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Body Composition

RELIABILITY OF AIR-DISPLACEMENT PLETHYSMOGRAPHY IN DETECTING BODY COMPOSITION CHANGES AFTER WATER INGESTION AND AFTER CREATINE SUPPLEMENTATION

MATTHEW D. VUKOVICH AND BRIAN M. PEETERS

South Dakota State University, Department of HPER, Brookings, SD 57007

ABSTRACT

RELIABILITY OF AIR-DISPLACEMENT PLETHYSMOGRAPHY IN DETECTING BODY COMPOSITION CHANGES AFTER WATER INGESTION AND AFTER CREATINE SUPPLEMENTATION. **Matthew D. Vukovich, Brian M. Peeters.** *JEPonline* 2003;6(2):115-122. The analysis of body composition by air-displacement plethysmography (ADP) has been previously validated. This study evaluated the use of the ADP following rapid weight gains by two different methods of altering hydration status: 1) by the consumption of water in 500 mL increments up to 2,000 mL; and 2) by creatine loading for 7 days. Twenty-eight healthy individuals were recruited for part one of this study. Subjects reported to the lab in a fasted condition. Body volume, with lung volume measurements, was measured twice and the results were averaged. This procedure was repeated until the subjects (n=18) consumed a total of 2,000 mL of water in 500 mL increments. A control group (n=10) participated in the same amount of trials, without drinking water for comparison. In part two, 12 males who had not consumed creatine for at least 3 months were evaluated by the ADP prior to and following 7d of creatine supplementation (21 g/day). A control group (n=12) was also analyzed before and after 7d. Body volume was measured twice on both occasions with the results averaged. Water consumption resulted in a significant increase in percent body fat and fat weight, which was not detected until after 1,000 mL had been ingested. There was no change in fat free mass with water consumption. Body density significantly decreased after 1,000 mL was consumed. With creatine supplementation, there was a significant increase in body weight (1.0 kg) and FFM (1.7 kg), while body fat decreased significantly (1.1% and 0.8 kg). The results of this study indicate that ADP can detect changes in body composition associated with a 1.0 kg or greater gain in body weight, but not 500 g. Furthermore, water consumption, water retention, and possibly dehydration can influence the body composition analysis performed by the ADP.

Key Words: percent fat, fat mass, fat free mass, body volume, body density, hydration, Bod Pod

INTRODUCTION

An air-displacement plethysmograph (ADP) system has recently been developed and validated (BOD POD, Life Measurements, Concord, CA) (1-6). The ADP system utilizes Boyle's law, in which there is an inverse relationship between pressure and volume ($P_1V_1 = P_2V_2$), to determine body volume. The body volume and body mass can then be used to calculate body density ($D = \text{mass}/\text{volume}$). Body composition is determined from body density by using Siri's equation ($\% \text{ fat} = 495/\text{density} - 450$) (7) or another appropriate equation to calculate percent body fat. McCrory et al. (2) reported that there was no significant difference in body composition analysis reported by hydrostatic weighing and air displacement plethysmography (ADP). A correlation of 0.93 and a standard error of estimate of 1.81 was reported between the two methods (2). Their findings indicate that the air-displacement method of body composition analysis appears to provide a reliable and valid method for assessing body composition. Furthermore, the ADP system of body composition analysis provides significant methodological advantages over hydrostatic weighing including time required to perform the analysis and the degree of discomfort the subject experiences during the analysis.

However, because of the newness of the ADP system, it is not known whether the ADP can accurately determine or track changes in body volume/composition following rapid changes in body weight and/or hydration status. Research has shown that hydration status can affect body composition analysis when performed by dual energy X-ray absorptiometry (DEXA), hydrodensitometry, total body potassium, and bio-electrical impedance (BIA) (8-10).

The reason for hydration status affecting the results of the analysis of body composition is the assumption by Siri and others (7) that all adults are identical in their ratios of water, protein and mineral and that they differ only in the amount of body fat. Therefore, this study was designed to evaluate the ability of the ADP system to track rapid gains in body mass following changes in hydration status due to water consumption and creatine loading. Water consumption will result in fluid being held primarily within the stomach and bladder while creatine supplementation has been reported to result in water retention (11) presumably by increasing the water content of the muscles (12). This study determined how the ADP analyzes changes in body composition following two different methods of hydration manipulation.

METHODS

Subjects

In *Study 1*, twenty-eight healthy, strength-trained males volunteered to participate in this study; ten of these individuals served as control subjects. Twelve males from *Study 1* who had not consumed creatine for at least three months participated in *Study 2*. An additional 12 males, who had not supplemented their diet with creatine also participated in *Study 2* and served as control subjects. All subjects gave written consent to participate in the study after being thoroughly informed of its purpose and procedures. The consent form and protocol for the study were in accordance with the American College of Sports Medicine's policy statement regarding the use of human subjects and informed consent.

Study 1

Experimental Design

Subjects reported to the laboratory following a six to 12 hour fast and were required to void. Height was measured to the nearest tenth of a centimeter. Body mass, to the nearest 0.01 kg, was assessed with the subject wearing Lycra workout shorts or swimsuits. Body volume was assessed by the method provided by the manufacturer of the ADP (Life Measurement Instruments, Concord, CA). Following a two-point calibration of the ADP, the subject entered the chamber with a swim cap on the head. The subject was instructed to sit still with hands on thighs and breath normally while body volume was assessed. Thoracic gas volume was assessed via an internal breathing circuit according to the methods described by Dempster and Aitkens (1). Percent fat

and fat free mass was calculated by the computer using the equation by Siri (7). Two complete tests were performed for the measurement of body volume/composition. For a detailed description of the operating principle and procedures see Dempster and Aitkens (1).

The subject then drank 500 mL of water. Two full assessments of body volume/composition were performed again but the average lung volume from the first two tests was entered. This procedure was repeated after the consumption of water in 500 mL increments until the subject consumed a total of 2,000 mL of water. The entire procedure lasted about 60 minutes. Subjects were not allowed to void during the testing procedure. The control group (n=10) performed the same number of body composition assessments without consuming water. This was done for comparison purposes and to track the reliability of the ADP in performing multiple measurements.

It was decided prior to the initiation of the study that subjects would consume a total of two liters of water. This would correspond to a two kilogram increase in weight. We chose this amount because we wanted to have a change in weight that was comparable to the change in weight associated with creatine consumption.

Study 2

Experimental Design

Subjects reported to the laboratory following a 6 to 12 hour fast and were required to void. Height was measured to the nearest centimeter. Body mass (to the nearest 0.01 kg) was assessed with the subject wearing Lycra workout shorts or swimsuits. Two full body volume/composition analyses were performed as described above with measurements of lung volume. Subjects then began a creatine supplementation regime that required them to consume 5.25 g of creatine monohydrate four times per day (21 g/day) for 7 days (Phosphagen HP, Experimental and Applied Sciences, Inc. Golden, CO). Following the 7 days subjects reported to the laboratory at the same time as the first test wearing the same shorts or swimsuit, and body volume/ composition was analyzed again. On each occasion, two full measurements were performed and the results were averaged. During the 7 days, subjects maintained their normal exercise program. A control group (n=12) was also analyzed before and after 7 days for comparison and to track the variation of the ADP in performing measurements 7 days apart. The control group did not consume creatine during the 7 days that separated the two tests.

Statistical Analysis

Data were analyzed using SPSS for Windows (v 11.0) statistical software. A repeated measures one-way analysis of variance (time as a factor) was used to analyze the data from *Study 1*. When a significant F value was found, a Tukey post-hoc test was performed to locate significant pair wise differences between means. An intra-class correlation was calculated for the control group to establish the variance and test-retest reliability of the ADP when performing multiple analyses in a short period of time. In *Study 2*, a paired t-test was used to determine significant differences between test one (pre-supplementation) and test two (post-supplementation). An intra-class correlation was also calculated for the control group in *Study 2* to establish the variance and test-retest reliability of the ADP when performing body composition analysis 7 days apart.

A post-hoc analysis was performed to determine if body volume and density responded differently to similar weight gains through either water consumption or water retention via creatine supplementation. A 2-way ANOVA was performed using the Pre (trial 1) and 1000 mL (trial 3) data from study 1 and Pre and Post creatine supplementation data from study 2.

Variables measured in both studies included body mass, body volume, fat mass, fat-free mass, percent body fat, and density. The alpha level was set at $p \leq 0.05$ for both studies. Values are reported as mean \pm SD.

RESULTS

Reliability testing

Study 1

Test-retest reliability in adult males (N=10) performing multiple analyses in a short period of time, produced an intra-class correlation (R) of 0.992 with a standard error of estimate (SEE) of 1.2 for percent body fat measurements and a R=0.960 and SEE=1.1 kg for fat free mass measurements.

Study 2

Test-retest reliability in adult males (N=12) measured 7 days apart, produced an intra-class correlation (R) of 0.984 with a standard error of estimate (SEE) of 1.0 for percent body fat measurements and a R=0.996 and SEE=1.1 for fat free mass measurements.

Study 1

Water consumption resulted in an increase in body mass that was approximately equal to the anticipated 500 g increase for each 500 mL of water consumed. Body mass increased significantly ($p<0.05$) following each 500 mL of water consumed (Table 1). Body volume also increased significantly ($p<0.05$) following the consumption of each 500 mL (Table 1).

There was no difference in percent body fat, fat weight, and body density following the consumption of 500 mL of water (Table 1). However, after the consumption of 1,000 mL of water there was a significant increase in percent body fat and fat weight, and a significant decrease in body density. The difference in percent body fat, fat weight and body density remained significant with the consumption of additional water and appeared to show a linear change.

Table 1. Body composition analysis following multiple measurements with (water) or without (Control) the consumption of 2,000 mL of water in 500 mL increments.

<i>Variable/Group</i>	<i>Pre</i>	<i>500 mL</i>	<i>1000 mL</i>	<i>1500 mL</i>	<i>2000 mL</i>
	<i>Trial 1</i>	<i>Trial 2</i>	<i>Trial 3</i>	<i>Trial 4</i>	<i>Trial 5</i>
<i>Body mass, kg</i>					
<i>Water</i>	81.47± 7.15	81.96± 7.14*	82.45± 7.14*	82.95± 7.13*	83.44± 7.13*
<i>Control</i>	86.84± 12.70	86.84± 12.69	86.83± 12.69	86.83± 12.69	86.83± 12.70
<i>Body Volume, L</i>					
<i>Water</i>	76.32± 7.16	76.84± 7.15*	77.46± 7.18*	77.99± 7.17*	78.56± 7.15*
<i>Control</i>	81.55± 12.00	81.44± 11.97	81.41± 11.99	81.45± 11.97	81.63± 12.02
<i>Density, g/cc</i>					
<i>Water</i>	1.068± 0.013	1.067± 0.014	1.065± 0.013*	1.064± 0.013*	1.063± 0.013*
<i>Control</i>	1.065± 0.015	1.066± 0.014	1.067± 0.012	1.066± 0.012	1.064± 0.012
<i>Body fat, %</i>					
<i>Water</i>	13.53± 5.67	13.87± 5.92	14.83± 5.86*	15.23± 5.58*	15.86± 5.58*
<i>Control</i>	14.25± 4.95	14.26± 6.01	14.11± 5.03	14.43± 5.38	15.30± 5.16
<i>Fat mass, kg</i>					
<i>Water</i>	11.17± 5.17	11.52± 5.37	12.47± 5.58*	12.87± 5.40*	13.44± 5.38*
<i>Control</i>	12.90± 4.95	12.32± 5.62	12.61± 5.14	12.56± 5.08	13.26± 4.99
<i>Fat-free mass, kg</i>					
<i>Water</i>	70.29± 5.86	70.44± 6.08	70.05± 5.94	70.09± 8.82	70.06± 5.85
<i>Control</i>	73.94± 11.51	74.52± 12.05	74.59± 11.46	74.34± 11.71	73.56± 11.47

Values are reported as mean±SD. * $p<0.001$ compared to Pre.

Fat-free mass (FFM) remained constant throughout the study and was not affected by the consumption of water (Table 1). However, the slight decline in FFM observed approached the level of significance set prior to the

study ($p=0.072$). The sum of the positive change in FM and the negative change in FFM approximately equaled the total gain in body mass.

Study 2

Creatine supplementation resulted in a significant increase in body mass, body density, and FFM, while the increase in body volume approached significance (Table 2).

Body fat expressed as a percentage or in kilograms significantly decreased.

Study Comparison

Consumption of 1,000 mL of water resulted in a weight gain of 0.98 ± 0.03 kg, similar to the weight gain experienced by individuals during creatine supplementation, 1.1 ± 0.4 kg (Figure 1). The consumption of 1,000 mL of water resulted in a significant increase in body volume (1.14 ± 0.15 L) that was greater than the change in volume measured during the creatine supplementation study (0.90 ± 0.55 L) ($p=0.08$). Creatine supplementation resulted in a significant increase in body density, while water consumption resulted in a significant decline in body density. These responses were significantly different from each other.

DISCUSSION

The results of this study indicate that changes in the body's hydration status either through fluid consumption or retention, which results in body mass changes of one kilogram or greater, can significantly alter body volume and density when analyzed by air-displacement plethysmography (ADP). The ADP appears to interpret rapid weight gains in body mass through water consumption as fat mass; while water retention through creatine supplementation was interpreted as fat-free mass. The discrepancy appears to be due to the measurement of body volume which then influences the calculation of body density.

The consumption of 500 mL of water resulted in a significant increase in body mass and body volume. According to the ADP analysis most of this change was interpreted as fat mass (FM) (0.35 kg) while the remaining change was interpreted as fat-free mass (FFM) (0.15 kg). Together, the change in FM and FFM

Table 2. Body composition analysis before and after 7 days of no treatment (Control) or following 7 days of creatine supplementation of 21 g/day (Creatine).

Variable/Group	Pre	Post	P Value
<i>Body mass, kg</i>			
Creatine	87.5 ± 13.4	88.5 ± 13.1	0.028
Control	85.7 ± 11.3	85.7 ± 11.3	0.58
<i>Body volume, L</i>			
Creatine	82.6 ± 14.4	83.3 ± 14.3	0.067
Control	80.3 ± 10.6	80.2 ± 10.7	0.61
<i>Density, g/cc</i>			
Creatine	1.062 ± 0.021	1.065 ± 0.023	0.014
Control	1.065 ± 0.011	1.066 ± 0.012	0.22
<i>Body fat, %</i>			
Creatine	16.1 ± 9.6	15.0 ± 10.1	0.007
Control	14.4 ± 4.7	14.3 ± 5.2	0.93
<i>Fat mass, kg</i>			
Creatine	15.1 ± 11.8	14.3 ± 12.2	0.015
Control	12.7 ± 4.8	12.4 ± 5.1	0.35
<i>Fat-free mass, kg</i>			
Creatine	72.4 ± 4.8	74.1 ± 5.1	0.002
Control	72.9 ± 9.8	73.4 ± 9.9	0.20

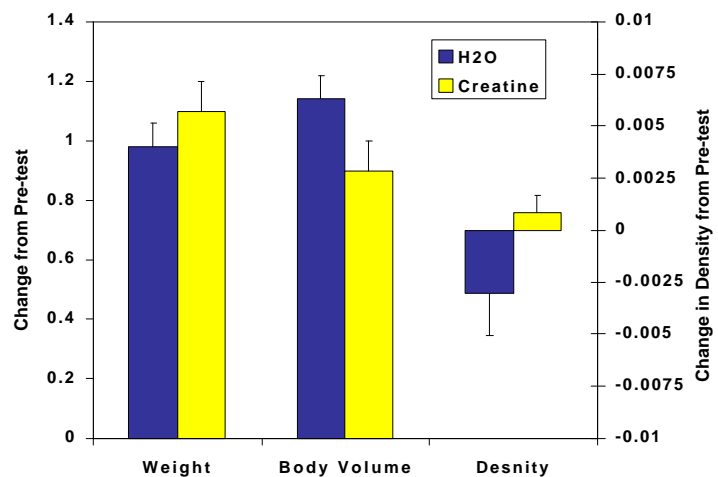


Figure 1. Data for the changes in body weight, body volume, and body density for the water and creatine groups.

accounted for the total change in body mass (0.5 kg). Following the consumption of 1,000 mL, body mass increased ~1 kg (0.98 kg). However, FM increased an average 1.3 kg from baseline (Pre) and FFM decreased an average 0.24 kg. The change in FM was beyond that which can be explained by the change in weight. This discrepancy was augmented when 1,500 mL and 2,000 mL of water were consumed. Following the consumption of 1500 mL, body mass had increased an average 1.48 kg, but FM had increased an average 1.7 kg and FFM decreased an average 0.2 kg. After 2,000 mL were consumed, body mass increased an average 1.97 kg, while FM increased to an average of 2.27 kg and FFM decreased ~0.2 kg. It is possible that the large consumption of water resulted in stomach and or bladder distension resulting in an increase in body volume that was out of proportion to the increase in body mass, resulting in a decrease in body density.

Creatine supplementation resulted in an average increase in body mass of 1.0 kg. However, the ADP interpreted this gain in body mass as a gain in FFM (average 1.7 kg) and a decrease in FM (average 0.8 kg). The ~1.0 kg gain in weight with creatine supplementation was the exact opposite to which occurred with the ~1.0 kg gain in weight with water consumption. The discrepancy between the two could be due to the changes in body volume associated with the 1.0 kg gain in mass. In Study 1, body volume increased an average of 1.14 L with the consumption of 1000 mL of water, while in Study 2, body volume only increased an average of 0.9 L. Weight gain was similar in the two studies (H₂O: 0.98±0.03 kg; Creatine: 1.1±0.4 kg); however, because of the greater change in body volume following consumption of 1000 mL, body density decreased resulting in the ADP interpreting the change as an increase in FM.

Other methods of body composition analysis have also had difficulties in interpreting changes in body composition associated with hydration status (8-10;13-15). Research investigating the effects of hydration on bio-electrical impedance (BIA) reported that percent fat values decrease when the subjects were hypohydrated (exercise in the heat) and increased following rehydration (10). Investigators utilizing the hydrostatic weighing (HW) method have reported that HW interprets states of dehydration (sweating and diuretics) with some inconsistency; one study reported increases in FFM (15), while another study reported decreases in FFM (8). Research utilizing DXA analysis have reported that fluid consumption results in an increase in FFM (9;15). However, Horber et al. (9) reported that DXA was unable to detect any changes in body composition following a light meal (155 g) and consumption of 400 mL of fluid. Therefore, it appears that both the DXA and the ADP are unable to detect changes in body composition with the consumption of 500 mL of fluid or less.

It is important to determine the limitations of body composition analysis methods. Many athletes (gymnasts, wrestlers, distance runners, rowers) feel that they may perform better at lower percentages of body fat. Therefore, it necessary to use a reproducible and accurate method of body composition analysis. Furthermore, it is also necessary to standardize the procedures for body composition analysis. Based on the current study, the ADP had difficulties interpreting changes in body composition associated with changes in hydration status that resulted in changes in body mass of one kilogram or greater. The manufacturer of the BOD POD[®] recommends the cessation of fluid 3 to 4 hours prior to analysis; this would allow enough time for the fluid to be distributed equally among intracellular and interstitial pools (16). In the current study, it is unlikely that water was equally distributed within the body in the hour of the study.

Conclusions

In summary, changes in hydration status through fluid consumption caused large fluctuations in body volume, thus influencing body density and body fat estimates. However, these changes were not observed until after 1000 mL were consumed. The consumption of fluids in volumes of 500 mL or less does not appear to affect the ADP system's ability to interpret body composition changes. However, water retention caused by creatine supplementation resulted in the ADP interpreting the change in body volume as an increase in body density, and thus an increase in fat-free mass and a decrease in fat mass. The standard errors for the percent body fat and

FFM associated with the ADP (1.2% and 1.1kg, respectively) do not preclude its ability to predict %BF and FFM accurately under normal states of hydration.

Address for correspondence: Matthew Vukovich, Ph.D., Dept. of HPER, Box 2820, South Dakota State University, Brookings, SD 57007. Phone: (605) 688-6580; Fax: (605) 688-5999; Email: matthew_vukovich@sdsate.edu

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