No differences in the body fat after violating core bioelectrical impedance measurement assumptions

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Abstract

Objective: It is unclear to what degree acutely violating bioelectrical impedance analysis (BIA) measurement assumptions will alter the predicted percent fat mass (%FM) and whether this differs by sex or body mass index (BMI).

Methods: %FM was assessed under control, dehydration, exercise, water, meal intake and non-voided bladder conditions with three BIA devices (Tanita: BC-418, TBF-314, & Omron HBF-306CN) (n=40).

Results: For all BIA devices, there were no differences in the %FM values between the control and the other conditions in men or women (-1.9 to 0.4%, p >0.05). Across the three devices and five conditions, 97% of %FM tests returned values within 5% of control (2 tests), and 86% of tests were within 2% of control despite violating an assumption. The errors were greatest with dehydration and females were more likely to have a %FM difference greater than 2% than males with dehydration using the hand-to-foot device (Tanita TBF-314: 59% versus 9%). There were no differences in %FM between control and the conditions when examined by BMI category (overweight: -2.8 to 0.1% and normal weight: -1.7 to 0.5%; BMI*trial, p=0.99).

Conclusion: %FM estimates were similar despite acutely violating the preliminary measurement BIA assumptions across a range of different BMIs. The minor variations in %FM are smaller than what would be expected with day-to-day variability or weight loss intervention, but may be larger in women than men.

Introduction

Bioelectrical impedance analysis (BIA) is a convenient, non-invasive and non-intrusive device for estimating body composition (Dehghan M., Merchant AT.2008, Foster KR., Lukaski HC.1996). BIA devices use proprietary or published equations based on the relationship between total or segmental impedance and total body water volume (Kyle et al. 2004). BIA equations for predicting body composition are based on the premise that when an alternating potential is applied to the body, the amount of current that passes through the conductive water-containing tissues is related with the amount of fat free mass (FFM). The impedance to the flow of electrical current can be used to estimate body composition where higher or greater electrical impedance is correlated with higher fat mass (Lukaski 1996; Kyle et al. 2004). These equations assume proper hydration and fluid distribution and violating this assumption may alter how BIA predicts FFM and total body water. Accordingly, the National Institute of Health recommends avoiding BIA measurements when participants are dehydrated, within 4-h of food and beverage consumption, have a full bladder and within 12 hours of moderate-to-strenuous exercise (The National Institutes of Health).

The commonly used BIA published equations were developed using normal weight (18.5 to 25 kg/m^2), generally healthy populations (Kyle et al. 2004). Some studies suggest that BIA analyses underestimates the percent fat mass (%FM) in individuals with overweight or obesity (> 25 kg/m^2), and may be related to differences in fluid distribution, resistive and volume properties among various body tissues (Baumgartner RN., Ross R., Heymsfield SB.1998, Kushner RF.1992). It is important to understand if violating these preliminary measurement BIA assumptions changes the estimation of body composition and if these discrepancies are greater among those with greater obesity.

Furthermore, the relative importance of the preliminary BIA measurement assumptions may vary across devices. Impedance can be assessed using foot to foot, hand to foot and hand-held devices which may differ in the tissues through which the main electrical current travels. Thus, the assumptions may influence BIA measures differently depending on the device used. These devices also vary by electrode characteristics (number, type and placement), electric current frequency (single or multiple frequencies) and body position at measurement [9]. The impact of not adhering to preliminary assumptions prior to the BIA assessment has not been fully explored.

Therefore, the aim of this study was to examine the effects of water intake, dehydration, food intake, exercise, and bladder voiding on acute BIA body composition and impedance measurements and if the effects are influenced by body mass index (BMI) categories.

Methods

Participants

Students and staff from York University were recruited via posters to participate in this study. Interested individuals were contacted through emails where the study objectives were further explained and questions about the visits answered. The inclusion criteria were:

(a) age 18–70 years, (b) able to speak/read English, and (c) screened through Physical Activity and Readiness Questionnaire for Everyone (PAR-Q+, www.eparmedx.com). Anthropometric data was obtained on height, body mass, waist, hip, ankle, bicep, wrist and waist diameter. Height and body mass were measured using a wall mounted measuring tape and digital scale respectively. Waist circumference was obtained on iliac crest of participants. Body Mass index (BMI) was deteremined using the following equation: body mass (kg)/height (meters)^2. Participants completed a questionnaire on age, sex, education, ethnicity, fluid and food intake, and current medications. One female was removed from all analyses as she had a large variability in body mass between the visits.

Written informed consent was obtained by all participants and ethics approval was obtained from the Human Participation Review Sub-Committee, York University's Ethic Review Board (certificate #: e2012-283).

Protocol

The three BIA devices used included the : (1) Tanita Body Composition Analyzer, Model: BC-418 (hand-to-feet), (2) Tanita, Model TBF-314 (foot-to-foot), and (3) Omron Fat Loss Monitor, Model: HBF-306CN (hand-to-hand). The two Tanita devices output total and regional body composition and impedance data while the Omron machine only outputs total percent fat mass

Visit 1:

At the first visit, participants were tested under three conditions (water trial, non-voided bladder trial and exercise trial) along with the control trial. Participants were instructed to drink 3L of water the day prior to testing to ensure proper hydration. In addition participants were instructed to (1) abstain from exercise on the day of the visit, (2) fast for 4–5 hours prior to their visit and (3) not void their bladder for at least 2 hours before the visit.

At the laboratory, participants were given 5 minutes to drink 1L of water and then shortly after underwent a BIA measurement (Water Intake Trial). After 30 minutes they had a BIA measurement with their bladder still unvoided (Non-voided Bladder (NVB) trial). Within 30–40 minutes of ingesting water, the volume of stomach contents usually return to the original state before the water intake [10]. Participants then voided their bladder on a urine reagent test strip (10 LG Parameter Urine Reagent Strips, Craig Medical Distribution, CA, USA) to test urine specific gravity [11]. The following reference values were used to determine hydration status: 1-1.010 indicates relative hydration, and a value of 1.020 or greater indicates relative dehydration [12]. Once the hydration levels were reached (1-1.010 on the urine reagent test strip), the BIA assessment was repeated (Control Trial).

Participants were then asked to run/speed walk on a treadmill at a moderate intensity (50–70% of age predicted HR_{max} using 220-age) for 15 minutes and then undergent BIA measurements again (Exercise Trial). Following the exercise for 15 minutes, the BIA measurement was repeated.

All the participants followed the same order of BIA measurements started with water trial, then non-voided bladder trial, control trial and then followed by exercise trial on Visit 1. The order was placed in order to keep the time between conditions consistent and limit any carry-over effect.

Visit 2:

Prior to coming to the laboratory for the second visit, particpants were asked to: (1) abstain from exercise on the day of the visit, (2) fast for 4–5 hours prior to their visit and (3) not void their bladder for 2 hours before the visit. In addition participants were instructed to not consume any fluid for 5–8 hours prior to the assessment. Upon arrival, participants voided their bladder on a urine reagent test strip to ensure that they were dehydrated prior to BIA assessment. Once the dehydration level was ensured, the BIA measurement was taken (Dehydrated trial).

Afterwards participants were given 30 minutes to consume a high fat meal ad libitum (325 g Dr. Oetker Ristorante Mozzarella Pizza (Kcal: 880, Fat: 44 g, CHO: 76 g, Protein: 36 g), Pringles Original (Per 16 chips, Kcal: 150, Fat: 9 g, CHO: 15 g, Protein: 1 g), and water. After confirming that participants had returned to adequate hydration status, we then measured BIA (Food Intake Trial).

Visit 3:

Participants underwent a Dual-energy X-ray Absorptiometry (DXA), total body composition assessment (bone mineral content, %FM, FFM) using a General Electric Lunar Prodigy (GE, USA).

Skinfold measurements were measured three times using caliper (Harpenden Skinfold Caliper, Model: CE 0120) at the triceps, biceps, subscapular, iliac crest and medial calf to estimate %FM. The %FM was calculated using Durnin JV and Womersley equation [13].

Statistical Analysis

Statistical analysis was performed using SAS verion 9.4 (SAS Institute Inc., Cary, N.C., USA), with a level statistical significance set at alpha ≤ 0.05. Means and standard deviation (M ± SD) were used to describe sample characteristics. A repeated measures ANOVA was used to compare %FM and impendance in each of the conditions (water intake, dehydrated, food intake, exercise, and non-bladder voiding) compared to the BIA control trial, and Sum of Skinfolds and DXA for each BIA machine stratified by sex. Post hoc analysis using tukey multiple comparison test was used to determine differences among BMI groups in their %FM and impedance variations amoungst trials.

The proportion of individuals with absolute differences in %FM of greater than day to day variation (< 2%, 2–5% or > 5%) between trials was examined for sex and BMI group differences by Chi-square tests with bonferroni adjustment. Because of the low numbers of participants with errors over 2% for many of the conditions, only sex differences were reported.

Lastly, we conducted the multiple regression analyses to identify the relationship between changes in impedance and body mass with %FM. The standardized estimates (expressed per standard deviation) were used to facilitate comparisons between the impedance and body mass beta estimates.

Results

The participant characteristics are shown in **Table 1** for men and women separately. The BMI ranged from 20.2 to 37.8 kg/m^2 for both men and women.

Influence of various factors on BIA measures of Percent Fat Mass

The %FM was assessed using three BIA devices (Tanita BC-418, Tanita TBF-314, and Omron HBF) under control, dehydrated, exercise, water and/or food intake, NVB conditions are shown in **Figure 1** for men and women separately. For all BIA devices, there were no mean differences in the %FM values between the control and any of the condition trials in either men (range of means: -1.2 to 0.3%) or women (range of means: -1.9 to 0.4%, p >0.05). Further, the differences in %FM between control and each condition trial was not significantly influenced by BMI class (BMI*trial, p=0.99).

Influence of various factors on BIA measures of Impedance

Impedance tested using two BIA devices (Tanita BC-418, and Tanita TBF -314) under various conditions (control, dehydrated, exercise, water and/or food intake, NVB) are shown in **Figure 2** for men and women separately. For both Tanita devices, there were no differences in the impedance values between the control and any of the condition trials (range: -26.6 to 3.1 Ω, p >0.05). Similar to %FM values, the differences in impedance between control and each condition trial was not significantly influenced by BMI (BMI*trial, p=0.99).

Further analyses were conducted to understand if changes observed in %FM between the condition and control trials were more strongly related to changes in impedance or body mass. In **Table 2,** the relationship between impedance and body mass with %FM in the control and condition trials are shown. The values of impedance and body mass for each condition are shown as the intra-individual difference between the control and the condition trial. During the control trial, total body impedance was more strongly related to %FM than body mass (standardized estimates; impedance, 5.13 to 8.48%, body mass, 4.89 to 5.59%). Similarly, we observed that the changes in total body impedance from the control trial were more strongly related with changes in %FM than changes in body mass for both Tanita BC-418 and TBF-314 **(Table 2)**. For example, one standard deviation change in impedance was associated with a 0.16 to 1.32% difference in FM while one standard deviation change in body mass was associated with a 0.22 to 0.79% difference in FM under various BIA conditions **(Table 2)**.

When examining individual level data, across the three devices and five conditions, 97% of participants had differences in %FM that were within the expected day-to-day variation (<5%) across all trials and BIA machines (one normal weight female participant when assessed using the Tanita BC-418 (5.8% lower %FM with dehydration) and one normal weight male participant when assessed using the Omron HBF (6.4% higher with water intake). Similarly, 86% of test conditions were within 2% of control.

Across the machines, bladder emptying and exercise having the least effect with over 95% of patients with differences of less than 2% while dehydration had the greatest variability with 68% of patients with less than 2% difference from control. Females were more likely to have an error of greater than 2% with dehydration than males when using the Tanita TBF-314 (**Figure 3**: 59% versus 9%; P<0.05). There were no differences by BMI category (P>0.05).

Discussion

Our findings suggest that acutely violating the preliminary measurement BIA assumptions does not significantly impact the derived %FM and impedance values. In general, women appear to have more variability in their BIA measures than men, particularly with dehydration using the hand-to-foot device. However, these minor differences in the measurements were similar among all participants regardless of their obesity status. The magnitude of the differences between trials are less than what is expected with day-to-day variation (< 5%).

The use of BIA devices to assess body composition is common in health and fitness facilities and research studies. Although the preliminary measurement BIA assumptions are well known, they are often not optimally followed in practice, particularly in the general public. It is recommended that BIA measurements be avoided when participants are dehydrated, within 4-h of food and beverage consumption, and within several hours of moderate-to-strenuous exercise [6] as these factors may influence the derived body composition assessment.

In terms of water and food intake, the literature is inconsistent on the magnitude and even direction of change (14–19). Similar to some studies [14, 15], we report non-statistically significant differences in %FM of ~ 1%. However, even in studies that report statistically significant differences with water and/or food intake, the magnitude of these differences are within ranges expected with day-to-day variation (generally < 2%) [16, 17][18]. Further, there were no consistent differences between studies that do or do not report significant differences in %FM in terms of diet composition, with high fat, high carbohydrate and ad libitum food intakes most commonly examined. The composition of the diet theoretically may influence body impedance and the rate of gastric emptying, however, one study reports that impedance values are similar immediately after consuming a meal and many hours later [19]. We extend these observations by demonstrating that impedance measures after food and water intake are not significantly different using either hand-to-hand, hand-to-foot or foot-to-foot BIA machines. Together, this suggests that food and/or water intake is unlikely to have a meaningful impact on impedance measured body fat assessment.

The non-voided bladder condition did not significantly change the impedance or %FM values when compared to the control trial. Although, the consumption of 1L of water did increase body mass it was not enough to statistically increase %FM. In this study, 1 kg difference in body mass is theoretically associated with a 0.68% higher FM which is in line with a previous study that suggests a non-voided bladder could affect BIA measurements by up to 1% [20]. Thus, non-voided bladder is likely to have minimal effects on %FM estimates.

There are several changes that occur with exercise such as changes in skin blood flow, temperature, heat production and fluid loss [19], that may increase or decrease impedance. The literature on the effects of exercise on estimated %FM and impedance is mixed with studies showing decreased impedance by 28–40 Ω [21], or no change in impedance following moderate intensity aerobic exercise [21–23] as observed in this study. In the literature, the largest differences observed are less than 1% FM even with exercise intensity of 60 to 83% HR_{max} for as long as 45 minutes. These minimal differences suggest that moderate intensity exercise is unlikely be associated with large differences in predicted %FM.

For dehydration, theoretically one would expect low fluid status would result in an increase in impedance and thus increase in predicted %FM. In this study, impedance was not significantly increased in the dehydrated condition, and in fact trended in the opposite direction (Women: -23.2%; Men: -9.8%) and %FM (Women: -1.9%; Men: 1.2%). The lower %FM is likely due to the reduction of average body mass of -0.74 kg among participants. A study conducted by Thompson et al 1991 also report a significant decrease in %FM in the dehydrated state after exercising for 30 minutes and sitting in a steam room when compared with control, though the exact %FM difference was not reported [24]. However, that study had a much larger decrease in body mass (average of 2.81%) than was observed in our study (< 1%). Further, we report that the differences in BIA measured %FM may be large in women than men. Reasons for this are unclear but may be due to differences in %FM and fat distribution. That said, it is important to consider that we did not observe differences by BMI category. Despite our large range in BMI (20.2 to 37.8 kg/m^2) the difference in %FM that resulted by violating the preliminary BIA assumptions are similar among all participants regardless of their BMI categories. Thus, future work may consider the potential sex differences in how these factors, and in particular dehydration may influence body composition assessment. Nevertheless, it is important to remember that the vast majority of values observed in this study were within 5% of control. Further, the < 2% differences we observe in this study is far lower than the 15 to 19.5% reduction in FM that are reported in exercise intervention even with minimal weight loss [25].

Further, these measures were generally comparable to DXA and SOS assessments. The exception was the Omron HBF (hand-to-hand model) in women where the %FM values were significantly lower than DXA and SOS. This reinforces the notion that %FM obtained cannot be directly compared between the various devices, but also suggests that the acute violation of the core BIA assumptions may not have a large influence on the %FM obtained regardless of the measurement site used. Further, these variations in %FM are far smaller than what one would expect with clinical weight loss interventions [26].

Some strengths and limitations of this study are worth mentioning. We are one of the few studies to examine the effect of violating the core BIA assumptions on the estimation of body composition among multiple BIA devices. In the current study, three BIA devices with different measurement sites were used. Although there are several different devices available on the market, they all use measures of impedance and body weight to assess body composition. That we also observe no differences in impedance suggest that these observations likely hold true for other BIA devices using different algorithms. However, we are unsure if the differences in body composition would be larger if more than one core BIA assumption was violated at the same time. We are also unsure if our results extend to older individuals or populations with chronic conditions. Finally, we have a relatively small sample of 40 adults, and retrospective power analyses suggest that 182 participants are needed for the largest difference (-1.9%FM) to be significant. Nevertheless, the clinical relevance of these differences of this magnitude even if significant are questionable as they are comparable to be what would be expected with the 2 to 5% day-to-day variation (18,33).

It can be concluded that preliminary measurement BIA assumptions have a very small effect (< 2%) on the derived %FM and impedance values. Women tend to have larger variability in %FM measures than men. Nevertheless, these differences associated with acutely violating the core BIA assumptions are far smaller than what would be expected with weight loss interventions and is within what is expected with day-to-day variation.

Declarations

Ethics approval and consent to participate

Written informed consent was obtained by all participants and ethics approval was obtained from the Human Participation Review Sub-Committee, York University's Ethic Review Board (certificate #: e2012-283).

Consent for publication – Not applicable

Competing interests – None declared

Availability of data and materials - The datasets during and/or analysed during the current study available from the corresponding author on reasonable request.

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Authors' contributions -

AKR analyzed, interpreted the data and wrote the manuscript. MDTF and ASF collected and helped in analyzing the data. VJ and JLK were major contributors in providing feedback, data interpretation and writing the manuscript. All authors read and approved the final manuscript.

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Tables

Table 1. Sample Characteristics by Sex

	Men	Women
Total Sample	n=23	n=17
Age (years)	24.0 ± 5.2	22.5 ± 3.4
BMI (kg/m^2)	25.9 ± 3.5	22.8 ± 2.8*
BIA Body Fat (%)		
BC-418	19.7 ± 6.6	29.4 ± 6.9*
TBF-314	20.0 ± 6.8	27.1 ± 6.4*
Omron HBF	17.9 ± 6.7	24.4 ± 5.8*
DXA Body Fat (%)	20.7 ± 9.0	30.2 ± 8.5*
Skinfolds Body Fat (%)	19.1 ± 5.5	29.1 ± 5.4*
Waist Circumference (cm)	79.7 ± 15.5	76.2 ± 6.3
BIA Impedance (Ω)		
BC-418	560.2 ± 65.6	728.0 ± 88.8*
TBF-314	479.5 ± 52.7	581.3 ± 68.9*

All the continuous values are presented as means ± SD and categorical values as prevalence %.

BMI = body mass index, * = significantly different from men (p<0.05)

Table 2. Change in %FM with changes in impedance and body mass after violating the preliminary measurement BIA assumptions

Baseline	BIA	Total Body Impedance			Body Mass (BM)		
		Partial R	Parameter Estimate (%FM/Ω)	Standardized Estimate (%FM/SD)	Partial R	Parameter Estimate (%FM/kg)	Standardized Estimate (%FM/SD)
Control trial	BC-418	0.83	1.03	8.48%	0.70	0.68	5.59%
	TBF-314	0.59	0.69	5.13%	0.57	0.66	4.89%
Trial	**BIA**	**Change in %FM with Impedance**			**Change in %FM with BM**		
		Partial R	Parameter Estimate (%FM/Ω)	Standardized Estimate (%FM/SD)	Partial R	Parameter Estimate (%FM/kg)	Standardized Estimate (%FM/SD)
Water intake	BC-418	0.82	0.75	0.79	0.85	0.23	0.24
	TBF-314	0.81	0.53	0.34	0.85	0.62	0.40
Voided Bladder	BC-418	0.95	0.75	0.52	0.85	0.38	0.27
	TBF-314	0.75	0.54	0.16	0.83	0.72	0.22
Exercise	BC-418	0.85	0.80	0.55	0.55	0.32	0.22
	TBF-314	0.80	0.72	0.34	0.69	0.50	0.24
Dehydration	BC-418	0.92	0.90	1.31	0.81	0.54	0.79
	TBF-314	0.93	0.90	1.18	0.84	0.54	0.71
Food intake	BC-418	0.94	0.94	1.32	0.73	0.35	0.49
	TBF-314	0.92	0.94	1.13	0.66	0.35	0.42

Standardized estimates are expressed as %change in fat mass per one standard deviation change in impedance or body mass. The values of impedance and body weight for each condition were shown as the intra-individual difference between the control and the condition trial.

Figures

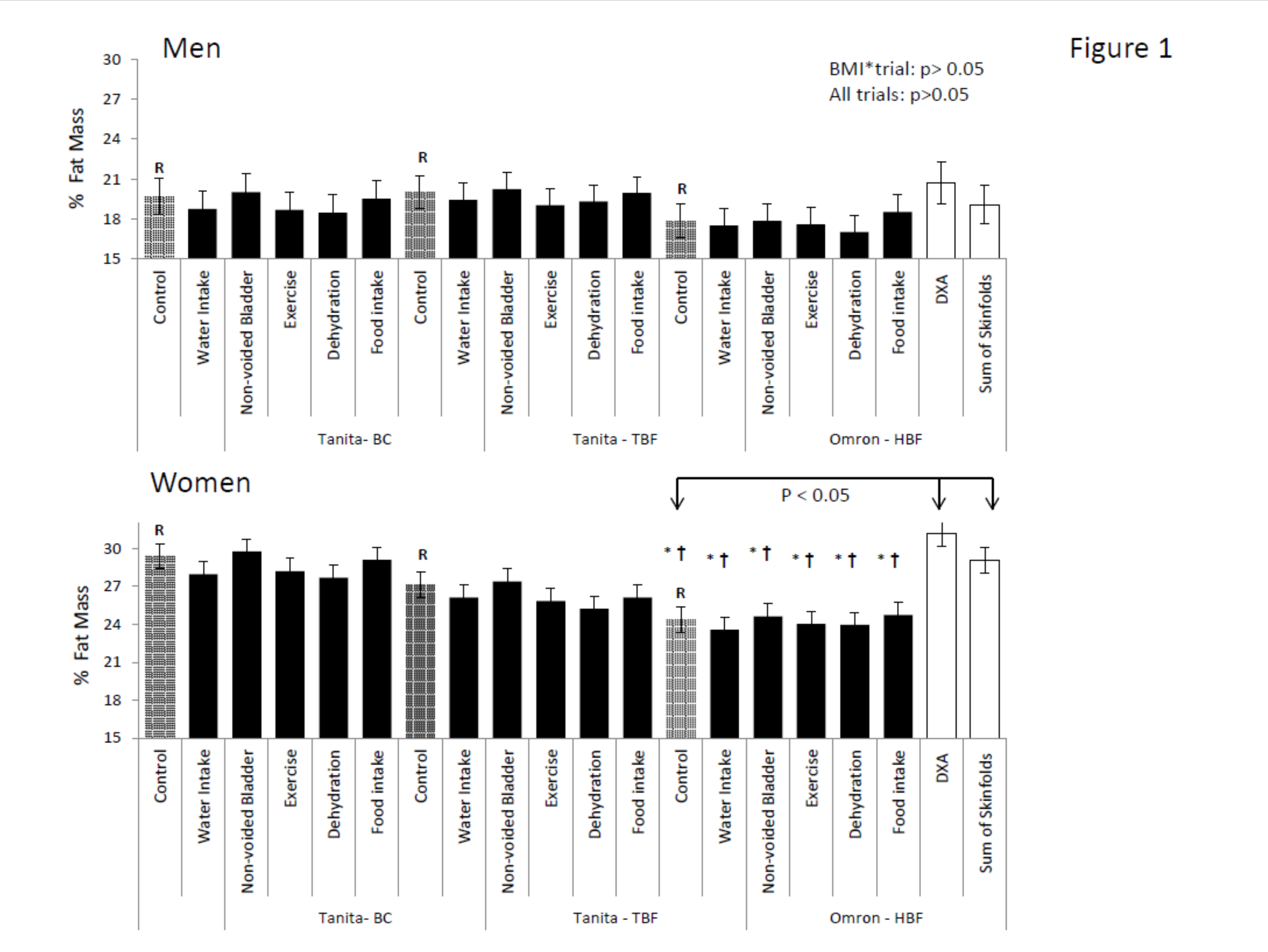

Figure 1

The average percent fat mass for each trial per BIA machine for men (n=23) and women (n=17). There were no differences between trials for each BIA machine for percent fat mass (p >0.05). * = Significantly different from DXA and †= significantly different from sum of skinfolds.

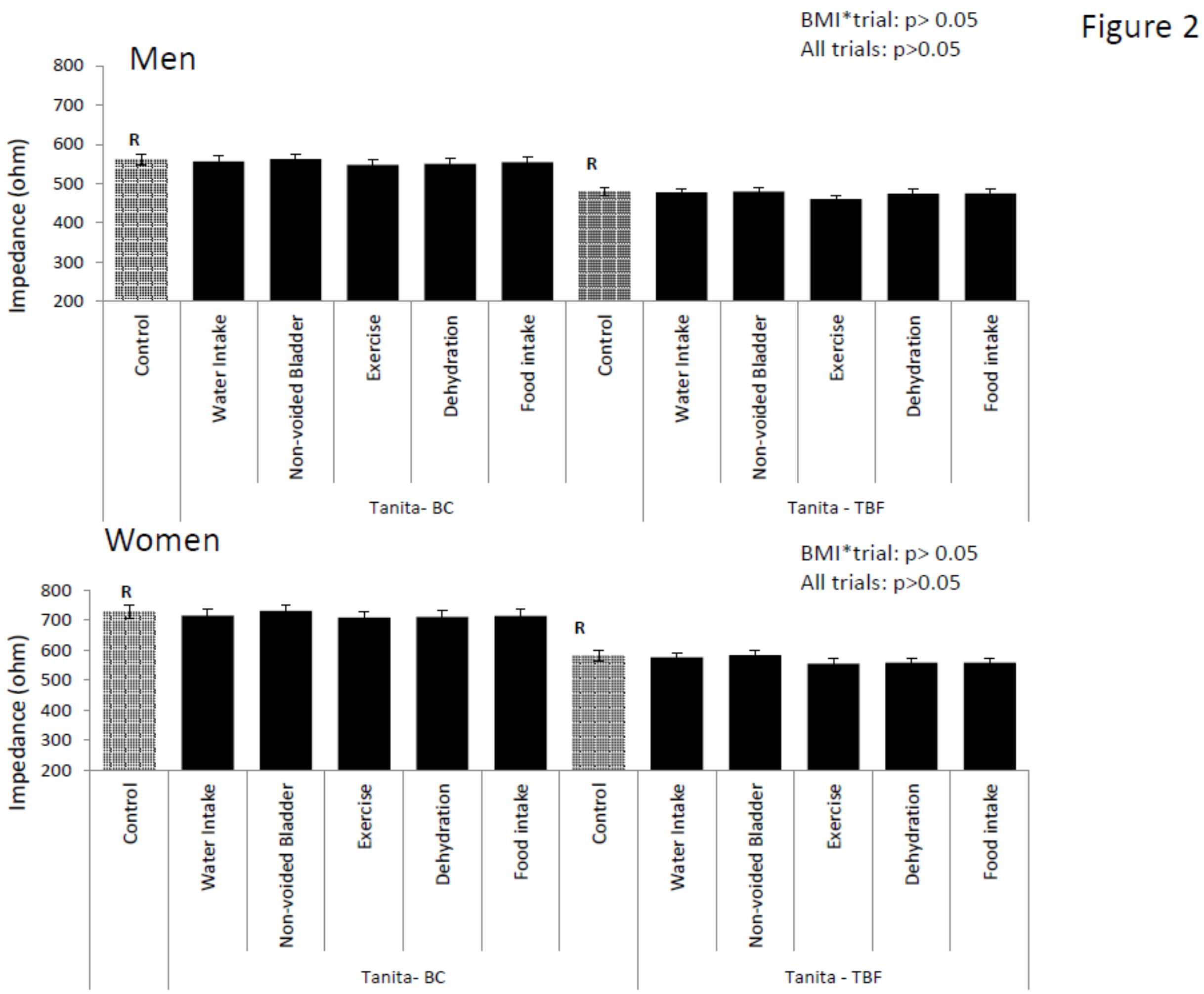

Figure 2

The average bioelectrical impedance for each condition per BIA Tanita machine for men (n=23) and women (n=17). There were no differences between conditions for each BIA machine for impedance from the reference group ($p > 0.05$).

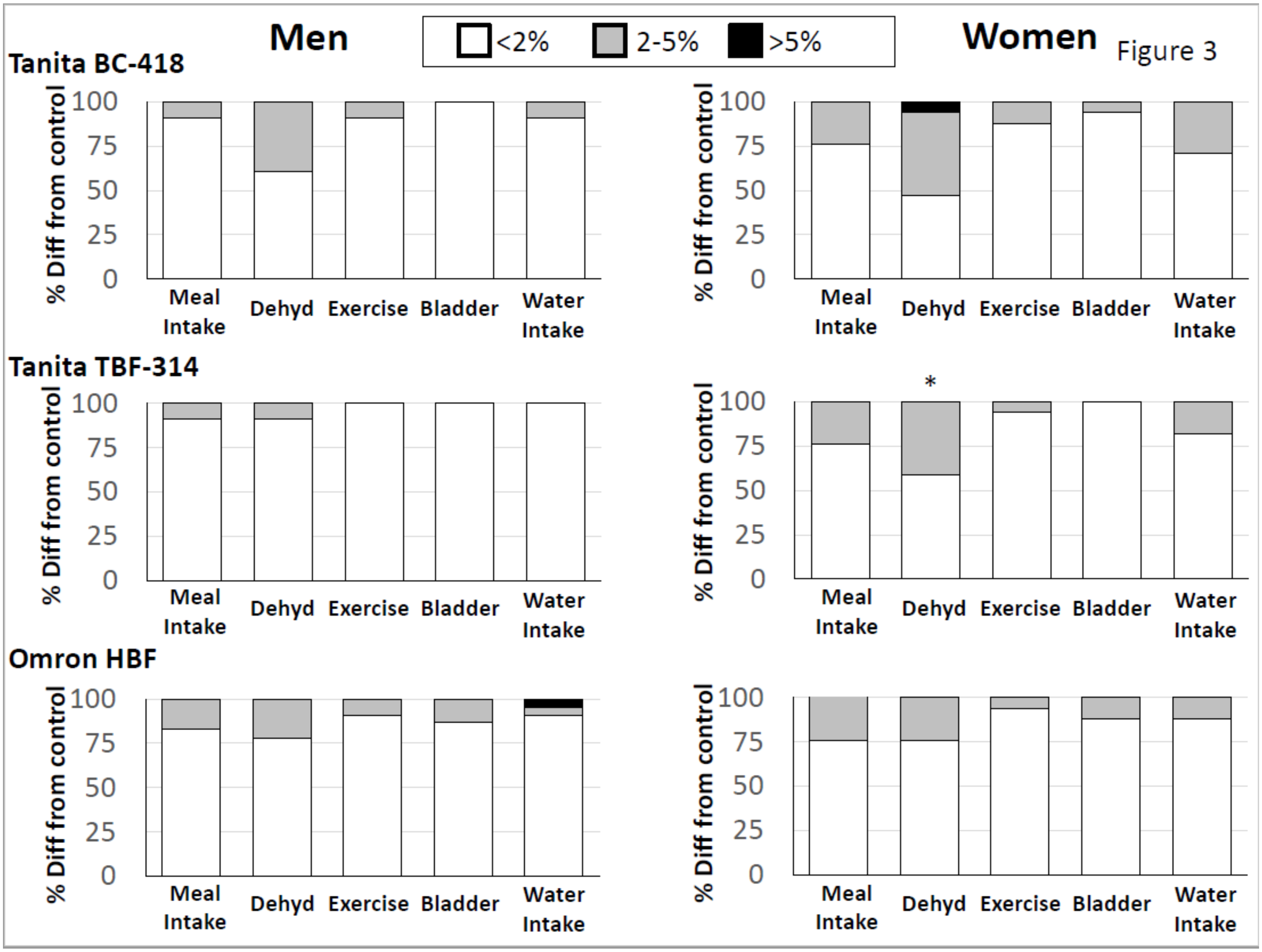

Figure 3

Prevalence of error rates by trial condition, sex and BIA device *Sex difference in the prevalence of error <2% within that device