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Original Research Article

DOES PHASE ANGLE MEASUREMENTS COMPARE WITH ROUTINE ANTHROPOMETRIC MEASUREMENTS FOR ASSESSMENT OF NUTRITIONAL STATUS OF SOUTH INDIAN CHILDREN?

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ABSTRACT

Background: Assessment of nutritional status in children has been of great importance as it affects every aspect of child's health, growth and development. Bioelectrical impedance analysis is a simple and non-invasive method for assessment which involves use of prediction equations, which are population specific and are based on the assumption of a constant hydration of Fat free mass. As in children the composition and density of the Fat free mass varies with age and clinical state, use of these equations is limited. However, Phase angle (PhA) is directly obtained from electrical properties of tissues i.e. resistance and reactance without use of any equations. **Objectives:** To assess the association between PhA and anthropometric indices and to determine whether PhA could be used as a parameter for assessing nutritional status in children.

Materials and Methods: This cross-sectional study included 65 apparently healthy children aged 6–10 years after obtaining parental informed consent and child assent. Anthropometric measurements and Bioelectrical impedance measurements using Body Stat Quadscan 4000 were performed under standard conditions. Phase angle measurements were calculated from the impedance values obtained at four different frequencies with the help of Phase angle software program provided by the manufacturer.

Results: The mean PhA for the entire study population was 11.4 ± 1.6. PhA values did not show any significant associations with anthropometric measurements; however, following normalization of impedance values for height, the corrected PhA demonstrated positive correlations with all anthropometric parameters, with statistically significant associations for weight and waist circumference ($r=0.291$ and 0.250 and $p < 0.05$).

Conclusion: The PhA values in children obtained in this study were higher compared to those found in other studies. No gender differences in Phase angle values were observed which is similar to other studies. PhA showed significant association with anthropometric measurements only after normalizing Impedance values for height. However, for considering Bioelectrical impedance Phase angle as a parameter for assessment of nutritional status in children needs to be further explored.

Keywords: Anthropometry, Bio impedance Phase angle, nutritional assessment.

INTRODUCTION

Body composition and growth being the key components of health, their assessment plays an important factor in determination of nutritional status of both individuals and populations.[1] There are various methods for estimation of body composition.[2] The commonly used field techniques are skinfold thickness measurements and bioelectrical impedance analysis. The other methods such as Air displacement plethysmography (ADP), Dual energy x ray absorptiometry (DEXA), Isotope dilution techniques, Total body potassium (TBK) are mainly laboratory based requiring specialized expensive equipment, consumables and trained technical expertise. Skinfold thickness is a commonly used field technique, which involves the measurement of skinfold thickness at various sites of the body. The sum of two or more of these measurements are used to predict body density from which body fat is estimated.[3,4] However, this method is observer dependent and also depends on regional distribution of subcutaneous fat and the proportion of fat situated subcutaneously.

Bioelectrical impedance analysis (BIA) is a relatively inexpensive, simple and safe method that uses a low-frequency electrical current to estimate various body composition parameters. It measures two bioelectrical parameters: resistance (R) and reactance (Xc).[5] Resistance is the opposition offered by body fluids and electrolytes and reactance is the ability of the membrane to sustain electrical potential.[2] Our body comprises of highly conductive lean tissues containing large amounts of water and conducting electrolytes which represents a low resistance electrical pathway, on the other hand fat and bone being poor conductors represent a high resistance electrical pathway. Reactance is a measure of the volume of cell membrane capacitance and an indirect measure of intracellular volume or the body cell mass.[6] Hence body fat, total body water and extracellular water offers resistance to electrical current, and cell membranes offer capacitive reactance. BIA involves use of predictive equations that are based on assumptions of constant tissue hydration, which is very unlikely when considering diseased conditions, critically ill patients,[5] or malnourished children.[10]

Due to the above-mentioned limitations of predictive equations, the use of raw data from the Bioelectrical impedance analysis has gained popularity in assessment and monitoring of nutritional status.[7] There has been a growing interest for the use of direct measures of BIA parameters such as resistance, reactance and phase angle in various epidemiological and clinical investigations.[7,19] Phase angle is obtained from the relation between the direct measures of resistance and reactance. It is a measure that expresses the changes in the amount as well as the quality of soft tissue mass and acts as an indicator of membrane integrity and water distribution between intra and extracellular spaces.[8] It is represented as arc tangent of the ratio Xc/R, being directly proportional to reactance (Xc) and inversely proportional to resistance (R).[9] Phase angle obtained from BIA is a quick, simple, practical, reproducible procedure, relatively easy to handle and non-invasive.[10-11] It appears to be a reliable measure as they are not based on assumptions of body components, models or regression equations.[12] Phase angle has been shown to be a reliable predictor of clinical outcomes, including morbidity and mortality across various patient populations.[13-17]

Anthropometric measurements including skinfold thickness are simple, rapid and can be applied for large population studies but they are associated with limitations such as the use of the regression equations which are mainly derived from western populations.[18] As the body composition varies with ethnicity, population specific equations have to be used. Several recent findings have shown that BIA can be used for nutritional assessment in children; however, this application is limited as there are no uniform equations that can be used in all populations. Nutritional status can also be evaluated using BIA (i.e. Phase angle) without use of any equations in children.[10] If normal values for phase angles in well-nourished children can be established, then the nutritional status and body cell mass of sick children might be determined.

As per our knowledge there is no current data on phase angle measurements of well-nourished and malnourished children from India (South India). The objectives of this study are to measure Phase angle using BIA in children aged between 6 to 10 years and compare them with routine anthropometric measurements for assessing nutritional status in South Indian children.

MATERIALS AND METHODS

Sixty-five children between the age group of 6 and 10 years were recruited from two different schools in Bangalore, of which there were thirty boys and thirty five girls. Age was confirmed from the school register. Before recruiting an explanation of the study protocol was provided to the parents and children in their native language. Consent from the parents and assent from the children were obtained. General physical examination was conducted and children who were clinically fit were recruited for the study. The inclusion criteria were: Boys and girls aged between 6 to 10 years, children willing to provide assent to participate and perform all the tests, apparently healthy, well and malnourished. The exclusion criteria were children having any medical history of acute or chronic illness or other physical and mental disability, children on medications for any systemic illnesses, childhood obesity, children with history of any cardiac or other implants.

Ethical clearance was obtained from the Institutional Ethics Committee (IEC) prior to commencement of the study.

Anthropometry:

Anthropometric parameters were measured first. The anthropometric assessment was done as per the guidelines given in the Anthropometry Procedures Manual published by the National Health and Nutrition Examination Survey (NHANES). Weight was measured using a standardized digital weighing scale (Salter Kent, England) to the nearest 0.1 kg.

Subjects were asked to wear minimal clothing and asked to remove their footwear prior to measurement. The height was measured by making subjects stand erect on a flat surface without foot wear using a standard stadiometer (Holtain Ltd, Crymych, Britain) and expressed to the nearest 0.1cm. The Mid upper arm circumference (MUAC), waist and hip circumference were measured to the nearest 0.1 cm using a standard, validated non-stretchable measuring tape. The skinfold thickness was measured using validated skinfold calipers (Holtain Ltd., Crymych, UK) to the nearest 0.2mm at 4 sites: Triceps, biceps, subscapular and suprailiac. Three readings were taken for all the above measurements and average of 3 readings were considered for analysis. Body mass index (BMI) was calculated from the height and weight as follows; BMI= weight (kg)/height^2 (meters). Fat mass was calculated using Wickramasinghe equation [26].

Fat mass (boys)= 0.68*A+0.246*T+0.383*SS-1.61-3.45

Fat mass (girls)= 0.68*A+0.246*T+0.383*SS-3.45

Where A is age in years, T is Triceps skin fold and SS is subscapular skin fold

Fat percentage was calculated as FM/weight*100

As Body weight= Fat mass +Fat free mass;

Fat free mass (FFM) is calculated as Body weight (kg) – Fat mass (kg).

Calculation of Upper arm muscle area (cm^2) using Frisancho's equation [27]

$$\text{Arm muscle diameter (cm)} = \frac{\text{arm circumference}}{\pi} - \text{TSF}$$

$$\text{Upper arm muscle area (cm}^2) = \frac{\pi}{4} \times (\text{arm muscle diameter})^2$$

Phase angle

PhA measurement protocol: Bioelectrical impedance analysis was performed with the Quad scan instrument BODYSTAT Quadscan 4000 (Bodystat Ltd, Isle of Man, British Isles) applying a current at 800µamps and at frequencies of 5, 50, 100 and 200 kHz. The instrument was calibrated each day by using the external calibrator provided by the manufacturer. BIA was measured with the subjects after an overnight fast and when the bladder was emptied

The subjects were made to lie down on a non-conducting surface (wooden bench), in supine position with arms and legs separated slightly. Standard ECG electrodes were applied on the right side with injecting electrodes placed on the dorsal metacarpal of hand and dorsal metatarsal of feet and the reading electrodes were placed between the radial styloid process and ulnar prominence of the wrist and between medial and lateral malleolus of the ankle joint on the same side after cleaning the skin area with 70% ethanol. The distance between injecting and reading electrodes was 5 cm. The subjects were advised not to move when the measurements were being taken. The following precautions were taken before performing the procedure: Subjects were advised not to consume any meals or food within 2 hours prior to the measurement, to avoid strenuous physical activity at least 12 hours prior, to lie down for minimum of 20 minutes to ensure fluid redistribution.

Phase angle was calculated using the phase angle calculation software version1.0 using Impedance values at four frequencies. The values obtained were entered into the Bodystat Phase angle program which provided results for phase angle, reactance and resistance for the four frequencies of 5, 50, 100 and 200 kHz. Phase angle obtained for 50kHz impedance value was considered for analysis.

RESULTS

A total of 70 subjects took part in our study, off which 2 of two of them who underwent anthropometric measurements showed their unwillingness to undergo Bioelectrical impedance analysis and 3 of other subjects whose collected data for BIA was found to be deficient and were excluded from the study. Since the original sample size calculated was 65, the data of the remaining subjects were analysed. These 65 subjects included 30 boys and 35 girls. The collected data was tested for normal distribution using the Q-Q plots. Since the data was normally distributed, it was represented as Mean ± SD and parametric tests were used for further analysis. Pearson correlation coefficient test was used to represent the association between the PhA and various parameters. The results were considered significant if the p value was <0.05.

Table 1 summarizes the anthropometric characteristics of the subjects for the entire study group. The mean age of subjects in this study was 7.65 ± 0.9 years, mean height (cm) and weight (kg) of 116.8 ± 8 and 19.41 ± 3.9, BMI for age was -1.19 ± 1.0. The mean mid upper arm circumference (cm) was 15.71 ± 1.5, mean waist and hip circumference (cm) was 48.69 ± 3.9 and 57.26 ± 4.6, Mean skin fold thickness (mm) of 24.2 ± 6. The upper arm muscle area (cm^2) was calculated using triceps skin fold and mid upper arm circumference as described in methodology section showed a mean value of 14.12 ±2.6. Body composition parameters such as Fat percentage, Fat mass and Fat free mass calculated from skin fold measurements were 26.23 ±8, 5.0 ±1.7 and 14.4 ±3.5 respectively.

Table 2 summarizes the bioelectrical impedance parameters of subjects for the entire study group. The mean Fat % was 24 ± 5.4, Fat mass (kg) and Fat free mass (kg) was 4.7 ± 1.4 and 14.8 ± 3.2. The mean extra and intra cellular water (ltr) was 7.8 ± 0.8 and 9.1±2.2. The mean impedance (Ω) at 50 kHz was 822.6 ±85, mean resistance and reactance (Ω) 805.9 ±81.6 and 164.2 ±33.4 respectively. The mean Phase angle at 50 kHz was 11.4 ±1.6. Table 3 represents Impedance values at 50 kHz normalized for height and their corresponding Phase angle value. As height is one of the determinants of the impedance values, these values were normalized for height by dividing them by height^2. The same was followed for the impedance values at all four frequencies and their corresponding Phase angles were obtained. The mean normalized impedance value was 614.3±121 and mean Phase angle (^{0}) at 50 kHz was 11.8±2.1.

Table 1: Baseline Anthropometric Characteristics

Parameters	Mean ± SD (n=65)	
Age (yrs)	7.65 ± 0.9	
Height (cm)	116.8 ± 8	
Weight (kg)	19.41 ± 3.9	
BMI(kg/m^2)	14.12 ± 1.4	
Z scores BMI for age	-1.19 ±1.0	
MUAC (cm)	15.71 ± 1.5	
Waist circumference (cm)	48.69 ± 3.9	
Hip circumference (cm)	57.26 ± 4.6	
Waist/Hip ratio	0.84 ± 0.1	
*UAMA (cm^2)	14.12 ±2.6	
#MSFT (mm)	24.2 ± 6	
Fat%	26.23 ±8	
Fat Mass (kg)	5.0 ±1.7	
Fat Free Mass (kg)	14.4 ±3.5	

MUAC- Mid upper arm circumference
*UAMA- Upper arm muscle area calculated from Frisancho's equation
#MSFT- Mean skinfold thickness (sum of the four skin foldBiceps, triceps, subscapular and suprailiac)
FM (kg) – calculated using Wickramasinghe equation

Table 2: Parameters Determined by Bioelectrical Impedance

Parameters	Mean ± SD (n=65)
Fat%	24 ± 5.4
Fat mass (kg)	4.7 ± 1.4
Fat free mass (kg)	14.8 ± 3.2
ECW (L)	7.8 ± 0.8
ICW (L)	9.1±2.2
Impedance(Ω)50kHz	822.6 ±85
Resistance (Ω)	805.9 ±81.6
Reactance (Ω)	164.2 ±33.4
Phase angle (^{0})	11.4 ±1.6

ECW- Extracellular water, ICW- Intracellular water

Table 3: Normalized impedance values and its corresponding phase angle values

Parameters	Mean ± SD (n=65)
Impedance (Ω) at 50kHz	614.3±121
Phase Angle (^{0}) at 50kHz	11.8±2.1

Analytical statistics

As the data was normally distributed Pearson correlation was applied to look for association of Phase angle with anthropometric measurements. Phase angle values showed a positive correlation with age (r = 0.018), height (r =0.002) and Fat mass (r = 0.056) which were not significant. However, a negative correlation was observed with BMI for age (r = -0.107) and all other anthropometric parameters whose correlation coefficient values are represented in Table 4. Graph 1 and 2 represents the association of Phase angle with age and BMI.

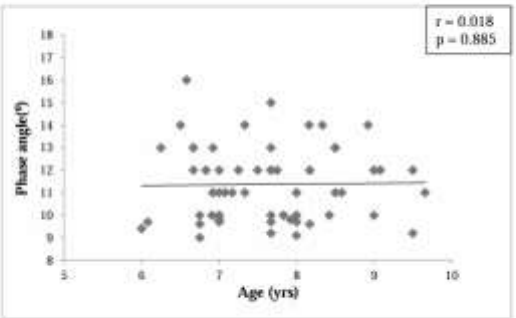
Table 5 represents the association of corrected Phase angle (Phase angle obtained from normalised impedance values) with anthropometric parameters which showed a positive correlation with age (r = 0.230), weight (r = 0.291), BMI for age (r = 0.101), waist and hip circumference, Upper arm muscle area, Fat mass and Fat free mass with significant correlation for weight ($p<0.05$).

Table 4: Association between phase angle and anthropometric parameters

Parameters	r value (n=65)	P value
Age (yrs)	0.018	0.885
Height (cm)	0.002	0.985
Weight (kg)	-0.027	0.832
BMI (kg/m2)	-0.105	0.405
Z scores BMI for age	-0.107	0.397
UAMA (cm^2)	-0.122	0.397
Waist circumference (cm)	-0.044	0.725
Hip circumference (cm)	-0.081	0.521

Fat mass (kg)	0.056	0.66
Fat free mass (kg)	-0.057	0.653

GRAPH 1: ASSOCIATION BETWEEN PHASE ANGLE AND AGE



GRAPH 2: ASSOCIATION BETWEEN PHASE ANGLE AND BMI

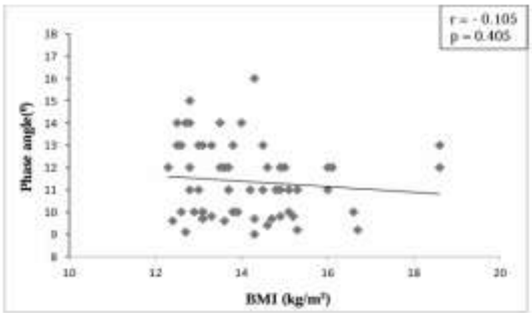
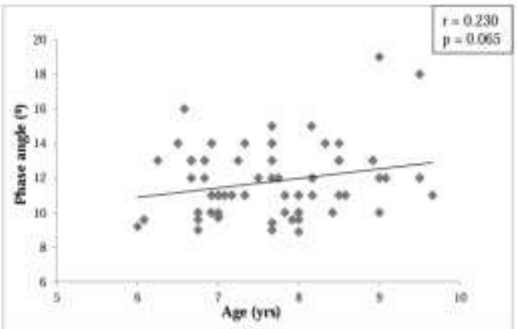


Table 5: Association between corrected phase angle values with anthropometric parameters

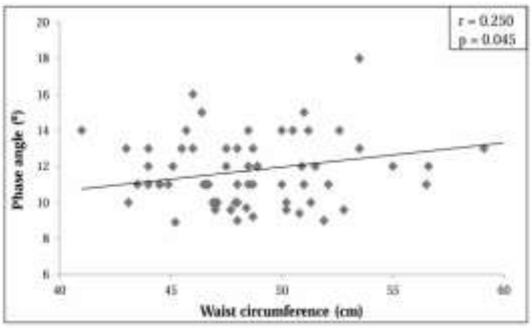
Parameters	r value (n=65)	P value
Age (yrs)	0.23	0.065
Height (cm)	0.264	0.034
Weight (kg)	0.291	0.019
BMI (kg/m2)	0.14	0.265
Z scores BMI for age	0.101	0.424
UAMA (cm^2)	0.181	0.149
Waist circumference (cm)	0.25	0.045
Hip circumference (cm)	0.173	0.169
Fat mass (kg)	0.189	0.131
Fat free mass (kg)	0.232	0.063

Significance considered at $p<0.05$

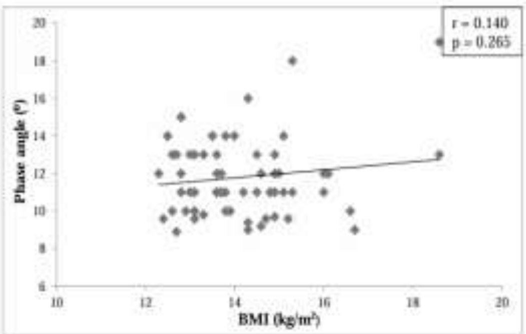
GRAPH 3: ASSOCIATION BETWEEN CORRECTED PHASE ANGLE AND AGE



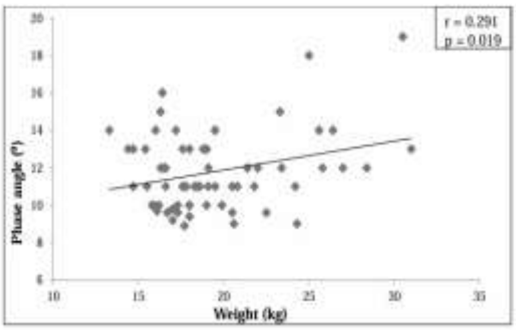
GRAPH 6: ASSOCIATION BETWEEN CORRECTED PHASE ANGLE AND WAIST CIRCUMFERENCE



GRAPH 4: ASSOCIATION BETWEEN CORRECTED PHASE ANGLE AND BMI



GRAPH 5: ASSOCIATION BETWEEN CORRECTED PHASE ANGLE AND WEIGHT



DISCUSSION

The key parameter used in our study was the Phase angle which was obtained using Bioelectrical impedance analysis (BIA). It has an advantage over BIA in the assessment of nutritional status as it is independent of use of regression equations.[10] In our study we attempted to look for the association of Phase angle with anthropometric variables and to determine whether Phase angle could be used as an easily measurable, non-invasive technique for assessment of nutritional status in children as compared to that of anthropometric parameters.

In our study the mean value of Phase angle (^{0}) obtained at 50 kHz was 11.4 ±1.6 which was high compared to studies performed in children of different population where the mean value of Phase angle was 5.3±1.1.[7,20] The difference in phase angle values is challenging to explain, especially with the unavailability of reference data and cutoffs for each specific population, as ethnic differences and different BIA analysers can influence the result.[20] Phase angle may depend on different configurations of BIA instruments; thus, these configurations should be considered when comparing Phase angle values with different studies.[21] However, as per our current knowledge there are no reference values for phase angle measurements in Indian children and this study was the first to document phase angle values in apparently normal healthy children.

With main determinants of PhA being age, gender and BMI, PhA measurements were correlated with the above. Phase angle values showed a positive correlation with age ($r = 0.018$). The results were not significant but concurred with results from previous studies.[7] This relation could be explained by growth-related increases in body cell mass and changes in tissue composition. As children grow, there is progressive expansion of metabolically active tissue and cell membrane mass, which increases reactance and thereby contributes to higher phase angle values. However, recent reviews suggest that age-related increases in phase angle are more marked during late childhood and adolescence, when pubertal changes in fat-free mass and body cell mass become more prominent, whereas changes may be less evident in younger prepubertal children.[23,24] The lack of a significant association with age in the present study may therefore be explained by the narrow age range of the study participants and the predominance of younger, prepubertal children.

It was observed that Phase angle showed a negative correlation with other parameters such as BMI, waist and hip circumferences, upper arm muscle area and FFM. These findings appear counterintuitive because phase angle is generally expected to show a positive relationship with body size and body cell mass. However, this discrepancy is likely explained by the influence of body size on impedance measurements. According to an earlier study performed by Wells et al (2002) it was shown that for the results to be considered comparable between individuals or populations there is a requirement for normalizing the measurements for body size.[22] In our study Phase angle being the key parameter, were obtained from Impedance values. As height is one of the determinants of Impedance i.e. Impedance (Z) = $\rho L^2/V$ where L is the length of the conductor which is considered equivalent to standing height or stature in humans, the impedance values were normalized for height by dividing them by height^2. The Impedance values for all the four frequencies were normalised for height and the corresponding Phase angle values were obtained. The corrected phase angle values at 50 kHz were further associated with anthropometric parameters, which showed positive correlation with age, weight, BMI, waist and hip circumference, upper arm muscle area, Fat mass and Fat free mass with significant correlation values for weight and waist circumference. This positive association explains that with an increase in BMI there is an increase in the number of cells either fat or muscle cells which brings about an increase in reactance that is directly proportional to amount of cell membrane and thus resulting in an increase in phase angle values.[5] Positive association with Upper arm muscle area is consistent with the data published by Nagano et al (2000) where they have shown a similar observation inferring that Phase angle reflects body cell mass in children, as skeletal muscle occupies the maximum portion of body cell mass.

The present study did not show any gender differences in Phase angle values, the values for boys being 11.24±1.6 and girls 11.5±1.6 which is consistent with previous paediatric studies performed in similar age group.[22] Several studies have demonstrated that although PhA increases progressively with age during childhood, marked gender differences become apparent only during adolescence. This can be attributed to pubertal increase in skeletal muscle mass in boys, whereas girls exhibit relatively greater fat mass accumulation. These physiological changes alter reactance and resistance values resulting in higher phase angle values among adolescent boys.

The findings of this study indicate that Phase angle measurements could be used as an indicator for assessment of nutritional status particularly when impedance measurements are interpreted after appropriate adjustment for body size. As phase angle measurement is rapid, non-invasive, portable, and independent of prediction equations, it offers considerable promise for nutritional assessment in clinical practice and large-scale school- and community-based screening programmes. Larger multicentric studies involving healthy Indian children are therefore required to establish normative reference ranges, validate clinically relevant cut-off values, and determine the role of phase angle in paediatric nutritional assessment.

CONCLUSION

The mean Phase angle values obtained in the present study was higher compared to other studies performed in children. There was no significant association between the original Phase angle measurements and anthropometric measurements. However, Corrected Phase angle obtained after normalizing Impedance values for height demonstrated positive associations with anthropometric parameters suggesting that adjustment for body size may improve its utility in growing children. These findings indicate that Corrected PhA may have potential to be used as non-invasive marker for nutritional assessment in children. However, more extensive research studies are required to determine the normal PhA values for healthy children and further validate its role in nutritional status assessment among healthy Indian children.

Limitations

As Bioimpedance measurements are influenced by a number of factors such as position of the body during procedure, ambient air and skin temperatures, physical activity, conductance of the examining table, food consumption and hydration status.[23] Most of the factors were controlled however; the effect of physical activity could not be controlled for, as subjects being children, it was difficult to restrain them from physical activity which could have contributed to small amount of variability in impedance measurements. Most of the studies on Phase angle have used single- frequency bioimpedance measurements which gave direct measures of resistance and reactance from which the phase angle was calculated, but in our study we used multi-frequency bioimpedance measurement which gave only the impedance measurements at 4 frequencies from which the phase angles were calculated with the help of the software provided by the manufacturer, whether this could have contributed to variations in phase angle values needs to be further evaluated.

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