

Bioelectrical impedance: effect of 3 identical meals on diurnal impedance variation and calculation of body composition^{1,2}

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ABSTRACT

Background: Bioelectrical impedance analysis (BIA) can be used for estimating body composition. Earlier studies showed that the ingestion of meals lowers bioelectrical impedance, but none studied the effect of repeated ingestion of an identical meal in narrow intervals on impedance measurements during 24 h.

Objectives: The objectives were to study the effect on bioelectrical impedance of 3 identical meals and to compare the results from single-frequency BIA measurements with those from multiple-frequency BIA measurements.

Design: Bioelectrical impedance was measured 18 times during 24 h in 18 healthy subjects [10 women and 8 men; $\bar{x} \pm$ SD age: 31.5 ± 11.7 y; body mass index (in kg/m^2): 22.2 ± 2.7]. An identical meal was given at breakfast, lunch, and dinner.

Results: Bioelectrical impedance decreased after ingestion of a standard meal ($P < 0.05$). The decrease in impedance lasted 2–4 h after each meal. The decrease was additive during the day, although it was more pronounced after the first meal because of the combined effect of rising from the supine position and meal ingestion. This is an important consideration when calculating body composition: percentage of body fat varied by 8.8% from the highest to the lowest measurement in women and by 9.9% from the highest to the lowest measurement in men. The bioelectrical impedance at 50 kHz was identical when measured with multiple frequencies or a single frequency.

Conclusion: The ingestion of meals leads to an additive decrease in bioelectrical impedance and thus to a decrease in the calculated percentage of body fat. *Am J Clin Nutr* 2001;74:474–8.

KEY WORDS Multiple-frequency bioelectrical impedance analysis, single-frequency bioelectrical impedance analysis, diurnal variation, body composition, meal ingestion

INTRODUCTION

The term bioelectrical impedance (BI) was introduced ≈ 50 y ago. Thomasset (1) was the first to report a relation between total body water and electrical impedance. The use of BI to estimate body composition is based on the different conductive and dielectric properties of various biological tissues at various frequencies of current.

Single-frequency bioelectrical impedance analysis (sfBIA) uses a frequency of 50 kHz to measure impedance and calculate body composition. Multiple-frequency BIA (mfBIA) instruments were

developed because the frequency necessary to detect the distribution between extracellular water (ECW) and intracellular water (ICW) is probably >50 kHz (2). During the past 10 y, numerous validation studies have been published concerning estimation of body composition with use of mfBIA (2–7). van Marken Lichtenbelt et al (3) showed that results from mfBIA and sfBIA were comparable in their study of 29 adults and that mfBIA appears to provide acceptable values for total body water and extracellular water compared with deuterium and bromide dilution.

BIA is an easily applied method of determining body composition. It is necessary, however, to measure BI under standardized conditions, and the method is sensitive to several physiologic factors. For example, body temperature is important when measuring BI (8–10). Additionally, for female subjects the variation in body fluids during the menstrual cycle affects BI (11). These physiologic factors are important to consider when comparing results between different studies in which BIA was used for body composition assessment or when the aim is to do repeated measurements over time, eg, in patient follow-up.

Several studies showed that the ingestion of a meal decreases BI (11–14). It is, however, natural to consume another meal within 4 h. The effect of several meals on BI, with frequent multiple measurements of impedance, has not been previously studied. A well-known limitation on the accuracy of BI for calculating body composition is the selection of appropriate prediction equations. However, a meal effect will influence calculated body composition regardless of the choice of equation. The purpose of this study was therefore to study the effect on BI of 3 identical meals and to compare the results from sfBIA with those from mfBIA.

SUBJECTS AND METHODS

Eighteen apparently healthy male and female university students and co-workers volunteered to participate in this study. Informed consent was given. The study was performed in accord with the Helsinki Declaration of 1975 as revised in 1983. The women were

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Received November 6, 2000.

Accepted for publication February 5, 2001.

TABLE 1
The nutritional composition of the test meal¹

Nutritional component	Content per meal
Energy (kJ)	2731 ± 324 (2338–3394)
Fat (% of energy)	34 ± 1 (33–35)
Protein (% of energy)	17 ± 0 (16–17)
Carbohydrate (% of energy)	49 ± 1 (47–51)
Calcium (mg)	155 ± 15 (134–184)
Iron (mg)	4.4 ± 0.5 (4.0–5.3)
Magnesium (mg)	117 ± 13 (99–143)
Sodium (mg)	771 ± 88 (677–955)
Potassium (mg)	1414 ± 170 (1190–1750)
Zinc (mg)	6.1 ± 0.7 (5.5–7.6)
Total fluid (mL)	618 ± 0

¹ $\bar{x} \pm SD$; range in parentheses. $n = 18$.

between day 9 and day 16 of their menstrual cycles. At the 0700 study start the subjects were in a fasting state and were dressed in light clothing. They rested or slept in the supine position for 1 h before the first BI measurement was done. The subjects then remained in a supine position, and impedance measurements were performed every 15 min for an additional 1 h. All the BI measurements were performed with both single- and multiple-frequency instruments at 18 time points during the 24 h studied.

The subjects rose from the supine position and were served a meal at 0915. The meal consisted of a cheeseburger with tomato, orange juice, coffee or tea, and a banana. The energy content in the meal was 27% of the individual predicted total daily energy requirement, and the amount of fluid given was 618 mL for all the subjects. Impedance was measured 30 min after the first meal was completed. The subjects then started their working day at the university. Subjects were served an identical meal at 1230 and at 1730.

Impedance measurements

A BIA-101 (Akern, Florence, Italy) was used for measuring sfBIA. For measuring mfBIA, the UniQuest-SEAC SFB-3 instrument (UniQuest Limited, Brisbane, Australia) was used. Both instruments were used according to the manufacturers' instructions. The electrodes were positioned at the middle of the dorsal surfaces of the hands and feet, respectively, proximally to the metacarpal-phalangeal and metatarsal-phalangeal joints and medially between the distal prominence of the radius and the ulna and between the medial and lateral malleoli at the ankle. Each additional BI measurement was taken after the subject had been in a supine position for 10 min. Manufacturer-supplied equations were used for calculating body composition from sfBIA. For calculating body composition from mfBIA, we used the manufacturer-supplied equation of Hannan et al (15).

Anthropometric measurements

Height was measured to the nearest 0.5 cm before the study started, and weight was measured to the nearest 0.1 kg within 5 min after every impedance measurement.

Statistical methods

All values are presented as means and SDs. Dunnett's *t* test was used to compare the impedance, ECW, and ICW between baseline and each consecutive measurement. Statistical calcula-

tions were performed by using the SPSS for WINDOWS (version 10.0; SPSS Inc, Chicago) software program.

RESULTS

Ten women and 8 men participated in this study. The subjects' mean age was 31.5 ± 11.7 y; their mean weight and height were 68.3 ± 7.7 kg and 1.76 ± 0.1 m, respectively; and their mean body mass index (in kg/m²) was 22.2 ± 2.7 . The nutritional composition of the test meal is presented in **Table 1**.

Impedance

The impedance at 50 kHz measured with mfBIA was identical to that measured with sfBIA. Women had a higher baseline impedance than did men (women, $602 \pm 51 \Omega$; men, $513 \pm 40 \Omega$). The diurnal variation in BI is shown in **Figure 1**. The postprandial decrease in BI lasted 2–4 h after the meals, with an apparent additive effect during the day. The decrease in impedance after the first meal was double the decrease after meals 2 and 3. Impedance returned to baseline values after one night of fasting. For single-frequency impedance, all measurements, except measurements 2, 3, 6, and 18, were significantly different from baseline ($P < 0.05$). The subject with the largest decrease in BI had a decrease of 11%, from 629 Ω at baseline to 557 Ω at measurement no. 17.

Body composition

Measuring BI in the fasting state after 1 h of resting or sleeping (BIA measurement no. 1) gave a calculated body fat percentage from sfBIA of $26.5 \pm 6.3\%$ for the women and $16.2 \pm 2.8\%$ for the men. With subjects remaining in a supine position, the calculated fat percentage increased to $27.1 \pm 6.6\%$ for the women and $17.2 \pm 3.1\%$ for the men (BIA measurement no. 5). The lowest calculated percentage of body fat was observed at BIA measurement no. 17 (195 min after dinner) for the women and at BIA measurement no. 11 (125 min after lunch) for the men. The lowest calculated mean body fat percentage was $24.8 \pm 5.6\%$ for the women and $15.5 \pm 3.3\%$ for the men. The difference between the highest and lowest calculated body fat percentage was 8.5% for the women and 9.9% for the men (2.3 and 1.7 percentage points, respectively). The subject with the largest decrease in percentage of body fat had a decrease of 13%, from 29.7% body fat at baseline to 25.9% body fat at measurement no. 17.

After the subjects rested or slept for 1 h (BIA measurement no. 1), the calculated body fat percentage calculated from mfBIA was $23.6 \pm 6.8\%$ for the women and $16.1 \pm 3.8\%$ for the men. With subjects remaining in a supine position, the fat percentage increased to $24.0 \pm 7.0\%$ for the women and $17.5 \pm 4.1\%$ for the men (BIA measurement no. 5). The lowest calculated body fat percentage was observed at BIA measurement no. 17 (195 min after dinner) for the women and at BIA measurement no. 11 (125 min after lunch) for the men. The lowest calculated mean body fat percentage was $21.7 \pm 7.0\%$ for the women and $14.9 \pm 4.6\%$ for the men. The difference between the highest and lowest calculated body fat percentage was 9.7% for the women and 7.5% for the men (2.3 and 1.2 percentage points, respectively). The subject with the largest decrease in percentage of body fat had a decrease of 23%, from 17.9% body fat at baseline to 13.7% body fat at measurement no. 17. After another night of fasting the calculated body fat percentages returned to baseline values.

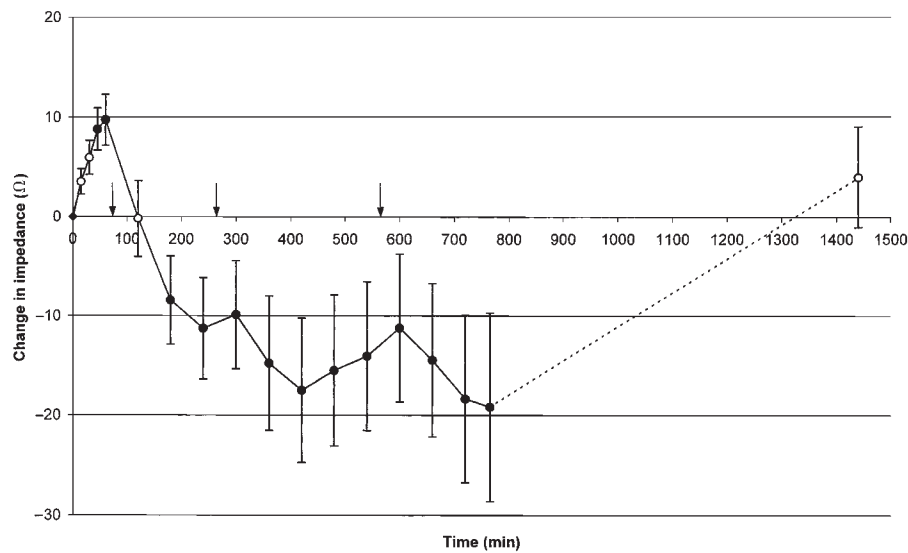


FIGURE 1. Mean changes (and 95% CI) from a baseline value of 563 Ω in single-frequency impedance during 24 h ($n = 18$). Arrows indicate time of meals. ●, significantly different from baseline ($P < 0.05$); ○, NS from baseline.

ECW and ICW calculated from mFBIA are shown in **Figures 2** and **3**.

DISCUSSION

Ingestion of a meal consistently led to a decrease in measured impedance in this study. Impedance decreased consistently for 2 h after the first meal and for 4 h after the second and third meals and then began to increase. The decrease in impedance after the first meal was double the decrease after meals 2 and 3. This was probably due to a combined effect of rising from a lying position and ingesting food and beverages after the first meal. A decrease in impedance produced by ingestion of one

meal was also shown by others (11–14). Deurenberg et al (11) reported that BI decreased by 13–17 Ω 2–4 h after intake of a liquid meal of 1941 kJ in 12 adult men. They also showed that BI decreased significantly by $4 \pm 4 \Omega$ after intake of beef tea but did not significantly decrease ($21 \pm 6 \Omega$) after intake of normal tea, suggesting that the observed effect was due to the intake of electrolytes. Gallagher et al (12) studied 11 males and 18 females and reported that intake of a solid meal (2301 kJ) led to a significant decrease in BI up to 4 h after the meal followed by an increase up to 5 h after the meal regardless of fat content. The authors of both studies concluded that the decrease in BI was probably related to changes in the fluid and electrolyte distribution that follow absorption and digestion of a meal. Rodriguez

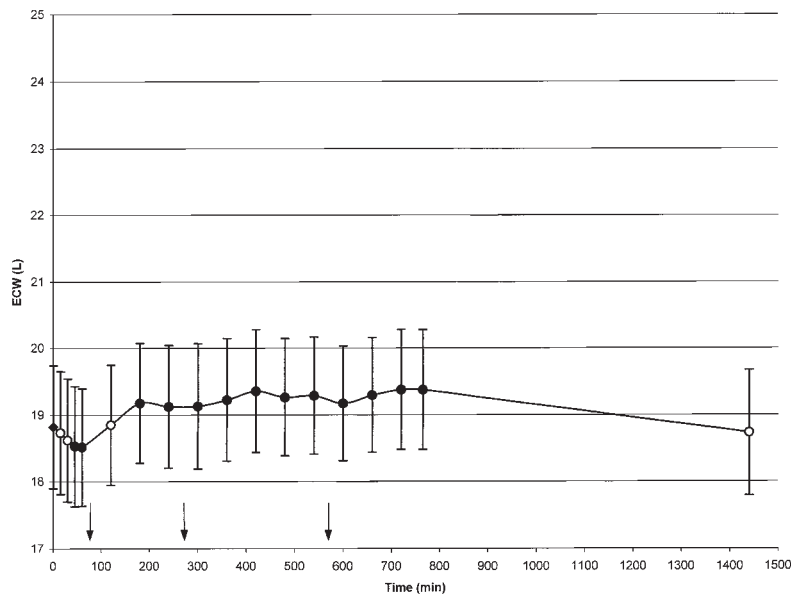


FIGURE 2. Mean extracellular water (ECW) (and 95% CI) calculated from multiple-frequency impedance measurements during 24 h ($n = 18$). Arrows indicate time of meals. ●, significantly different from baseline ($P < 0.05$); ○, NS from baseline.

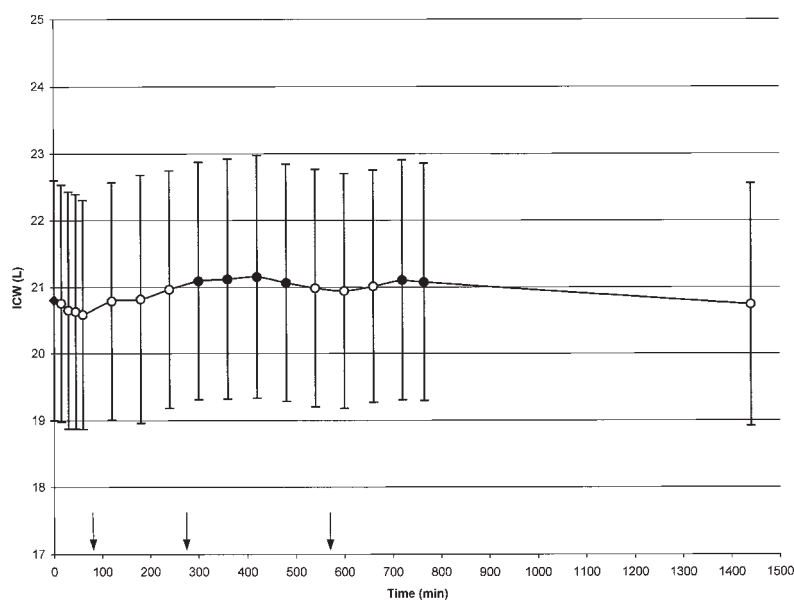


FIGURE 3. Mean intracellular water (ICW) (and 95% CI) calculated from multiple-frequency impedance measurements during 24 h ($n = 18$). Arrows indicate time of meals. ●, significantly different from baseline ($P < 0.05$); ○, NS from baseline.

et al (14) also found a decrease in impedance after food intake in children.

In a study of 12 males, Fogelholm et al (13) showed that resistance decreased significantly ($4\text{--}6 \Omega$) 2–4 h after a meal with a high concentration of electrolytes. Resistance also decreased after a meal low in electrolytes ($2\text{--}3 \Omega$); however, this decrease was not statistically significant. Resistance tended to return to baseline values after 7 h, which was confirmed by Gallagher et al (12). The meals used in the present study had the same electrolyte concentrations as those in the high-electrolyte meal used by Fogelholm et al (13), except for a lower sodium concentration in the present study.


Because food and beverage intake was identical for the 3 meals in this study, we conclude that the postprandial decrease in impedance was additive, such that the introduction of another meal led to a further decrease in impedance. Thus, we would expect that a subject's BI measured in the evening after normal meal consumption throughout the day would be lower than that subject's BI measured in a fasting state. Time of BI measurement, especially with respect to meals, must be considered in study design and interstudy comparisons.

Rodriguez et al (14) suggest that the decrease in impedance may be consistent with a redistribution of extracellular fluids. The results from the mfBIA (Figures 2 and 3) show that ECW increased immediately after a meal as a result of fluid intake but that ICW was relatively stable during the whole study period. The most marked decrease in impedance was noted after the first meal. This decrease may have been a combined effect of electrolyte intake and redistribution of extracellular fluids, an effect of changing from a supine body position to an ambulatory one. The decrease found after the 2 later meals must have been a result of the meals, because there was no change in body position (ie, all subjects were ambulatory). Because impedance increased 3–4 h after all 3 meals, we conclude that the decrease in postprandial impedance was a direct effect of the ingestion of

a meal and was not due to redistribution of the body fluids caused by change in body position.

The BI in the female subjects was higher than that in the male subjects. This difference represents the women's increased resistance due to a lower amount of body water. This result was also found by others (4, 5, 11). The additive, postprandial decrease in impedance was consistent in both sexes.

The difference in calculated body fat percentages between multiple- and single-frequency BI in the female group was due to the different equations used for calculating body composition. There were no obvious differences between the 2 methods in the male group, possibly because men have less body fat than do women and there is therefore a lower possibility of detecting differences. Thus, the choice of equation can influence the results in studies using BIA.

This study showed that measurements of BI must be done in the fasting state. Ingestion of a meal leads to a decrease in BI, and after several meals there is an additive decrease. Thus, the percentage of body fat calculated with use of prediction equations is also decreased. 

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