Changes of bioelectrical impedance after a body weight reduction program in highly obese subjects

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ABSTRACT. **We used bioelectrical impedance analysis (BIA) as an exploratory tool to monitor the changes in body composition induced by a short-term (3-wk) weight reduction (energy-restricted diet, moderate aerobic exercise conditioning and psychological counselling) in 175 highly obese subjects (body mass index, BMI=41.7±5.8 kg/m^2). The decrease in weight and BMI after the weight reduction program was 3.4% (geometric mean, $p<0.0001$) and 3.7±1.3 kg/m^2 (mean±SD, $p<0.0001$), respectively. Bioelectrical impedance (Z) increased of about the same value at each of the measured frequencies (from 6±10% at 5 kHz to 5±9% at 100 kHz, mean±SD, $p<0.0001$). A statistically significant increase in Z_5:Z_{100} was also seen ($p<0.0001$), but its clinical significance is questionable owing to its low absolute value (<1%). Taken together, these data suggest that no clinically relevant change in body water distribution occurred in our subjects as a result of the weight reduction program. However, the changes in Z did not satisfactorily predict the changes in anthropometric dimensions despite the evidence of a substantial association between Z and anthropometry both before and after the weight reduction program. Thus, accurate predictions of body composition changes in obese subjects may require more than two BIA measurements so as to have a better description of the weight-losing process.**
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INTRODUCTION

Assessment of body composition is important in obese subjects undergoing weight (Wt) loss. Ideally, Wt-losing programs should be targeted at reducing fat mass (FM) while preserving fat-free mass (FFM) (1). Addition of exercise to diet preserves FFM to a greater extent than diet alone and helps maintain Wt loss (2).

Although bioelectrical impedance analysis (BIA) offers accurate estimates of total body water (TBW), extracellular water (ECW) and FFM in obese subjects (3-5), it is controversial whether BIA is accurate enough to be employed for monitoring body composition changes in obese subjects (6). There is nonetheless some potential for impedance (Z) measurements to be employed as indexes of body water distribution (BWD). In fact, at low frequencies (≤5 kHz), an alternating electrical current cannot cross cell membranes and Z acts as an index of ECW. At higher frequencies (≥100 kHz), however, the current enters the cells and Z behaves as an index of TBW. Accordingly, the ratio between Z at low and high frequencies has been proposed as an indicator of BWD (6, 7).

One of the services provided by our Institute is a short-term (3-wk) integrated Wt reduction program (energy-restricted diet, moderate aerobic exercise conditioning and psychological counselling) for highly obese subjects. Owing to the scarcity of BIA data on subjects with this degree of obesity and preliminary to the direct measurement of BWD changes with dilution techniques, we evaluated the modifications of Z induced by this program and their relationship with anthropometric changes in a large sample of obese subjects of both sexes.

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SUBJECTS AND METHODS

Subjects

After giving informed consent, 175 obese subjects were consecutively enrolled into the study at the 3rd Division of Metabolic Diseases of the Italian Institute for Auxology (Piancavallo, Italy). With α set to 0.0005, the employed sample size ensured a power of 0.97 to detect a significant variation in Z at 50 kHz after the Wt reduction program. Obesity was diagnosed on the basis of a body mass index (BMI)≥30 kg/m^2 (8). Subjects with diabetes or major organ disease (heart, lung, liver and kidney) were excluded from the study. Anthropometric and Z measurements, as described below, were performed before and after 3 wk of the Wt reduction program.

Weight reduction program

During the study period, the subjects consumed a 5 to 7.5 MJ diet with 21% energy from proteins, 53% from carbohydrates and 26% from lipids (7% saturated, 18% monounsaturated and 4% polyunsaturated). For 5 d/wk, the subjects performed aerobic physical activity according to the following scheme: 1) 1-hr dynamic exercise performed with both arms and legs at moderate intensity under the guide of a therapist; and 2) 30 min of cycloergometer exercise at 60 W intensity or, alternatively, 4-km outdoor leisure walking on flat. The subjects underwent also a psychological counselling program consisting of 2-3 sessions/wk of individual and/or group psychotherapy performed by clinical psychologists.

Anthropometry

Wt, height (Ht), and waist (WC) and hip circumference (HC) were measured following the Anthropometric Standardization Reference Manual (9). BMI was calculated as Wt (kg)/Ht^2 (m) and waist:hip ratio (WHR) as WC (cm)/HC (cm).

BIA

Total-body Z was measured at frequencies of 1, 5, 10, 50 and 100 kHz using a tetrapolar plethysmograph (Human-IM Scan, DS-MediGroup, Milano, Italy), according to standardized procedures (6).

Statistical analysis

Statistical analysis was performed on a MacOS computer using the Statview 5.0.1 and SuperANOVA 1.1 software packages (SAS Institute, Cary, NC, U.S.A.). All measured variables were normally distributed. Absolute and percent Wt loss (the difference between final and initial Wt in kg and percent units) was log-transformed to reach the normal distribution. Comparison of anthropometric and bioelectrical characteristics before and after the Wt reduction program was performed by paired t tests. The effect of sex on these differences was determined by using unpaired t tests. A general linear model (GLM) was used to determine the variance contributed to Z by anthropometric dimensions before and after the Wt reduction program. An interaction term consisting of sex and the anthropometric predictor (X*sex) was added to the GLM to control for the confounding effect of sex. A similar procedure was used to test the contribution of anthropometric changes to Z changes. Statistical significance was set to a value of $p<0.05$ for all tests. Values are given as mean±SD unless specified otherwise.

Table 1 - *Anthropometric and bioelectrical characteristics of obese subjects before and after the weight reduction program. A dash (-) denotes unchanged values.*

	Before	After
N	175	-
Sex (F:M, %)	76/23	-
Age (yr)	52±14	-
Wt (kg)	108±18	105±17*
Ht (m)	1.6±0.1	-
BMI (kg/m^2)	41.7±5.8	40.2±5.7*
BMI class (I/II/III, %)	9/36/56	16/41/43
WC (cm)	118±14	112±13*
HC (cm)	129±12	123±12*
WHR	0.92±0.01	0.91±0.01
Z_1 (Ω)	513±67	542±71*
Z_5 (Ω)	495±66	524±69*
Z_{10} (Ω)	485±66	511±68*
Z_{50} (Ω)	438±59	462±61*
Z_{100} (Ω)	416±55	437±58*
Z_5:Z_{100}	1.19±0.03	1.20±0.04*

*$p<0.0001$ *vs* before. Wt: weight; Ht: height; BMI: body mass index; WC: waist circumference; HC: hip circumference; WHR: waist:hip ratio; Z_x: impedance at frequency x.

Table 2 - *Variance of body impedance explained by anthropometric variables before the weight reduction program. A minus (-) sign before the (adjusted) R^2 value denotes an inverse correlation.*

	Z_1	Z_5	Z_{10}	Z_{50}	Z_{100}	Z_5:Z_{100}
Age	-0.04**	-0.05*	-0.05*	-0.02*	NS	-0.30*******
Wt	-0.29******	-0.30******	-0.30******	-0.32******	-0.32******	NS
Ht	-0.03*	-0.03*	-0.03*	-0.05***	-0.06***	0.09******
BMI	-0.24******	-0.26******	-0.25******	-0.23******	-0.22******	NS
WC	-0.21******	-0.23******	-0.23******	-0.22******	-0.21******	NS
HC	-0.12******	-0.12******	-0.11******	-0.09******	-0.09******	-0.02*
WHR	-0.04*	-0.05***	-0.05***	-0.06****	-0.07*****	NS

*p<0.05, **p<0.01, ***p<0.005, ****p<0.001, *****p<0.0005, ******p<0.0001. Z_x: impedance at frequency x; Wt: weight; Ht: height; BMI: body mass index; WC: waist circumference; HC: hip circumference; WHR: waist:hip ratio. The interaction of all covariates with sex was not significant.

RESULTS

The anthropometric and bioelectrical characteristics of the subjects before and after the Wt reduction program are given in Table 1.

The enrolled subjects were mainly female (F:M ratio=3.3) so that the (possibly) confounding effect of sex was taken into account in further statistical analyses. As expected, the majority of subjects had class III obesity (56% *vs* 36% class II and only 9% class I).

On the pooled sample, the decrease in Wt and BMI after the Wt reduction program was 3.4% (geometric mean, p<0.0001) and 3.7±1.3 kg/m^2 (mean±SD, p<0.0001), respectively. Due to a similar absolute decrease in WC and HC (-5±6 cm and -6±6 cm respectively, mean±SD, p<0.0001 for both), WHR did not change (p=NS). A similar absolute and percent increase of Z was observed at all the employed frequencies (from 6±10% at 5 kHz to 5±9% at 100 kHz, mean±SD, p<0.0001 for both). A statistically significant (p<0.0001) increase was also seen for Z_5:Z_{100}, although its clinical significance is questionable owing to its low absolute value (<1%).

Wt loss was more pronounced in males than females (4.3 *vs* 3.2%, geometric means, p<0.0001), and the same was true for BMI (-1.9±0.4 *vs* -1.4±0.3 kg/m^2, mean ±SD, p<0.0001) and WC (-8±7 *vs* -5±6 cm, mean±SD, p<0.05). However, the changes in HC, WHR, Z and Z_5:Z_{100} were not influenced by sex (p=NS).

The variance of Z explained by the anthropometric dimensions before the Wt reduction program is given in Table 3.

Table 3 - *Variance of body impedance changes explained by anthropometric changes. A minus (-) sign before the (adjusted) R^2 value denotes an inverse correlation.*

	ΔZ_1	ΔZ_5	ΔZ_{10}	ΔZ_{50}	ΔZ_{100}	ΔZ_5:Z_{100}
ΔWt[†]	-0.08*****	-0.08*****	-0.07****	-0.07*****	-0.02***	-0.02***
ΔWt%[†]	-0.13******	-0.12******	-0.11******	-0.10******	-0.05******	-0.05***
ΔBMI	-0.10******	-0.10******	-0.09*****	-0.09*****	-0.02*	-0.02*
ΔWC	0.01	NS	NS	NS	NS	NS
ΔHC	NS	NS	NS	NS	NS	NS
ΔWHR	NS	NS	NS	NS	NS	NS

*p<0.05, **p<0.01, ***p<0.005, ****p<0.001, *****p<0.0005, ******p<0.0001. Z_x: impedance at frequency x; Wt: weight; Ht: height; BMI: body mass index; WC: waist circumference; HC: hip circumference; WHR: waist:hip ratio. [†]The log-transformed value of the module was used in order to have a normally distributed variable and to account for the negative values.

undergoing a short-term integrated Wt reduction program based on energy-restricted diet, moderate aerobic exercise conditioning and psychological counselling. Z increased of about the same value at each of the measured frequencies (from 6±10% at 5 kHz to 5±9% at 100 kHz). A statistically significant increase in Z_5:Z_{100} was also seen but its clinical significance is questionable owing to its low absolute value (<1%). Taken together, these data suggest that no clinically relevant change in BWD occurred in our subjects as a result of the Wt reduction program. The increase of Z at low and high frequencies was partly explained by the concomitant decrease of WC and HC. An inverse relationship does exist in fact between body circumferences and Z, with a substantial contribution from WC and HC (10). Even if this cannot be considered a demonstration of the applicability of the Ohm's law to the human body, which is neither linear nor isotropic as the ideal ohmic conductor (11), it has many practical implications. In fact, proportionality of Z changes and stability of their relationship with circumferences do not have to be expected when the composition of the underlying conductor undergoes substantial changes. Unbalanced diets are known to produce changes in both TBW and its distribution between ECW and ICW, as exemplified by many studies of malnutrition (12). It is of more interest, however, that the changes in Z did not satisfactorily predict the changes in anthropometric dimensions despite the evidence of a substantial association between Z and anthropometry both before and after the Wt reduction program. Interestingly, the relationship between Z and Wt, BMI and WC did not change before and after Wt loss implying that, in homeostatic conditions, the relationship between Z and body composition as detected by anthropometry does not change for a Wt loss of this entity. This suggests at the very least that two measurements of Z during a Wt loss program are not enough to have a reliable prediction of body composition changes ad described by Wt, BMI and WC.

Since the relationship between Z_5:Z_{100} and BMI did change after the Wt reduction program (significantly different intercepts), this may be seen as corroborating the theory that changes in the ECW:TBW ratio are at least in part responsible for the inability of BIA to predict body composition changes (13). However, one should also consider that: 1) the relationship of Z_5:Z_{100} with BMI was not significant before the Wt reduction program; 2) the percent change in Z_5:Z_{100} as a result of the Wt reduction program was minimal (<1%); and 3) the relationship of Z_5:Z_{100} with Wt and WC before and after the Wt reduction program was unchanged. Although this does not deny the importance of the ECW:TBW ratio, it suggests however that this explanation was not applicable to our subjects.

Obese-specific predictive equations available in the literature were used to assess TBW, ECW alongside with FM and FFM in the study subjects (data not shown). A substantial percentage of subjects showed values of body hydration (TBW:Wt) and ECW:ICW not compatible with their known physiological limits. Even if this had to be partly expected because of the well-known population-specificity of predictive formulae, it clearly warrants against the use of the available formulae to assess body composition in our (and possibly other Italian) subjects. We can only hypothesize that the high values of BMI of our subjects were partly responsible for the bias associated to the use of these formulae, but this requires confirmation by using a gold-standard technique to assess TBW and ECW.

In conclusion, using BIA as an exploratory tool, no clinically relevant differences of BWD were detected in highly obese subjects after a mean Wt loss of about 4% obtained with diet and exercise. This suggests that the study population has not suffered functionally important changes in body composition and that the initial relation between body compartments was maintained after the Wt reduction program. Moreover, accurate predictions of body composition changes in obese subjects may require more than two BIA measurements so as to have a better description of the Wt-losing process. The use of body composition reference methods is clearly needed to fully ascertain the clinical relevance of this finding.

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Wt was the best predictor of Z at all frequencies. In comparison, BMI explained from 5 to 10% less variance of Z than Wt. The contribution of WC to Z was very close to that of BMI while HC gave a less relevant contribution. Age, Ht and WHR were the poorest predictors of Z. Thus, further analyses focused on Wt, BMI and WC. Interestingly, sex did not influence the prediction of Z from any of the anthropometric covariates.

Despite some minor changes in the amount of explained variance, the relative contribution of anthropometric dimensions to Z was substantially unchanged after the Wt reduction program (data not shown). However, the prediction of Z changes from anthropometric changes was hindered by the substantially lower amount of explained variance as compared to the predictions performed in static conditions (Table 3).

It is nonetheless to be pointed out that the relationship between Z and Wt, BMI and WC was similar before and after the Wt reduction program, as can be inferred from the comparison of slopes and intercepts of the regression lines. However, the intercept of the regression of Z_5:Z_{100} *vs* BMI did increase significantly ($p<0.05$) after the Wt reduction program (Fig. 1).

DISCUSSION

We used BIA as an exploratory tool to monitor the changes in body composition of highly obese subjects

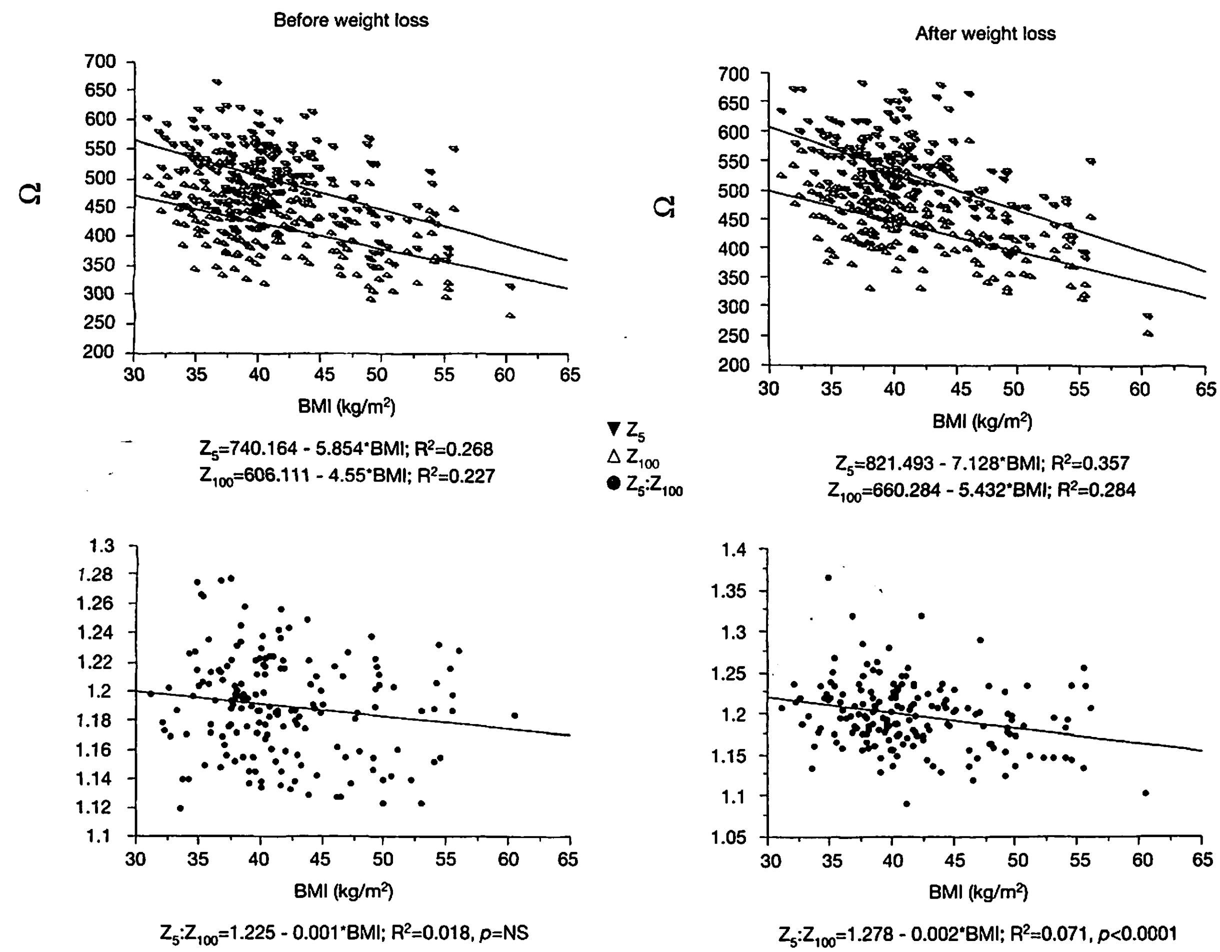

Fig. 1 - *Relationship between body mass index (BMI) and impedance (Z) before and after the weight reduction program. Comparison of regression lines revealed only significantly different intercepts for Z_5:Z_{100} vs BMI.*

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