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ORIGINAL ARTICLE

The effect of acute fluid consumption on measures of impedance and percent body fat estimated using segmental bioelectrical impedance analysis

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Background/Objectives: To determine the effect of acute fluid consumption on measures of impedance and percent body fat (%BF) estimated using segmental bioelectrical impedance analysis (SBIA).
Subjects/Methods: Seventy-six healthy, recreationally active adults (41 women; 35 men) volunteered to participate in this study (mean ± s.d.; age, 21.0 ± 1.6 years; body mass index, 25.0 ± 3.2 kg/m^2). Subjects had their body composition assessed on three separate occasions. After a baseline measurement, subjects consumed 591 ml of water (H_2O), a carbohydrate/electrolyte drink (CHOE) or received nothing (CON). Subjects were reassessed 20, 40 and 60 min following (POST) the baseline measure in each fluid condition.
Results: Twenty minutes after drinking a H_2O or CHOE beverage, %BF (1.1 and 1.2%), impedance (12 and 14 Ω) and body mass increased significantly ($P<0.001$). During the CON trial, %BF (0.3 and 0.5%) and impedance (7 and 11 Ω) also increased significantly above baseline values at 40 and 60 min POST. However, the normal hourly variability was significantly ($P<0.009$) less than the observed fluid-induced %BF alterations. The greatest %BF increases were observed in the lightest subjects, who were women. Fluid type had no effect on the magnitude of change POST.
Conclusions: Twenty minutes after drinking, %BF estimates increased approximately 1.0% due to elevations in impedance and body mass. As such, we recommend adhering to the pretest fluid restriction guideline to avoid fluid-induced alterations in SBIA body composition measures. In addition, use of a consistent testing schedule may minimize normal %BF variation over time.
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Keywords: body composition; hydration; total body water; urine specific gravity

Introduction

The bioelectrical impedance analysis (BIA) method of assessing body composition is more frequently being used in a variety of clinical and health-related settings (NIHTAC, 1996; Nunez *et al*., 1997; Lukaski, 2000). Partially responsible for the increase in popularity may be the development of the relatively inexpensive and easy-to-use leg-to-leg and segmental BIA analyzers (LBIA and SBIA). These contact-electrode analyzers, which measure impedance as a participant stands on a scale-like platform, differ significantly from the traditional BIA method that requires the accurate placement of gel electrodes at specific anatomical locations. LBIA and SBIA have been found to have overall performance characteristics for impedance measurement and body composition analysis similar to traditional BIA while offering the advantage of increased speed and ease of measurement (Nunez *et al*., 1997; Pietrobelli *et al*., 2004).

The LBIA and SBIA analyzers introduce an electrical current into the body and measure the impedance to current flow. Fat-free mass, because of its high water and electrolyte content, is highly conductive, whereas adipose tissue contains little water and is therefore a poor conductor (that is, higher impedance). This differential response to an electrical current is the basis of the BIA assessment of body composition. Many contact-electrode analyzers operate at a

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low-energy, single-frequency current and primarily reflect the extracellular water compartment from which total body water, fat-free mass and percent body fat (%BF) are estimated by pre-programmed equations (Heyward and Wagner, 2004). The accuracy of the body composition estimates (for example, %BF) provided by the analyzer is dependent on the accuracy and precision of the impedance measurement (Roche *et al*., 1996). A potential source of error with the BIA method is intraindividual variability in the hydration state. Earlier research examining the traditional BIA and LBIA methods has shown that impedance is affected by factors that produce shifts in body fluids or electrolytes (Deurenberg *et al*., 1988; Gomez *et al*., 1993; Kushner *et al*., 1996; Andreacci *et al*., 2006; Dixon *et al*., 2006). Therefore, controlling pretest behaviors that may alter hydration state is recommended when using BIA technology (Roche *et al*., 1996; Heyward and Wagner, 2004).

For instance, no eating or drinking 4 h before testing is a traditional BIA pretest guideline (Heyward and Wagner, 2004); however, there is a lack of consensus within the literature relative to the impact of fluid consumption and BIA measures. Several studies examining the traditional BIA method have reported significant changes in whole-body impedance, %BF and total body water after drinking (Deurenberg *et al*., 1988; Rising *et al*., 1991; Gomez *et al*., 1993; Saunders *et al*., 1998; Demura *et al*., 2002), whereas others have reported no effect (Elsen *et al*., 1987; Deurenberg *et al*., 1988). In addition, although individuals may adhere to pretest guidelines in a controlled laboratory setting, compliance in the field may be unlikely. If necessary, stringent pretest guidelines significantly reduce the practicality of utilizing the LBIA and SBIA analyzers for body composition assessment in the clinical setting. Recently, our laboratory examined the effect of acute fluid consumption on measures of impedance and %BF using the LBIA contact-electrode technology (Dixon *et al*., 2006). In this study, impedance was unchanged but mean %BF values increased 20 min after drinking 591 ml of water (H_2O) or a carbohydrate/electrolyte (CHOE) beverage. Although statistically significant, the %BF overestimation was relatively small (~0.5 %BF) and was thought to have little practical significance.

The SBIA analyzer contains a scale-like platform, similar to LBIA, accompanied by two handgrip electrodes. Contrary to LBIA, which uses a lower body (that is, leg-to-leg) electrical pathway, SBIA %BF estimates are based on a whole-body (that is, foot-to-hand) impedance measurement. To date, the effect of fluid consumption on body composition measures determined by SBIA is unknown. As such, the purpose of this investigation was to determine the effect of acute fluid consumption on measures of impedance and %BF estimated using SBIA. It is anticipated that our findings may further clarify whether a pretest fluid restriction guideline is necessary when using the SBIA contact-electrode technology.

Materials and methods

Subjects

Seventy-six healthy, recreationally active adults (41 women; 35 men) between 18 and 23 years of age volunteered to participate in this study. The Bloomsburg University Institutional Review Board approved the study protocol and methods. All subjects signed an informed consent form before participation.

Study procedures

Each subject reported to the body composition laboratory for testing on three separate days. Subjects were instructed to adhere to the following traditional BIA and manufacturer-recommended pretest guidelines (Heyward and Wagner, 2004): (a) no food or drink within 4 h of the test, (b) no exercise within 12 h of test, (c) no alcohol consumption within 48 h of the test, (d) empty bladder within 30 min of the test and (e) no diuretic medications within 7 day of the test. Subject compliance to these guidelines was confirmed before each experimental trial.

After an initial baseline measurement of impedance, %BF, total body water and body mass, subjects consumed 591 ml (that is, 20 ounces) of H_2O, a common CHOE drink (Gatorade; Pepsi-Cola Company, Chicago, IL, USA) or received nothing, which served as the control (CON). The CHOE drink was selected because of the comparatively higher electrolyte content of the beverage (~270 mg sodium, ~75 mg potassium and ~35 g carbohydrate). Drinks were served cold (3–5 °C) to increase the gastric emptying rate from the stomach (Costill and Saltin, 1974). Subjects were permitted 10 min to consume each beverage. The treatment order for each subject was determined using a counterbalanced assignment. The SBIA measures were reassessed 20, 40 and 60 min following (POST) the baseline measure in each treatment condition. During the 60 min POST treatment time period, subjects sat quietly. Laboratory temperature was maintained at a constant 22 °C for all assessments. Urine specific gravity (USG), measured by a hand-held Misco digital fiberoptic refractometer (Misco Corp., Cleveland, OH, USA), was recorded at baseline and 60 min POST. Urinary measures have been reported to be an effective method of assessing the hydration state (Shirreffs, 2003). Height was determined using a Seca 240 wall-mounted mechanical measuring rod (Seca Corp., Hanover, MD, USA).

Segmental bioelectrical impedance analysis

The BC-418 8-contact-electrode analyzer (Tanita Corporation of America Inc., Arlington Heights, IL, USA) was used to determine SBIA measurements. Each subject, wearing only a *t*-shirt and shorts, stood erect holding the hand electrodes with bare feet placed properly on the contact electrodes of the SBIA instrument. Arms were held in the straight down

position without touching their sides. As previously described (Pietrobelli *et al*., 2004), the SBIA system consists of four contact electrodes (two anterior and two posterior) that are mounted on the surface of a platform scale and each extremity handgrip has an anterior and posterior electrode. All measurements are carried out using a constant single-frequency current (50 kHz, 500 μA). Whole-body impedance was measured using an ipsilateral foot–hand electrical pathway. The SBIA analyzer automatically calculates %BF using pre-programmed proprietary equations developed by the manufacturer. The 'athletic mode' was selected based on subject activity levels as per the manufacturer's guidelines.

Statistical methods

Data were analyzed using SPSS 16.0 for Windows (SPSS Inc., Chicago, IL, USA). All values are expressed as mean ± s.d. unless otherwise noted. The between-day coefficient of variations for impedance and %BF were calculated as s.d./mean × 100%. Dependent variables were analyzed using a two-way repeated measures analysis of variance. The within-subjects factors were fluid condition with three levels (CON, H_2O and CHOE) and time with four levels (baseline, 20, 40 and 60 min). Pairwise comparisons were conducted using the Holm's Sequential Bonferroni approach to discriminate between means when analysis of variance yielded significant results. Bland–Altman plots were constructed and correlation coefficients were computed to determine whether body mass or baseline hydration status affected the magnitude of change POST (Bland and Altman, 1986). Statistical significance was established *a priori* at $P<0.05$ for all analyses.

Results

Subject characteristics of the 76 adults who participated in this investigation are presented in Table 1. The average testing duration for completing all three fluid conditions was 8.4 ± 1.7 days. The between-day coefficient of variations for impedance ranged from 0.0 to 6.5%, with group means of 2.2 ± 1.5% (day 1–2). The between-day coefficient of variations for %BF ranged from 0.0 to 13.1%, with group means of 3.4 ± 3.3% (day 1–2).

A two-way within-subjects analysis of variance was conducted to evaluate the effect of fluid condition and length of time to assessment on the dependent variables (%BF, impedance, body mass and total body water). A significant interaction effect was found for %BF ($F(6,445)=29.0$, $P<0.001$) (Figure 1). *Post hoc* analysis of the interaction indicated that %BF was significantly different ($P<0.009$) from CON values at 20, 40 and 60 min in the H_2O and CHOE trials. The fluid condition ($F(2,150)=9.8$, $P<0.001$) and time ($F(3,225)=93.7$, $P<0.001$) main effects were also statistically significant.

A significant interaction effect was found for impedance ($F(6,448)=13.9$, $P<0.001$) (Figure 2). *Post hoc* analysis of the interaction indicated that impedance was significantly different ($P<0.001$) from CON values at 20 min in both fluid consumption trials. The time ($F(3,225)=98.7$, $P<0.001$) main effect was also statistically significant.

A significant interaction effect was found for body mass ($F(6,449)=29.0$, $P<0.001$) (Figure 3). *Post hoc* analysis of the interaction indicated that body mass was significantly different ($P<0.001$) from CON values at 20, 40 and 60 min in the H_2O and CHOE trials. The fluid condition ($F(2,150)=13.9$, $P<0.001$) and time ($F(3,225)=206.4$, $P<0.001$) main effects were also statistically significant.

A significant time main effect was found for total body water ($F(3,225)=36.9$, $P<0.001$) (Figure 4). *Post hoc* analysis of the main effect indicated that total body water was significantly lower ($P<0.001$) than baseline at 40 and 60 min in the CON trial, and 20, 40 and 60 min in the H_2O and CHOE trials.

Table 1 Subject characteristics

	Women (n = 41)		*Men (n = 35)*	
	Mean ± s.d.	*Range*	*Mean ± s.d.*	*Range*
Age (years)	20.8 ± 1.1	18.7–24.9	21.2 ± 2.0	18.0–27.6
Height (cm)	163.2 ± 7.1	146–181	174.9 ± 7.4	162–192
Body mass (kg)	63.5 ± 9.4	46.6–85.0	80.1 ± 11.8	54.8–110.8
BMI (kg/m^2)	23.9 ± 2.9	18.7–31.9	26.2 ± 3.1	19.6–32.7
Body fat (%)	25.3 ± 4.8	15.0–34.4	14.9 ± 4.8	5.3–25.8

Abbreviation: BMI, body mass index.

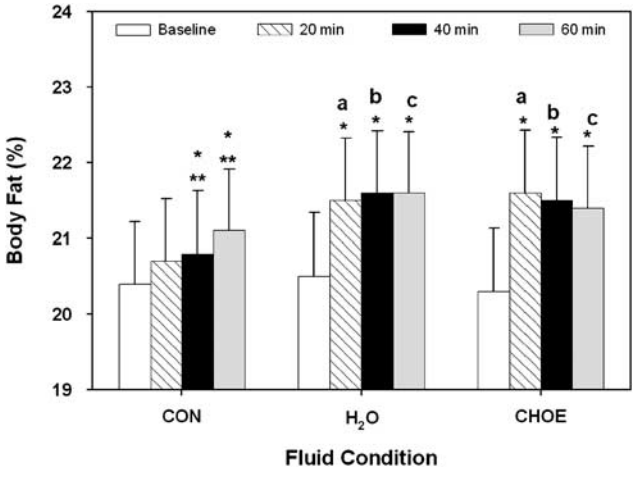

Figure 1 Percent body fat values over time for each fluid condition (mean ± s.e.m.). *Significantly different from baseline; **significantly different from 20 min; $P\leqslant0.005$. Also, a, significantly different from 20 min CON; b, significantly different from 40 min CON; c, significantly different from 60 min CON; $P\leqslant0.009$.

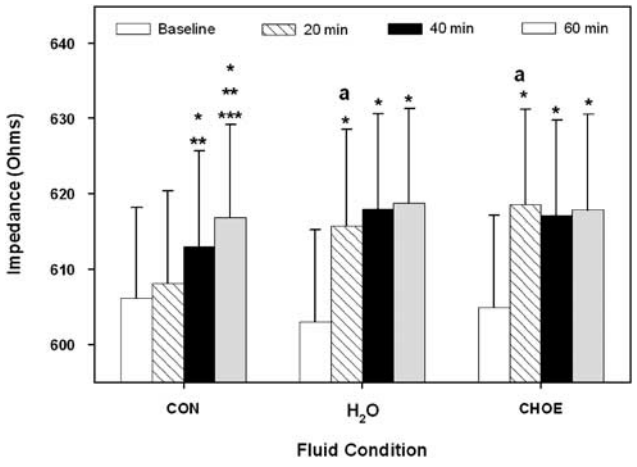

Figure 2 Impedance over time for each fluid condition (mean ± s.e.m.). *Significantly different from baseline; **significantly different from 20 min; ***significantly different from 40 min; $P \leqslant 0.001$. Also, a, significantly different from 20 min CON; $P \leqslant 0.015$.

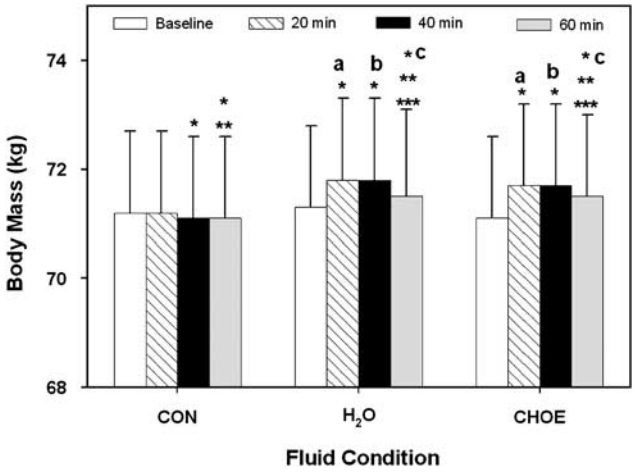

Figure 3 Body mass values over time for each fluid condition (mean ± s.e.m.). *Significantly different from baseline; **significantly different from 20 min; ***significantly different from 40 min; $P \leqslant 0.001$. Also, a, significantly different from 20 min CON; b, significantly different from 40 min CON; c, significantly different from 60 min CON; $P < 0.001$.

Individual differences in body mass influenced the %BF and impedance change POST. A consistent pattern of change was observed over time and across fluid conditions; therefore, we have selected to present the 20 min data as the most dramatic change in dependent variables occurred at this time point. According to the Bland–Altman analysis, body mass influenced the %BF change at 20 min POST in the H_2O (overall: $r = 0.50$, $P < 0.001$; women: $r = 0.69$, $P < 0.001$) and CHOE (overall: $r = 0.43$, $P < 0.001$; women: $r = 0.41$, $P = 0.009$) conditions, but not during the CON trial (Figure 5). As shown in Figure 5, at 20 min POST, %BF increased in the majority of the subjects after drinking

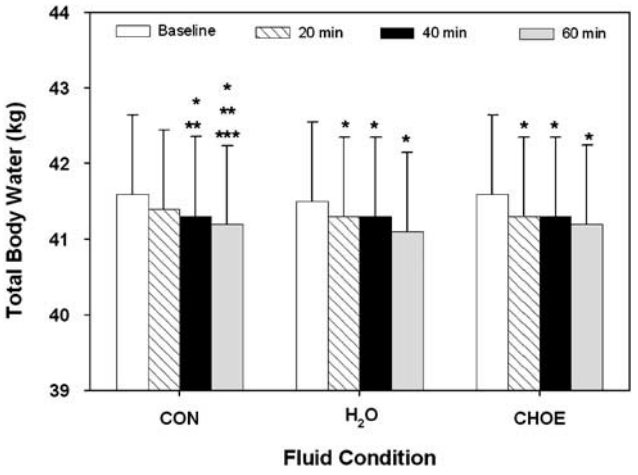

Figure 4 Total body water values over time for each fluid condition (mean ± s.e.m.). *Significantly different from baseline; **significantly different from 20 min; ***significantly different from 40 min; $P < 0.001$.

($H_2O = 98\%$; CHOE = 100%) compared with 55% in the CON condition. The total sample differences in %BF from baseline to 20 min POST (mean ± s.d.) were -0.1 ± 0.5, -1.1 ± 0.7 and -1.2 ± 0.6 %BF for CON, H_2O and CHOE, respectively. Similarly, the change in impedance at 20 min POST was also influenced by individual body mass in the H_2O (overall: $r = 0.51$, $P < 0.001$; women: $r = 0.58$, $P < 0.001$), CHOE (overall: $r = 0.35$, $P = 0.002$) and CON (overall: $r = 0.26$, $P = 0.025$) conditions (Figure 6). As shown in Figure 6, at 20 min POST, impedance increased in the majority of the subjects after drinking ($H_2O = 90\%$; CHOE = 91%) compared with 61% in the CON condition. Furthermore, the total sample differences in impedance from baseline to 20 min POST (mean ± s.d.) were -2.0 ± 9.3, -11.9 ± 10.8 and $-13.6 \pm 10.9\ \Omega$ for CON, H_2O and CHOE, respectively.

Hydration state, as determined by baseline USG, had no impact on the %BF or impedance magnitude of change after ingestion. A significant decrease in USG ($P < 0.0001$) was observed at 60 min POST from baseline in the H_2O (1.008 ± .007 vs 1.018 ± .007 g/ml) and CHOE (1.009 ± .008 vs 1.019 ± .007 g/ml) fluid consumption trials. No significant differences were observed for USG over time during the CON trial.

Discussion

Owing to the ease of measurement, contact-electrode BIA analyzers (for example, LBIA and SBIA) have become a common method of assessing body composition in clinical settings. To increase the accuracy of measurement, it is recommended that individuals avoid consuming fluids for up to 4 h before the test (Heyward and Wagner, 2004). Previous research examining LBIA technology has shown

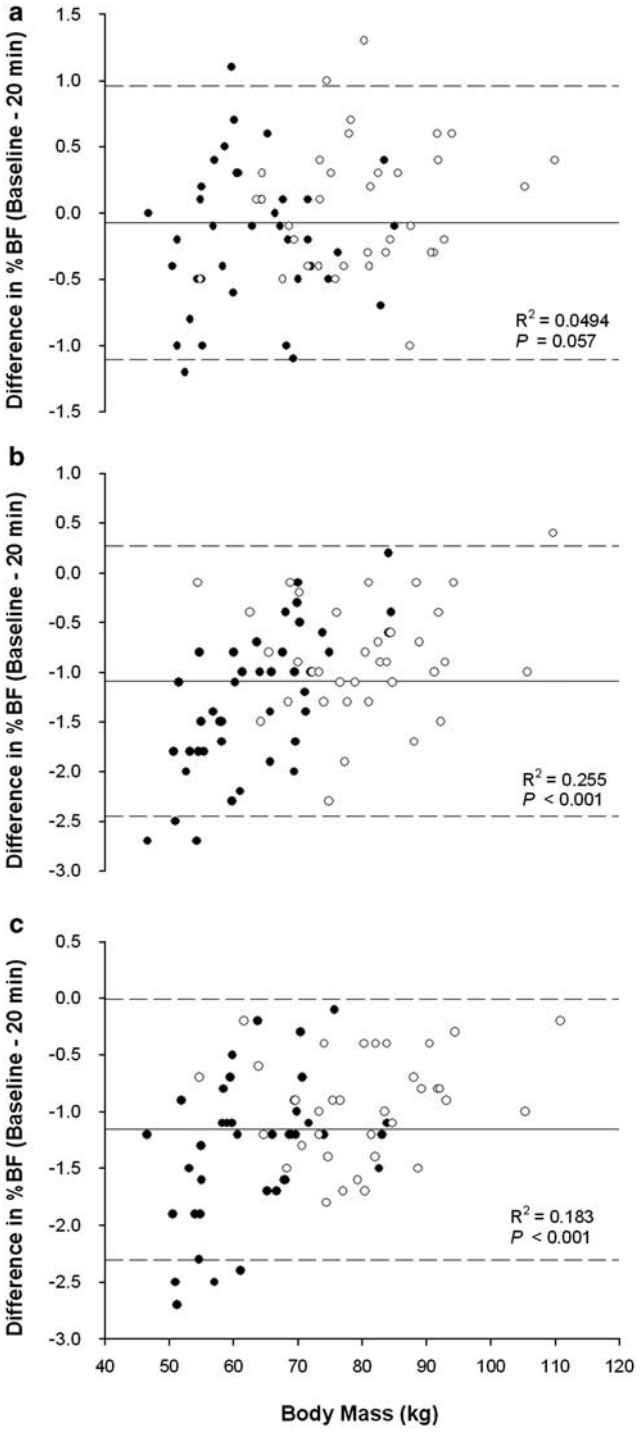

Figure 5 Scatter plots exploring individual differences in %BF during the fluid conditions ((**a**) = CON; (**b**) = H_2O; and (**c**) = CHOE)). The difference between baseline and 20 min %BF is plotted against body mass for the women (●) and men (○). Negative values represent an increase from baseline. The mean difference is represented by the solid line, and the dashed lines represent ± 2 s.d. from the mean.

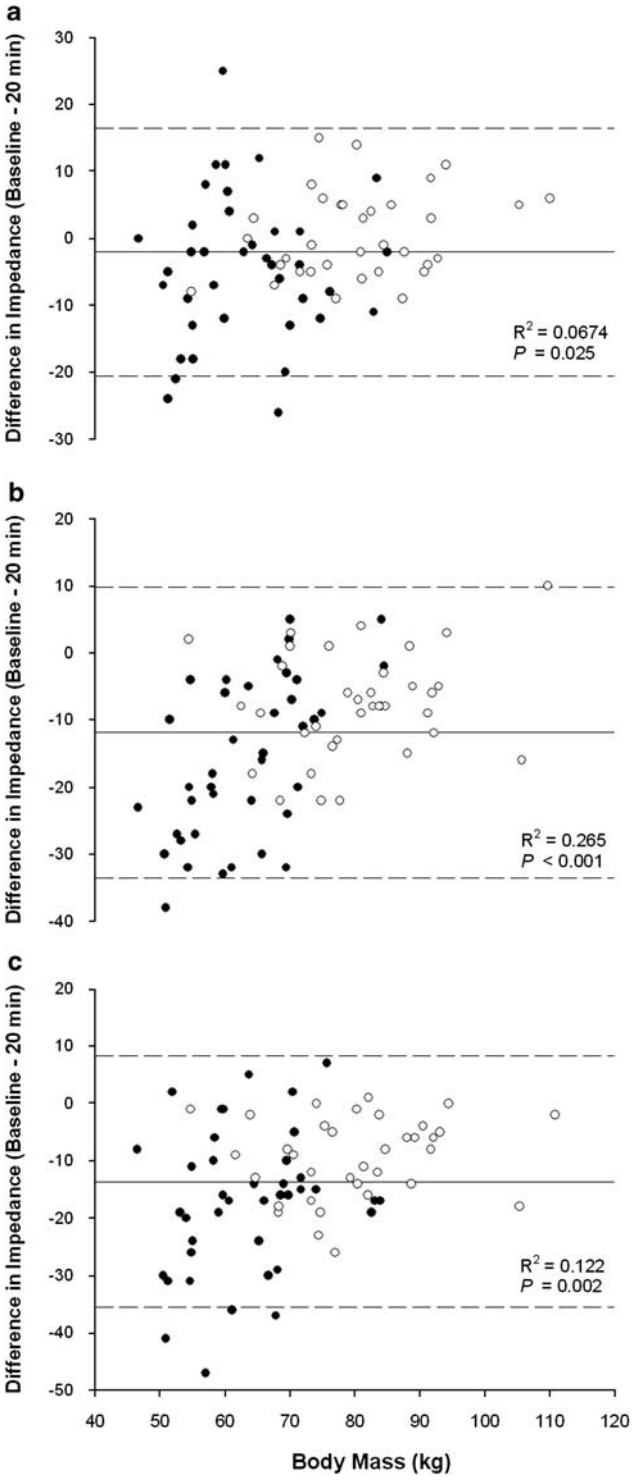

Figure 6 Scatter plots exploring individual differences in impedance during the fluid conditions ((**a**) = CON; (**b**) = H_2O; and (**c**) = CHOE)). The difference between baseline and 20 min impedance is plotted against body mass for the women (●) and men (○). Negative values represent an increase from baseline. The mean difference is represented by the solid line, and the dashed lines represent ± 2 s.d. from the mean.

increases in %BF following drinking (Dixon *et al*., 2006). The present investigation examined the impact of acute fluid consumption on body composition measures determined by a relatively new SBIA analyzer (Tanita; BC-418). It was anticipated that SBIA, which estimates %BF based upon a whole-body impedance measurement, may be more sensitive to fluid consumption than the LBIA technology, which assesses only the lower extremity.

This study confirms that fluid consumption before SBIA assessment has a significant influence on body composition measures. SBIA-measured %BF increased significantly 20 min after drinking a H_2O and CHOE beverage (1.0 and 1.2%, respectively) and remained elevated for up to 60 min after ingestion. During the CON trial, %BF also increased significantly above baseline at 40 and 60 min POST (0.3 and 0.5%, respectively). However, the CON trial variability was significantly lower than the %BF changes observed after drinking. The %BF value, as calculated by the LBIA and SBIA analyzers, is derived from proprietary equations combining impedance and body mass measurements with height, gender and age information. Therefore, any %BF alterations are a resultant of changes in the measured impedance and/or body mass value. Presently, both impedance and body mass were significantly increased after drinking at the 20, 40 and 60 min POST assessments, resulting in a %BF overestimation. The contribution that each variable had on the overall magnitude of %BF change cannot be specifically determined without access to the manufacturer's proprietary equations. Most importantly, fluid-induced elevations in impedance and body mass are interpreted by the analyzer's pre-programmed regression equations as higher %BF readings.

As shown in Figure 2, impedance increased significantly above baseline in the CON and fluid consumption trials; however, the pattern of change differed depending upon whether fluid was ingested or not. The impedance change that occurred after drinking had two distinct phases; (1) there was a rapid initial increase in impedance 20 min after drinking followed by (2) a leveling off, which lasted for the 60 min testing period. This response was evident in both drinking trials and was independent of the beverage type. As suggested by Gomez *et al*. (1993), a redistribution of blood from the periphery to the core in response to a large volume of fluid entering the stomach and gastrointestinal tract may have contributed to the initial impedance elevation. Thereafter, the absorption of the beverages and subsequent dilution of body fluid electrolytes may have caused impedance to remain significantly elevated above baseline for up to 60 min post-consumption (Gomez *et al*., 1993). Consequently, total body water was underestimated 20, 40 and 60 min after ingesting the beverages.

During the CON trial, impedance was significantly increased above baseline at the 40 and 60 min time points (7 and 11 Ω, respectively). However, the impedance increase was gradual as opposed to the rapid fluid-induced elevation observed 20 min after drinking. Whole-body impedance has been previously reported to increase if the body water content in the upper and lower limbs decreases due to a shift in body water to the trunk (Slinde *et al*., 2003; Oshima and Shiga, 2006). Our subjects walked to the laboratory for testing and then sat quietly for 60 min, excluding the brief time (<1 min) required to stand on the analyzer for the assessment. The redistribution of body water from the active skeletal muscle in the extremities to the torso may have resulted in the gradual impedance increase over time during the CON trial. Collectively, it is apparent that ingesting fluids caused impedance to increase 20 min POST, a response that was not observed in the CON trial. Impedance then remained elevated at 40 and 60 min; however, the increase was not significantly different than the normal hourly variability observed during CON trial. Although the impedance increases were similar between the CON and fluid trials at 40 and 60 min, it is likely that different mechanisms were responsible for the observed alterations.

The Bland–Altman plots revealed that body mass influenced the magnitude of change after drinking. As shown in Figures 5 and 6, the greatest %BF and impedance increases were observed in the lightest women, whereas the heavier subjects (both genders) tended to show less of a change. All subjects, regardless of body size, consumed the same volume of fluid. As such, the beverage volume had a greater impact on SBIA body composition measures in lower body mass individuals, which were primarily women in our sample. Given that the heavier women responded similarly to men of equal weight, we suspect that a light body mass, as opposed to gender differences, resulted in the systematic bias observed in this study. Overall, clinicians should recognize that fluid consumption influences SBIA body composition measures and may cause a more dramatic change in individuals of low body mass.

Research examining the effect of acute fluid consumption on SBIA measurements is non-existent; therefore, direct data comparisons are not possible. Previously, Dixon *et al*. (2006) examined the effect of acute fluid consumption on body composition measures determined by a common LBIA analyzer (Tanita; TBF-300A). In this study, LBIA-measured impedance was unchanged after consuming H_2O or a CHOE beverage, whereas %BF increased significantly at 20 min and remained elevated 60 min POST. The authors suggested that the increased body mass (~500 g) associated with the fluid consumption trials most likely resulted in the slight increase in LBIA-measured %BF values (~0.5%). Presently, beverages of an equal volume and similar electrolyte content to those of Dixon *et al*. (2006) were consumed before the SBIA assessment. Unlike LBIA, significant increases in SBIA-measured impedance (13 and 14 Ω) were observed at 20 min accompanied by comparatively larger increases in %BF (1.0 and 1.1%) in the H_2O and CHOE trials, respectively. One possible explanation for the apparent sensitivity difference between the LBIA and SBIA analyzers is that once consumed, the fluid takes time to spread throughout the body, and with

the LBIA analyzer using a leg-to-leg electrical pathway, it is more difficult to reflect whole-body changes (Demura *et al*., 2002). Murray *et al*. (1997) examined the gastric emptying rates of several beverages including water and a 6% CHOE drink, similar to that used presently. Twenty minutes after ingesting 400 ml of the fluid, approximately 25% of the original volume (100 ml) remained in the stomach, independent of beverage type. Our subjects consumed an additional 200 ml per beverage and therefore, it is likely that an indeterminate volume of fluid remained in the stomach at certain assessment time points. By measuring whole-body impedance (foot–hand), the SBIA analyzer may be more sensitive to the fluid alterations induced by drinking than LBIA, perhaps by detecting fluid located in the abdominal/trunk region.

The CHOE drink (that is, Gatorade) used in this study, which contained a comparatively higher electrolyte content, produced similar impedance and %BF changes after consumption as H_2O. The USG reductions observed 60 min after drinking were also comparable and independent of beverage type. Therefore, it appears that the impact of fluid consumption on SBIA measurements was more dependent on the volume rather than on the electrolyte concentration of the ingested beverages. Our findings support those who previously reported that the type of hydrating solution (H_2O or Gatorade) did not influence gastric emptying rate (Murray *et al*., 1997) or BIA-determined %BF changes post-consumption (Saunders *et al*., 1998).

Limitations of this study include that our subject sample consisted of healthy, active adults. Whether similar findings would occur in populations that differ considerably in body composition characteristics (for example, older adults, sedentary individuals, children and so on) is unknown. Second, the impact that fluid ingestion has on SBIA body composition values before 20 min or beyond 1 h cannot be determined from this study. It is evident from these data that dramatic changes in impedance and %BF occurred 20 min after ingestion. In addition, each variable remained significantly elevated above baseline for up to 60 min POST. However, the amount of time required to first detect fluid-induced alterations in SBIA-determined body composition measures and the time required to return to baseline after consumption cannot be determined from our data and requires clarification.

In summary, the consumption of 591 ml of H_2O or a CHOE beverage before SBIA assessment significantly increased impedance and body mass 20 min after drinking, which resulted in a %BF overestimation of approximately 1.0%. When examined relative to body mass, the greatest %BF and impedance increases tended to occur in the lightest women. When one considers the fluid-induced %BF elevations observed presently with the inherent prediction error for BIA, which ranges from 3.0 to 4.0 %BF in adults (Heyward and Wagner, 2004), it is apparent that drinking may further reduce the accuracy and precision of this method. As such, we recommend adhering to the traditional BIA pretest fluid restriction guideline to avoid fluid-induced alterations in SBIA body composition measures. In addition, a significant %BF overestimation (0.3–0.5%) was also observed during the CON trial. To control for normal hourly variability, we recommend using a consistent testing schedule, preferably conducting the SBIA assessment soon after the patient/client arrives to the testing facility, to minimize variation over time. This information is important for clinicians, researchers, athletic trainers and other health and fitness professionals who currently use this technology to assess and/or monitor body composition in the field.

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