Bioelectrical impedance analysis: population reference values for phase angle by age and sex[1–3]

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ABSTRACT

Background: Phase angle is an indicator based on reactance and resistance obtained from bioelectrical impedance analysis (BIA). Although its biological meaning is still not clear, phase angle appears to have an important prognostic role.

Objective: The aim of this study was to estimate population averages and SDs of phase angle that can be used as reference values.

Design: BIA and other methods used to evaluate body composition, including hydrodensitometry and total body water, were completed in 1967 healthy adults aged 18–94 y. Phase angle was calculated directly from body resistance and reactance, and fat mass (FM) was estimated from the combination of weight, hydrodensitometry, and total body water by using the 3-compartment Siri equation. Phase angle values were compared across categories of sex, age, body mass index (BMI), and percentage FM.

Results: Phase angle was significantly ($P < 0.001$) smaller in women than in men and was lower with greater age ($P < 0.001$). Phase angle increased with an increase in BMI and was significantly inversely associated with percentage fat in men. Phase angle was significantly predicted from sex, age, BMI, and percentage FM in multiple regression models.

Conclusions: Phase angle differs across categories of sex, age, BMI, and percentage fat. These reference values can serve as a basis for phase angle evaluations in the clinical setting. *Am J Clin Nutr* 2005;82:49–52.

KEY WORDS Bioelectrical impedance analysis, phase angle, nutritional assessment, body composition, diagnostic methods

INTRODUCTION

Bioelectrical impedance analysis (BIA) is a noninvasive, inexpensive, and portable method that has been used mainly for body-composition analysis over the past decade. However, BIA does not measure body composition directly. It measures 2 bioelectrical parameters: body resistance and reactance. Resistance is the opposition offered by the body to the flow of an alternating electrical current, and it is inversely related to the water and electrolyte content of tissue. Reactance is related to the capacitance properties of the cell membrane, and variations can occur depending on its integrity, function, and composition (1).

BIA is considered to be a statistically derived fat-estimation method, because it depends on a regression analysis between impedance and a reference method for the development of a prediction formula (2). Many prediction equations are available to estimate body compartments as a function of resistance, reactance, anthropometric variables (weight and height), sex, and age. Prediction equations are only valid for the specific population they are developed for, which makes these equations inappropriate in clinical situations. Patients who are malnourished, who are critically ill, and who have eating disorders have a fluid imbalance; therefore, the constant hydration of lean body mass may not be acceptable (3).

Phase angle is a derived measure obtained from the relation between the direct measures of resistance and reactance (4). Phase angle is calculated directly from reactance and resistance:

$$\text{Phase angle} = \text{arc-tangent reactance/resistance} \times 180°/\pi \qquad (1)$$

Its biological meaning and pathogenic effects are not completely understood. Phase angle has been interpreted as an indicator of membrane integrity and water distribution between the intra- and extracellular spaces (4). Phase angle has also been used to predict body cell mass (5, 6); for this reason, it has also been used as a nutritional indicator in adults and children (6, 7).

Some authors have studied the role of phase angle as a prognostic indicator. A positive association was shown between phase angle and survival in patients with HIV-positive AIDS (4, 8), with lung cancer (9), undergoing hemodialysis (5, 7), and who are critically ill (10, 11). These authors suggested that phase angle could be an important tool for evaluating clinical outcome or for monitoring disease progression and may be superior to other serum or anthropometric nutritional indicators.

The lack of phase angle reference values has limited its use in clinical and epidemiologic situations. Such values are needed to properly assess individual deviations in relation to the population average and to analyze the influence of phase angle on various outcomes within epidemiologic studies. We conducted the present study to understand the relation between phase angle and such variables as sex, age, race, and body-composition indicators [eg, body mass index (BMI) and percentage fat]. We also estimated population averages and SDs for phase angle to serve as

reference values. With these reference values, it is possible to standardize individual values and to make comparisons between different age and sex groups in clinical or population studies.

SUBJECTS AND METHODS

Between 1986 and 1999, a study to evaluate body composition was performed at the St Luke's–Roosevelt Hospital Center in 1967 healthy adults aged 18–94 y, who were recruited from hospital staff and the local area. All subjects were fully informed about the study objectives and methods and were asked to sign a written consent form. The Institutional Review Board of St Luke's–Roosevelt Hospital approved the study.

The subjects were studied after fasting for $\geq$8 h. Several body-composition tests were performed, such as hydrodensitometry and total body water (TBW). Of direct interest to the present analysis, body weight (BW) was measured to the nearest 0.1 kg with a Weight-Tronix Scale (Scale Electronics Development, New York, NY) while each subject was wearing a hospital gown, underwear, and no shoes; height was measured to the nearest 0.1 cm with a wall-mounted stadiometer (Holtain Ltd, Crosswell, United Kingdom). BMI (in kg/m^2) was calculated as body weight/height squared. BIA was performed with the use of an RJL instrument (model 101; RJL Systems, Mt Clemens, MI), which applies an 800-μA current at a frequency of 50 KHz. The measurements were performed under a strict standardization of the procedure, according to the National Institutes of Health (12). The subjects were in a supine position 5 min before the measurement, which was performed under a thermoneutral environment of 25 °C. Phase angle was calculated as previously described (1). Fat mass (FM) was estimated by using the three-compartment Siri equation:

$$\text{FM} = 2.1 \times \text{body volume} - 0.8 \times \text{TBW} - 1.3 \times \text{BW}$$

(2)

and %FM was estimated as

$$\%\text{FM} = (\text{FM/weight}) \times 100$$

(3)

Total body water was obtained from tritium space (^{3}H$_2$O; in L) and corrected for nonaqueous hydrogen exchange. The details about these body-composition methods (TBW and hydrodensitometry) are described in detail elsewhere (2).

The statistical analyses were performed by using STATA 6.0 (Stata Corporation, College Station, TX) (13). The correlations between phase angle and the other variables were estimated. The crude effect of sex, race, age, BMI, and %FM on phase angle was assessed by comparing the means of the first 2 variables (t test and ANOVA, respectively) and by using the correlation coefficients for the last 3 variables. A multiple linear regression analysis was used to adjust the effects of the variables and to identify those variables that were independently associated with phase angle. On the basis of these results, we could identify the smallest set of variables that explained most of the observed variability, so that reference values could be calculated for the smallest number of subgroups. The usual significance level of 5% was used for all tests.

RESULTS

The age, weight, height, and BMI of the 1967 study subjects are presented in **Table 1**; 46% of the subjects were white, 22%

TABLE 1
Age, weight, height, and BMI of the study subjects[1]

	Men (n = 832)	Women (n = 1135)	P[2]
Age (y)	46.3 ± 18.3	48.1 ± 17.7	0.02
Weight (kg)	77.5 ± 14.7	67.9 ± 17.5	< 0.001
Height (cm)	173.6 ± 7.6	161.5 ± 7.0	< 0.001
BMI (kg/m^2)	25.6 ± 4.2	26.0 ± 6.4	0.1

[1] All values are $\bar{x}$ ± SD.

[2] t test.

were African American, 14% were Asian, and 18% were Hispanic or of another race. The women (58%) were significantly older than the men. The mean BMI was 25.9; and no significant difference was found between the women and the men.

Phase angle was significantly larger in the men than in the women (7.48 ± 1.10 ° and 6.53°± 1.01 °, respectively; $P <$ 0.001). A comparison of phase angle by race showed a significant difference in crude analysis ($P <$ 0.001): 6.55 ± 1.10 ° for Asians, 6.82 ± 1.13 ° for whites, 7.00 ± 1.01 ° for multiracial subjects, 7.21 ± 1.19 ° for African Americans, 7.33 ± 1.13 ° for Hispanics, and 7.45 ± 0.98 ° for other races.

Phase angle showed a positive correlation with BMI ($R^2 =$ 0.17) and a negative correlation with age and %FM ($R^2 = -0.49$ and -0.32, respectively); all correlations were significant ($P <$ 0.001).

The final regression model obtained was rather complex and explained almost one-half of the observed variance in phase angle ($R^2 = 0.49$). After age and sex were controlled for, race was no longer significant, which suggested that the crude association was due to confounding. Sex, age, BMI, and %FM remained associated with phase angle, including the interactions of sex with age and of BMI with %FM. However, for sex and age it was possible to achieve 82% of the variability explained by the full model (0.40 out of 0.49).

Because BMI was significantly associated with phase angle in the previous analysis, it was important to check whether the distribution of this variable in our sample was similar to its distribution in the population. We thus compared the mean BMIs, by sex and age, with the mean BMIs published by Flegal and Triano (14) with the use of population-based data from the third National Health and Nutrition Examination Survey (NHANES III). Some differences were found: men and women from the study conducted in New York had a BMI lower than that of the NHANES III value, especially those aged >50 y. (The largest mean differences in BMI were 1.7 in men and 2.3 in women.) To correct for this difference, phase angle values were adjusted by NHANES III BMI means for each age and sex category. Mean differences of 0.03 and 0.04 ° were found between the original and adjusted values for women and men, respectively. The largest differences were found in persons aged >70 y: −0.09° (−1.5%) in women and −0.07° (−1.1%) in men. The corrections were of no clinical relevance, and the adjustment for BMI was abandoned.

Given that sex and age accounted for most of the phase angle variability explained by available variables and that BMI and %FM are not always available in clinical situations (eg, for bed-ridden patients), phase angle reference values were estimated for the subgroups generated by sex and age only.

TABLE 2
Phase angles according to age group and sex[1]

	Phase angle		
Age group	Men (n = 832)	Women (n = 1135)	P[2]
18–20 y	7.90 ± 0.47 (6.97, 8.75) [17]	7.04 ± 0.85 (5.90, 8.91) [20]	<0.001
20–29 y	8.02 ± 0.75 (6.83, 9.17) [178]	6.98 ± 0.92 (5.64, 8.55) [171]	<0.001
30–39 y	8.01 ± 0.85 (6.64, 9.48) [178]	6.87 ± 0.84 (5.57, 8.36) [242]	<0.001
40–49 y	7.76 ± 0.85 (6.53, 9.00) [121]	6.91 ± 0.85 (5.57, 8.33) [165]	<0.001
50–59 y	7.31 ± 0.89 (6.12, 8.68) [106]	6.55 ± 0.87 (5.48, 7.96) [205]	<0.001
60–69 y	6.96 ± 1.10 (5.40, 8.88) [111]	5.97 ± 0.83 (4.69, 7.48) [180]	<0.001
≥70 y	6.19 ± 0.97 (4.77, 8.01) [121]	5.64 ± 1.02 (4.22, 7.04) [152]	<0.001

[1] All values are $\bar{x}$ ± SD; 5th and 95th percentiles in parentheses. *n* values in brackets.
[2] *t* test.

The distribution of phase angle was fairly normal in our data. Mean (±SD) phase angles, and 5th and 95th percentiles, are shown by age and sex in **Table 2**. The overall mean phase angle mean was 6.93 ± 1.15 °; 7.48 ± 1.10 ° for men, and 6.53 ± 1.01 ° for women. Phase angle was significantly greater in the men than in the women in all age categories. There was a significant and decreasing linear trend in phase angle with age, in both sexes. Phase angle decreased from 7.90 ° (youngest group) to 6.19 ° (oldest group) in men and from 7.04 ° (youngest group) to 5.64 ° (oldest group) in women.

DISCUSSION

Phase angle has been reported to be a prognostic tool in various clinical situations, such as HIV (4, 8), bacteremia (15), cirrhosis of the liver (16), renal disease (5, 17–19), pulmonary tuberculosis (20), and cancer (9, 21). Despite this, relatively little is known about reference values for phase angle in healthy populations. The objective of this study was to obtain phase angle values in a sample of healthy subjects who were volunteers in other body-composition studies. This fact enabled us to study not only phase angles but also the relation of phase angles to other characteristics of body composition, such as body fat measured by using reference methods.

Phase angle can be calculated as the arc-tangent of the ratio of reactance to resistance and then converted to degrees. Some authors have used a simplified equation (phase angle = reactance/resistance; converted to degrees) to obtain its value. Although not strictly correct, the simplified equation gives similar results because the ratio between reactance and resistance results in very small values (from 0.06 to 0.2 in our sample). In this situation, the arc-tangent returned a similar value, but this would not have happened if the values were larger.

The high inverse correlation with age and positive correlation with BMI were also found by Dittmar (22). The finding of a higher phase angle in persons with a higher BMI is not surprising. Phase angle is directly related to cell membranes (amount and functional status), which are what reactance stands for. Persons with higher BMIs have more cells (fat or muscle cells), and this results in higher phase angle values.

The age- and sex-related differences found in our study were not found in some previous studies. Baumgartner et al (1), in the first study of phase angle and body composition, found no significant difference in phase angle values between sex and age groups. Selberg and Selberg (16) also found no significant difference in phase angle values by sex in healthy subjects, probably because of their very small sample size (74 adults and 48 subjects aged <18 y in Baumgartner et al's study and 50 subjects in Selberg and Selberg's study) and consequent lack of power. This difference, however, was found in larger studies of healthy adults (23, 24) and in a hemodialysis population (25). Buffa et al (26) also showed a significant decrease in phase angle with age in healthy elderly subjects, and Kyle et al (27) found the same age and sex differences in 2740 healthy adults.

The decrease in phase angle values with increasing age may suggest that phase angle is an indicator of function and general health, not only an indicator of body composition or nutritional status. The phase angle values found in a hemodialysis population were clearly smaller than those found in our healthy sample (median: 5.16 ° in men and 4.01 ° in women) (25). In the same study, the presence of diabetes resulted in phase angle values that were even smaller. A mean phase angle of 4.57 ° was found in lung cancer patients, and the survival of patients with a phase angle smaller than this value was significantly shorter (9). The use of standardized values found in our study makes possible the individual comparison of healthy and sick people with its age- and sex-specific phase angle mean. This approach is more likely to indicate a high-risk situation than is the comparison of individual values with the overall mean phase angle.

A study conducted in a Swiss population of healthy subjects was designed to determine reference values for fat-free mass, FM, and %FM obtained from BIA (23). In the Swiss population, phase angle values were smaller than those found in the present study (10.5% in men and 7.7% in women). Although the prevalences of overweight and obesity were lower in the Swiss study than in the US population in the present study, phase angle values remained smaller even after adjustment for BMI and %FM. This may suggest that phase angle, as other anthropometric variables, may have reference values that are specific to each population. Further studies are necessary to show how phase angle differs between different populations and whether they vary with the bioimpedance device used.

Once the sample was obtained from the subjects, we needed to know whether it could be considered representative of the US population. The adjustment for differences in the BMI distribution in the NHANES III data presented no clinically relevant effect on age- and sex-specific phase angle values. We are confident that our results can be used as reference values for the US

population and possibly for other populations with similar body composition. However, the reference values for the youngest group (18–20 y of age) in our study should be used with caution because of the small sample size of each sex in this group.

Because phase angles differ by age and sex, it becomes difficult to compare values across populations of different sexes and of different age groups. One way to make such values comparable, regardless of age and sex, is to standardize them, as is commonly done with nutritional status (eg, weight is standardized for age and sex and transformed into a *z* score). Standardized phase angles for specific age and sex groups can be obtained by dividing mean age- and sex-specific phase angles by their SDs. Standardized phase angles have a mean of 0 and an SD of 1 for everyone and are comparable regardless of age and sex.

The prognostic role of phase angle is easier to assess if standardized values are used. Standardized phase angles on the positive side of the scale (ie, values greater than the mean) are expected for healthy subjects. Sick individuals (eg, cancer patients) are expected to have negative standardized phase angles (ie, values lower than the mean), which become increasingly lower with a worsening prognosis. The use of standardized phase angles are likely to produce better results than is the use of a single population reference value for identifying high-risk persons.

In summary, we showed that phase angle changes with sex and age. Its dependence on body composition is complex, being determined by BMI, %FM, and their interaction. The age- and sex-specific means and SDs presented in this study make it possible to calculate standardized phase angle values that make comparisons across subjects possible, even when the age and sex of the population vary widely. Also, studies of the prognostic value of phase angle in various subject groups—such as surgical, cancer, and intensive care patients—will now have access to a single set of reference values. Furthermore, cutoffs determined to identify high-risk subjects, based on standardized phase angles, will not depend on the age and sex structure of the studied samples.

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