) and the volume of interstitial water in adipose tissues increases (25) with increases in adiposity. Therefore, the associations observed in the present study between phase angles and %BF could reflect changes in the distribution of body water among fat and fat-free compartments associated with increased adiposity. These changes primarily appear to occur in the trunk and may involve changes in intraabdominal as well as subcutaneous adipose tissues. To test this hypothesis it would be necessary to measure resistance and reactance in the trunk over a range of frequencies of alternating current and to obtain intraabdominal adipose tissue volume from computed tomography.

Several previous studies support the hypothesis that phase angles are sensitive to differences in water distribution. Using equipment similar to that employed in the present study, Spence et al (26) measured the resistance and reactance at a fixed frequency for the chests of patients with renal failure before and after hemodialysis. Resistance, reactance, and phase angle increased after dialysis but the relative change was greater for reactance and for phase angle than for resistance. Moreover, the relative change in phase angle for the chest (+32%) was greater than that for the whole body (+20%). These changes in the components of impedance were inversely correlated with changes in total body water, which decreased 5% after dialysis. In a similar study, Subramanyan et al (27) also demonstrated statistically significant changes in phase angles at a fixed frequency for the whole body because of therapy (sodium restriction, diuretics, and other medications) in patients with congestive heart failure. These changes were inversely correlated with changes in total body water. In addition, Jenin et al (6) showed that the ratio of impedance measured at a low frequency (5 kHz) and impedance measured at a high frequency (100 kHz) can be used as an index of the extracellular portion of total body water.

The present study shows that ϕ_t can be used to predict %BF. The error of the prediction is similar to that for regression estimation equations using MSK or W/S^2 and considerably better than an equation using ϕ_w. Moreover, the inclusion of ϕ_t significantly improved the prediction of %BF after accounting for variation from sex, age, W/S^2, and MSK, suggesting an association with intraabdominal adipose tissue that cannot be measured by conventional anthropometry. Thus, the bioelectric phase angle of the trunk, calculated from measurements of resistance and reactance for the trunk, may be used as a simple and comparatively accurate index of percent body fat. It may be useful particularly for clinical applications in which conventional anthropometric techniques are impractical. Bioelectric phase angle for the trunk may be used also with measurements of stature, weight, and skinfold thicknesses to improve estimations of percent body fat using these variables in survey research. The results of this study indicate that the use of bioelectric impedance for estimating body composition may be more complex than is generally recognized and that potential applications exist that have been overlooked in previous research. Measurement of resistance and reactance for body segments for a range of frequencies could clarify as well as improve the associations between bioelectric impedance and body composition.

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