

Original Article

Assessment of hydration status and body composition of athlete and non-athlete subjects using Bioelectrical Impedance Analysis

SHASHIKALA SIVAPATHY^{1*}, CHUNG YUAN CHANG¹, WEN JIN CHAI², YEE KWANG ANG³ AND HIP SENG YIM¹

¹Faculty of Applied Sciences, UCSI University, No 1 Jalan Menara Gading, UCSI Heights, 56000 Kuala Lumpur, MALAYSIA.

²Sports Nutrition Centre, National Sports Institute, Bukit Jalil, 57000 Kuala Lumpur, MALAYSIA.

³Graduate School of Medicine, Perdana University, Block Band D1, MAEPS Building, MARDI Complex, 43400 Serdang, Selangor. MALAYSIA.

Published online: June 25, 2013

(Accepted for publication May 24, 2013)

DOI:10.7752/jpes.2013.02026;

Abstract:

Hydration status is a preliminary factor that influences the body composition assessment using bioelectrical impedance analysis. The present study aims to determine the hydration status on body fat mass and fat free mass in a sample of athletes and non-athletes by bioelectrical impedance analysis and comparing with air-displacement plethysmography. Body fat mass and fat free mass of 10 athletes and 22 non-athletes aged 18–30 years old were assessed using bioelectrical impedance analysis and air-displacement plethysmography. Hydration status was determined using Urine Specific Gravity by a refractometer. T-test was performed to analyze significant differences between variable and correlation coefficient test were performed using Spearman's rho. Body fat mass and fat free mass were found significantly different ($p < 0.01$) between athletes and non-athletes. Significant difference was observed in overall body fat mass ($p < 0.01$) and fat free mass ($p < 0.05$) assessed by bioelectrical impedance analysis in different hydration states (hydrated and dehydrated). No significant difference was found in body fat mass and fat free mass of athletes assessed by bioelectrical impedance analysis in different hydration states. Non-athletes showed a significant difference ($p < 0.05$) in body fat mass and fat free mass measured by bioelectrical impedance analysis in different hydration states. No significant difference was observed in fat free mass and body fat mass in males assessed by bioelectrical impedance analysis in different hydration state whereas significant difference was found in females ($p < 0.05$). Body fat mass and fat free mass were found to be comparable as measured by bioelectrical impedance analysis and air-displacement plethysmography in both hydration states. Air-displacement plethysmography showed no significant in body fat mass and fat free mass measurements in different hydration states comparing to bioelectrical impedance analysis. However hydration status was found to be significantly affecting body fat mass and fat free mass analysis using bioelectrical impedance analysis in non-athletes and athletes. Factors such as Body Mass Index, age and hydration status need to be taken into consideration to avoid unreliable results. Large number of subjects will be able to show better significant difference between the measurements.

Key Words: Bioelectrical Impedance Analysis, Air Displacement Plethysmography, Body Fat Mass, Fat Free Mass, Hydration status

Introduction

Bioelectrical impedance analysis (BIA) is a common technique used to assess body composition such as fat mass and lean body mass among athletes. In addition, the BIA provides hydration status indicator, indicating intracellular and extracellular fluid volumes (de Fijter *et al.* 1993). However, BIA has its limitation, where the amount of water in the body might influence the electrical resistance and reactance that lead to undesirable results in the end (de Fijter *et al.* 1993; Oppliger and Bartok 2002). The BIA measuring the reactance and resistance in the body when currents of typical frequency (5 kHz to 1MHz) were applied through the subjects (Oppliger and Bartok 2002). By measuring the resistance and reactance on difference frequencies, extracellular water (ECW) and intracellular water (ICW) as well as total body water (TBW) can be predicted using the formulated regression equations (Oppliger and Bartok 2002).

Currently, the BIA instrument is designed to be marketed commercially and able to measure body fat percentage by different formulated software and extra regression equations for parameters such as weight, height and age (Biaggi *et al.* 1999; Deurenberg and Yap 2002). The advantages of BIA are it is relatively cheap and easy to be used for population studies (Deurenberg and Yap 2002). A newer technique, namely air-displacement

plethysmography (ADP) has been used to measure body composition. Currently, there is only one commercially available system known as BODPOD (Life Measurement, Inc, Concord, CA), which offers quick, comfortable, automated, non-invasive and safe for the measurement of body composition in population studies (Fields *et al.* 2002).

Hydration status has been found to influence body composition assessment when analyzed using BIA machine (de Fijter *et al.* 1993). There are no gold standard methods to date in defining hydration status. Many studies have shown that TBW measurement is closely related to the hydration status of an individual (Oppliger and Bartok 2002; Pialoux *et al.* 2004). In addition, an increase of TBW will cause the fat mass being underestimated by BIA, or vice versa. Thus, this study aims to determine the hydration status on body fat mass (BFM) and fat free mass (FFM) in a sample of athletes and non-athletes by BIA and compared with ADP as a standard which is relatively similar to that of hydrostatic weighing (Biaggi *et al.* 1999; Utter *et al.* 2003).

Materials and Methods

Approval and Location of study

This study was approved by the Research and Scholarly Activity Committee, Faculty of Applied Sciences, UCSI University, Kuala Lumpur. All the body composition assessments were conducted at the Sports Nutrition Laboratory, National Sports Institute (Institut Sukan Negara, ISN) and the approval was obtained from ISN the Director of Research and Academic, ISN.

Participants

A total of 10 athletes (6 males and 4 females) from ISN and 22 non-athletes (7 males and 15 females) from UCSI University aged between 18 to 29 years old were conveniently recruited with informed consent. Subjects are Malaysian Malay, Chinese or Indian ethnics. Subjects from non-athletes group are having normal body mass index (BMI) 18.5–24.9 kgm⁻²; whereas, subjects from athletes group are having normal range and pre-obese BMI which is 18.5–29.9 kgm⁻². Pre-obese subjects are selected as lean body mass (LBM) or muscle in athletes is denser than fat, hence, increases the BMI reading; and athletes have higher LBM and lower body fat percentage. In addition, athletes who have BMI > 25 are having < 13% and < 20% of body fat for male and female, respectively (Fall 2008.; WHO 1995).

Procedure and Instruments

Body compositions of the subjects were assessed using the Direct Segmental Multi-frequency Bioelectrical Impedance, where 10 impedance measurements were assessed using 20 kHz and 100 kHz frequencies at each of the five segments (right arm, left arm, trunk, right leg and left leg). The assessments of body volume and density were performed using BODPOD Body Composition System (Life Measurement, Inc, Concord, CA). Total body density is converted to body fat percentage by using Siri's formula (Biaggi *et al.* 1999; Claros *et al.* 2005).

Hydration status of the athletes was assessed by a refractometer with a small amount of urine awake (which the initial part of urine stream was discarded) was collected from the subjects using urine container. Height and weight were measured using stadiometer (Seca 220 measuring rod, Hamburg, Germany) and weighing scale (Seca 703 digital medical scale, Hamburg, Germany), respectively and the body mass index (BMI) was calculated using the following formula: BMI = weight in kg/height in m².

Data Collection

Subjects were given a form to record their fluid intake for the past three consecutive days before the assessment in Session 1. The form contains columns to record consumption time, type of fluid and its volume intake (Holben *et al.* 1999). Body composition assessments are divided into two sessions whereby session 1 required subjects in euhydrated status and session 2 required subjects in dehydrated status. For subjects who attending session 1, they were reminded to consume fluid as usual in a day before assessments. However, for subjects who attending session 2, they were reminded to reduce their fluid intake a day before assessments. They were advised to take small sips of water but not large gulps when they feel thirsty. Subjects were required to fast for at least 4 hours to minimize the errors before assessments (Dixon *et al.* 2009).

Session 1 Upon arrival, the subjects have to identify themselves and hand in the urine container with the urine awake as well as the fluid intake record to the investigator. Pre-screening assessment was done after the subject is ready with proper clothing. Then, the subject proceeded with physiological assessments using BIA and followed by BODPOD. After the assessment, the subjects were reminded to come for the Session 2 on a designated date. Light snacks and drink were provided at the end of the assessment.

Session 2 Upon arrival, the subjects have to identify themselves and hand in the urine container with the urine awake. Pre-screening was done after the subject is ready with proper clothing. Then the subject proceeded with physiological assessments using BIA and followed by BODPOD. After completed all the assessments, questions and results of the assessments were briefly discussed with the participants.

Data Analysis

All data were analyzed using Statistical Package for Social Sciences (SPSS, version 17). Normality test was done to all measurements collected during the data collection period. T-test was performed to analyze the significant differences for parametric measurements and Wilcoxon and Mann-Whitney U-tests were used for non-parametric measurements. Correlation coefficient test was performed using Spearman's rho. The significant level of all the tests were set at $p < 0.05$.

Results and discussion

A total of 32 subjects (31% athletes and 69% non-athletes) were recruited in this study. As shown in Table 1, there were 13 males (41.0%) and 19 females (59.0%) in total. Majority of the subjects were Chinese (69.5%), followed by Malay (27.5%) and Indian (3.0%).

Table 1: Distribution of athletes and non-athletes according to race and gender

Race	Athletes (n=10)		Non-athletes (n=22)		Total
	Male (%)	Female (%)	Male (%)	Female (%)	
Chinese	4 (40.0)	3 (30.0)	4 (18.2)	11 (50.0)	22 (69.5)
Malay	1 (10.0)	1 (10.0)	3 (13.6)	4 (18.2)	9 (27.5)
Indian	1 (10.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (3.0)
Total	6 (60.0)	4 (40.0)	7 (31.8)	15 (68.2)	32 (100.0)

Table 2 shows the overall total body water, hydration status and fluid intake. Mean total body water of all subjects was 32.5 ± 8.0 kg (hydrated status) and 32.4 ± 7.6 kg (dehydrated status). Total body water of all subjects had shown no significant difference between two different hydration statuses. Overall well-hydrated subjects has U_{sg} mean of 1.013 ± 0.005 and dehydrated subjects has U_{sg} mean of 1.024 ± 0.003 . The value of urine specific gravity index has shown good differentiation between two different hydration statuses with a significant difference. For fluid intake during hydrated status, overall mean was 2741.6 ± 724.1 ml while dehydrated status has mean fluid intake of 1737.7 ± 1098.0 ml. The fluid intake record had also shown significant difference between two different hydration states.

Table 2: Overall total body water, hydration status and fluid intake

	Hydrated status	Dehydrated status
TBW (kg)	32.5 ± 8.0^a	32.4 ± 7.6^a
U_{sg} (index)	1.013 ± 0.005^a	1.024 ± 0.003^b
Fluid intake record (ml)	2741.6 ± 724.1^a	1737.7 ± 1098.0^b

Results were expressed as mean $\pm$ standard deviation.

Different superscripts (^{a-b}) within a row denote significantly different ($p < 0.05$).

Athletes were found to be significantly higher in total body water compared to non-athletes in both hydration status (Table 3). This happens due to the higher amount of lean body mass which stores more water in an athlete's body. Higher intake of fluid was observed in athletes and this might be due to frequent sweat loss and urination in a long period of training and exercises. The physiological changes caused dehydration and hence the athletes required more water to replenish the lost. As a result, athletes might require more fluid intake to balance the water lost during training and competition to avoid dehydration.

The correlation coefficient between hydration index and fluid intake of the study subjects was -0.428 ($p < 0.01$). The correlation had shown moderate inverse relationship between fluid intake and hydration index. A significant weak positive correlation ($r=0.343$ $p<0.01$) was found between total body water and fluid intake. This finding shown that fluid intake prior the BIA assessments were moderately affecting the measurements results especially the lean body mass measurement.

A significant positive correlation ($r=0.999$; $p<0.01$) was also found between fat free mass and total body water. The strong positive correlation had shown the calculation of fat free mass by BIA could be a possible strong factor based on total body water. Thus the measurements assessed by BIA will become unreliable in individual with fluctuations in total body water. According to the correlation results, it provides evidence on the proportional relationship between fat free mass, fluid intake and total body water. Fat free mass is possibly overestimated when individual has higher fluid intake prior BIA assessment. Hence, increase of fluid intake will indirectly mislead BIA in assessment of fat free mass due to disturbed body water.

Table 3: Hydration status and fluid intake of athletes and non-athletes

	Athletes (n=10)	Non-athletes (n=22)
<u>Hydrated status</u>		
TBW (kg)	40.6 ± 6.0 ^a	28.9 ± 5.6 ^b
U _{sg} (index)	1.015 ± 0.003 ^a	1.013 ± 0.005 ^a
Fluid intake record (ml)	3208.5 ± 632.7 ^a	2529.3 ± 671.9 ^b
<u>Dehydrated status</u>		
TBW (kg)	40.5 ± 5.7 ^a	28.8 ± 5.7 ^b
U _{sg} (index)	1.024 ± 0.003 ^a	1.025 ± 0.004 ^a
Fluid intake record (ml)	2514.0 ± 1142.3 ^a	1384.8 ± 896.0 ^b

Results were expressed as mean ± standard deviation.

Different superscripts (^{a-b}) within a row denote significantly different ($p < 0.05$).

Table 4 shows the body composition of athletes and non-athletes according to gender. Body fat mass of male athletes had found a non-significant difference compared to non-athletes measured by BIA and ADP. However, male athletes show lower fat percentage than non-athletes measured by BIA and ADP. Besides, fat free mass of athletes assessed was higher than non-athletes by BIA and ADP ($p < 0.05$, $Z_{(BIA)} = -3.000$, $Z_{(ADP)} = -3.000$). On the other hand, females had shown no significant difference on body fat mass between athletes and non-athletes. Yet, female athletes had observed significant lower in body fat percentage compared to female non-athletes. Fat free mass of female athletes was significantly higher than non-athletes ($p < 0.05$, $Z_{(BIA)} = -3.001$, $Z_{(ADP)} = -2.801$). According to the result from BIA and ADP in Table 4, athlete had lower body fat and is more muscular compared to non-athletes. The muscle mass had increased the body weight of athletes whereby fat free mass have higher density compared to fat mass. Whalley *et al.* (2004) had shown that athletes' body composition assessments were higher in BMI, less body fat mass and higher fat free mass compared to non-athletes. Lawan *et al.* (2008) reported that the weight of athletes is significantly higher than in non-athletes. They predicted that the increase in muscle mass of athletes might due to the vigorous training or particular training activities, that increase in the body weight.

Table 4: Body composition of athletes and non-athletes

	Male		Female	
	Athletes (n=6)	Non-athletes (n=7)	Athletes (n=4)	Non-athletes (n=15)
Body weight (kg)	69.9 ± 5.1 ^a	60.5 ± 11.0 ^a	60.7 ± 7.2 ^a	50.0 ± 5.5 ^b
<u>BIA</u>				
Body fat mass (kg)	8.3 ± 4.2 ^a	11.7 ± 7.2 ^a	13.5 ± 5.1 ^a	14.7 ± 3.2 ^a
Body fat percentage (%)	11.5 ± 5.2 ^a	18.1 ± 7.1 ^a	22.4 ± 5.9 ^a	29.2 ± 4.2 ^b
Fat free mass (kg)	62.2 ± 2.5 ^a	49.9 ± 5.1 ^b	47.2 ± 2.3 ^a	35.5 ± 3.3 ^b
<u>ADP</u>				
Body fat mass (kg)	8.7 ± 5.6 ^a	11.6 ± 9.8 ^a	14.7 ± 4.2 ^a	14.2 ± 3.7 ^a
Body fat percentage (%)	12.2 ± 7.2 ^a	18.0 ± 11.0 ^a	24.0 ± 4.4 ^a	28.3 ± 5.8 ^a
Fat free mass (kg)	61.1 ± 3.5 ^a	48.6 ± 5.4 ^b	45.8 ± 3.4 ^a	35.7 ± 3.8 ^b

Results were expressed as mean ± standard deviation.

Different superscripts (^{a-b}) within a row for each gender denotes significantly different ($p < 0.05$).

Table 5 shows body compositions of athletes and non-athletes with different hydration status. Body fat mass and body fat percentage measured by BIA had shown higher in hydrated states compared to dehydrated states among athletes. During hydrated states, body fat mass and fat free mass of athletes were measured 10.6 ± 5.4 kg and 55.5 ± 8.3 kg respectively. BIA had measured body fat mass and fat free mass of athletes in dehydrated states which the values are 10.8 ± 4.9 kg and 55.4 ± 7.9 kg, respectively. Furthermore, fat free mass of athletes

assessed by BIA also shown higher value in hydrated states (55.5 ± 8.3 kg) compared to dehydrated states (55.4 ± 7.9 kg). However, no significant difference was seen in the measurements mentioned between two different hydration states.

ADP assessments on athletes showed no significant difference between two hydration states in body fat mass, body fat percentage and fat free mass. Body fat mass, body fat percentage, and fat free of athletes measured by ADP in hydrated states were 11.1 ± 5.7 kg, $16.9 \pm 8.5\%$, and 55.0 ± 8.6 kg, respectively. On the other hand, the body fat mass, body fat percentage, and fat free of athletes measured by ADP in dehydrated states were 11.3 ± 5.6 kg, $17.2 \pm 8.3\%$, and 54.7 ± 8.4 kg, respectively.

From the outcome of BIA in non-athletes, there were no significant difference in body fat mass, body fat percentage, and fat free mass between different hydration states. Body composition assessed using ADP in non-athletes showed no significant difference between body fat mass, body fat percentage and fat free mass. As the result, athletes had showed not to be affected their body composition assessments by using BIA with different hydration status compared to non-athletes which are affected by the hydration status.

Table 5: Body compositions of athletes and non-athletes on different hydration status

	Hydrated status	Dehydrated status
<u>BIA: Athletes</u>		
Body fat mass (kg)	10.6 ± 5.4^a	10.8 ± 4.9^a
Body fat percentage (%)	16.4 ± 7.9^a	15.9 ± 7.2^a
Fat free mass (kg)	55.5 ± 8.3^a	55.4 ± 7.9^a
<u>ADP: Athletes</u>		
Body fat mass (kg)	11.1 ± 5.7^a	11.3 ± 5.6^a
Body fat percentage (%)	16.9 ± 8.5^a	17.2 ± 8.3^a
Fat free mass (kg)	55.0 ± 8.6^a	54.7 ± 8.4^a
<u>BIA: Non-athletes</u>		
Body fat mass (kg)	13.8 ± 5.0^a	14.0 ± 4.6^a
Body fat percentage (%)	26.1 ± 7.4^a	25.7 ± 7.6^a
Fat free mass (kg)	39.7 ± 7.9^a	39.4 ± 8.0^a
<u>ADP: Non-athletes</u>		
Body fat mass (kg)	13.4 ± 6.2^a	13.5 ± 6.3^a
Body fat percentage (%)	25.0 ± 9.0^a	25.2 ± 8.8^a
Fat free mass (kg)	39.8 ± 7.1^a	39.8 ± 7.3^a

Results were expressed as mean $\pm$ standard deviation.

Different superscripts (^{a-b}) within a row denote significantly different ($p < 0.05$).

Table 6 shows the overall means of measurements measured by BIA and ADP which include body fat mass, body fat percentage and fat free mass. In hydrated state, body fat mass had shown no significant difference between BIA and ADP. Also, no significant difference found in body fat percentage and fat free mass between BIA and ADP. On the other hand, no significant difference was found in body fat mass, body fat percentage and fat free mass between BIA and ADP in dehydration states.

Table 6: Overall body composition measurements on different methods and hydration status

	Hydrated state		Dehydrated state	
	BIA	ADP	BIA	ADP
Body fat mass (kg)	12.8 ± 5.2^a	12.7 ± 6.0^a	12.5 ± 4.8^b	12.8 ± 6.1^b
Body fat percentage (%)	23.2 ± 8.8^a	22.5 ± 9.5^a	22.4 ± 8.5^b	22.7 ± 9.3^b
Fat free mass (kg)	44.8 ± 10.8^a	44.5 ± 10.5^a	44.3 ± 10.8^b	44.4 ± 10.3^b

Results were expressed as mean $\pm$ standard deviation (n=32).

Different superscripts (^{a-b}) within a row for each hydration status denote significantly different ($p < 0.05$).

A study on the precision and accuracy has been done for few methods including HW, ADP, DEXA and BIA (Ellis 2001). In assessing fat free mass, DEXA shows to be most accurate (1.5%) and precise (1-4%) compare to other methods. ADP and HW were placed second where both the precision and accuracy are 1-2% and 2-3% respectively. Lastly, BIA had shown the lowest precision (2-4%) and accuracy (2-8%) among all the methods. DEXA had the lowest amount of detectable change (1.5 kg) compared to ADP (2 kg), HW (2 kg) and BIA (4 kg).

This study had some limitations. Small sample size and unequal gender ratio might lead to biased results as well as too small for comparison and good statistical analysis. The in compliance of the subjects in either fluid intake or fasting will directly affect the result of the BIA and ADP as well as the hydration index.

Conclusion

In conclusion, hydration status was found significantly associated with BFM and FFM analysis using BIA in non-athletes. BFM and FFM have shown no significant difference between two methods in both hydration states. Similarly, ADP showed no significant difference in BFM and FFM between hydrated and dehydrated state.

References

- Biaggi, R.R., Vollman, M.W., Nies, M.A., Brener, C.E., Flakoll, P.J., Levenhagen, D.K., Ming, S., Karabulut, Z., & Chen, K.Y. (1999). Comparison of air-displacement plethysmography with hydrostatic weighing and bioelectrical impedance analysis for the assessment of body composition in healthy adults. *American Journal of Clinical Nutrition* 69: 898-903.
- Claros, G., Hull, H.R., & Fields, D.A. (2005). Comparison of air displacement plethysmography to hydrostatics weighing for estimating total body density in children. *BioMed Central* 5:37-42.
- De Fijter, C.W.H., de Fijter, M.M., Oe, L.P., Donker, A.J.M., & de Vries, P.M.J.M. (1993). The impact of hydration status on the assessment of lean body mass by body electrical impedance in dialysis patients. *Advance Peritoneal Dialysis* 9: 101-4.
- Deurenberg, P., & Yap, M.D. (2002). Validation of skinfold thickness and hand-held impedance measurements for estimation of body fat percentage among Singaporean Chinese, Malay and Indian subjects. *Asia Pacific Journal of Clinical Nutrition* 11(1): 1-7.
- Dixon, C.B., Ramos, L., Fitzgerald, E., Reppert, D., & Andreacci, J.L. (2009). The effect of acute fluid consumption on measures of impedance and percent body fat estimated using segmental bioelectrical impedance analysis. *European Journal of Clinical Nutrition* 63(9): 1115-1122.
- Ellis, K.J. (2001). Selected body composition methods can be used in field studies. *Journal of Nutrition* 131: 1589S-1595S.
- Fall, D.W. (2008). Body composition and its effect on the sports performance spectrum. *NSCA's Performance Training Journal* (7): 5-10.
- Fields, D.A., Goran, M.I., & McCrory, M.A. (2002). Body-composition assessment via air-displacement plethysmography in adults and children: a review. *American Journal of Clinical Nutrition* 75: 453-467.
- Holben, D.H., Hassell, J.T., Williams, J.L., & Helle, B. (1999). Fluid Intake Compared with Established Standards and Symptoms of Dehydration among Elderly Residents of a Long-Term-Care Facility. *Journal of the American Dietetic Association* 99(11): 1447-1450.
- Lawan, A., Ali, M.A., & Bauchi, S.S.D. (2008). Evaluation of 12-lead electrocardiogram (ECG) in athletes and non-athletes in Zaria, Nigeria. *Pakistan Journal of Physiology* 4: 1-10.
- Oppliger, R.A., & Bartok, C. (2002). Hydration testing of athletes. *Sport Medicine* 32(15): 959-971.
- Pialoux, V., Mischler, I., Mounier, R., Gachon, P., Ritz, P., Coudert, J., & Fellmann, N. (2004). Effect of equilibrated hydration changes on total body water estimates by bioelectrical impedance analysis. *British Journal of Nutrition* 91: 153-159.
- Utter, A.C., Goss, F.L., Swan, P.D., Harris, G.S., Robertson, R.J., & Trone, G.A. (2003). Evaluation of air displacement for assessing body composition of collegiate wrestlers. *American College of Sports Medicine* 35: 500-505.
- Whalley, G.A., Doughty, R.N., Gamble, G.D., Oxanham, H.C., Walsh, H.J., Reid, I.R., & Baldi, J.C. (2004). Association of fat-free mass and training status with left ventricular size and mass in endurance-trained athletes. *Journal of the American College of Cardiology* 44: 892-896.
- World Health Organization (WHO) Expert Committee (1995). Physical status: the use and interpretation of anthropometry. WHO Technical Report Series 854.