SHORT COMMUNICATION

Short-term effects of exercise on body water distribution of severely obese subjects as determined by bioelectrical impedance analysis

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ABSTRACT. **We have previously shown that a short-term weight (Wt) reduction programme consisting of energy restriction, physical activity and psychological counselling, produces physiological changes of body water distribution (BWD) in obese subjects as detected by bioelectrical impedance analysis. The present study was aimed at testing the contribution of diet and physical activity to the observed changes in BWD. A number of 96 obese inpatients were consecutively enrolled in the study at our Obesity Clinic. During a 3-wk period, they underwent a body Wt reduction programme comprising the same dietary strategy and psychological counselling. The programme differed as far as physical activity is concerned, with 52 subjects randomized to a baseline exercise programme (BEP), 22 to a cardiovascular exercise programme (CEP) and 22 to a cardiovascular and strength programme (CSP). Absolute and percent Wt reduction was significantly higher in CSP than BEP subjects ($p<0.05$) and the same hold for the changes in impedance (Z) at frequencies of 5, 50 and 100 kHz ($p<0.05$). The change in the Z_5 / Z_{100} ratio did not show however any between-group difference (p=NS). The average values of Z changes were 1.5 to 2 times higher in CEP and 5.0 to 5.5 times higher in CSP than BEP subjects. We conclude that the type of exercise performed does influence the absolute changes of total body water and extracellular water but not BWD in severely obese subjects undergoing Wt loss.**
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INTRODUCTION

Using bioelectrical impedance analysis (BIA) as an exploratory tool, we have shown that a short-term weight (Wt) reduction programme consisting of energy restriction, physical activity and psychological counselling, produces physiological changes of body water distribution (BWD) in highly obese subjects (1). Wt reduction in our study was in fact accompanied by: 1) the same increase in bioelectrical impedance (Z) at frequencies of 1, 5 (Z_5), 10, 50 (Z_{50}) and 100 (Z_{100}) kHz and, 2) no relevant change in the Z_5 / Z_{100} ratio. Thus, while absolute changes occurred inside total body water (TBW, detected by frequencies ≥100 kHz) and extracellular water (ECW, detected by frequencies ≤5 kHz), these changes had the same direction and magnitude and no change occurred in BWD between ECW and TBW (detected by the Z_5 / Z_{100} ratio) (2, 3). Although these changes might be due to diet and/or physical activity, the study protocol did not allow us to test this hypothesis. In order to investigate how these changes in Z are produced, we designed another study where obese subjects were given the same dietary treatment while undergoing different types of exercise.

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SUBJECTS AND METHODS

Study design

A number of 96 obese inpatients were consecutively enrolled in the study at the 3rd Division of Metabolic Diseases of the Italian Institute for Auxology (Piancavallo, Italy). Inclusion criteria were: 1) body mass index (BMI) >35 kg/m^2; 2) age >18 yr; 3) absence of complications other than diabetes and hypothyroidism, provided that they were well compensated. Cardiovascular disease, orthopaedic disease hampering physical activity and uncontrolled diabetes mellitus were reasons for exclusion. During a 3-wk period, the subjects underwent a body Wt reduction programme comprising the same dietary strategy and psychological counselling. The programme differed as far as physical activity is concerned, with 52 subjects randomized (by means of a computer-generated table) to a baseline exercise programme (BEP), 22 to a cardiovascular exercise programme (CEP) and 22 to a cardiovascular and strength programme (CSP). With α set to 0.002, the employed sample size ensured a power of 0.915 to detect a significant between-group (BEP, CEP and CSP) difference in Z_{50} after the Wt reduction programme. The study protocol was approved by the Ethics Committee of the Italian Institute for Auxology and all subjects gave their written informed consent.

Treatments

All subjects consumed a 5.0 to 7.5 MJ diet with an average 21% energy from proteins, 53% from carbohydrates and 26% from lipids. The energy content of the diet was determined by subtracting about 1.2 MJ from measured or estimated basal energy expenditure. All subjects underwent also a psychological counselling programme, consisting of 2-3 sessions/week of individual and/or group psychotherapy. Group psychotherapy was performed by clinical psychologists and lectures, demonstrations and discussions, with or without a supervisor, took place daily.

BEP subjects performed aerobic activity for 5 d/wk according to one of the two schedules: 1) 30 min/d of indoor jogging, dynamic aerobic standing and floor exercise performed with arms and legs under the guidance of a therapist, and 30 min/d of cycloergometer exercise at 60 W or 2) 4 km outdoor leisure walking on flat terrain. CEP subjects performed aerobic exercise on cycloergometer, treadmill and armergometer for 35 min/d at 50% of VO_2 max during the first wk and at 60% of VO_2 max in the following two wk. CSP subjects performed the same exercises of the CEP group for 30 min/d and isometric force training of the main thoracic and lower limb muscle groups by means of 15 repetitions of 3 different kinds of exercises on specific ergometric machines (leg press, chest press, vertical traction). The training intensity was 40% of 5 maximal repetitions during the first wk and 50% and 60% during the second and the third wk, respectively.

Measurements

Wt and height (Ht) were measured following the *Anthropometric Standardization Reference Manual* (4). BMI was calculated as Wt (kg)/Ht (m) ^{2} (5). Total-body Z was measured at frequencies of 1, 5, 10, 50 and 100 kHz using a tetrapolar impedance plethysmograph (Human-IM Scan, DS-Medica, Milano, Italy) according to standardized procedures (6). Only values of Z at 5, 50 and 100 kHz are used in this report, because their changes were representative of those which occurred within the whole spectrum.

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, USA). All measured and calculated variables were normally distributed and between-group (BEP, CEP and CSP) variances were homogeneous. The "zero" hypothesis of no between-group differences in bioelectrical changes after the Wt reduction programme was tested using general linear models employing the value of change as the outcome variable and the type of physical activity (BEP, CEP and CSP) as predictor. An interaction term between physical activity and sex was added to the models to test the effect of sex on the changes. *Post-hoc* between-group comparisons were performed with the Scheffe's test. A similar approach was used to compare the baseline characteristics of the study groups. Statistical significance was set to a value of $p<0.05$ for all tests. Values are given as mean ±SD.

RESULTS

The baseline measurements of the study subjects are given in Table 1.

The higher number of female subjects is a reflection of the fact that the majority of patients seeking Wt loss in obesity clinics are women (1). No patient was

Table 1 - *Baseline characteristics of obese subjects (mean±SD). BEP=basal exercise programme; CEP=cardiovascular exercise programme; CSP=cardiovascular and strength programme; Wt=weight; Ht=height; BMI=body mass index; Zx=impedance at x kHz.*

	Study group†		
	BEP	CEP	CSP
N	52	22	22
Sex (F/M)	36/16	16/6	17/5
Age (years)	34±8*	29±7*,**	30±8**
Wt (kg)	112±17*	118±22*	114±16*
Ht (m)	1.65±0.09*	1.67±0.10*	1.66±0.09*
BMI (kg/m²)	41.3±5.1*	42.2±5.7*	41.5±4.2*
Z_5 (Ω)	520±60*	526±75*	513±71*
Z_{50} (Ω)	453±45*	463±68*	442±61*
Z_{100} (Ω)	427±42*	436±64*	419±58*
Z_5/Z_{100}	1.22±0.06*	1.21±0.04*	1.23±0.08*

*,**Values not sharing the same superscript are significantly different at the p<0.05 level.
†Group*sex interaction not significant for any of the dependent variables.

Table 2 - *Changes of Wt and impedance after the weight reduction programme (mean±SD). Abbreviations: BEP=basal exercise programme; CEP=cardiovascular exercise programme; CSP=cardiovascular and strength programme; Δ=change; Wt=weight; Zx=impedance at x kHz.*

	Study group†		
	BEP	CEP	CSP
ΔWt (kg)	-4.0±1.4*	-5.1±2.0*,**	-5.4±2.4**
ΔWt% (%)	-3.6±1.1*	-4.2±1.1*,**	-4.7±1.9**
ΔZ_5 (Ω)	9±56*	20±51*,**	52±36**
ΔZ_5% (Ω)	2±10*	4±10*,**	11±7**
ΔZ_{50} (Ω)	8±44*	12±50*	47±33**
ΔZ_{50}% (Ω)	2±10*	3±11*	11±8**
ΔZ_{100} (Ω)	7±41*	11±49*,**	41±38**
ΔZ_{100}% (Ω)	2±9*	3±11*,**	10±9**
$\Delta Z_5/Z_{100}$	0.001±0.056	0.003±0.067	0.004±0.075

*,**Values not sharing the same superscript are significantly different at the p<0.05 level.
†Group*sex interaction not significant for any of the dependent variables.

involved in systematic physical activity before enrollment. Ten patients had diabetes mellitus and 6 had hypothyroidism that were well controlled by appropriate treatments. The energy content of the diet was 6.1±0.9 MJ for BEP, 6.4±1.2 MJ for CEP and 6.2±1.9 MJ for CSP subjects (p=NS, ANOVA).
There was no significant association between group (BEP, CEP and CSP) and sex as determined by contingency analysis (Pearson's Chi-square, p=NS). CSP subjects were significantly older (p<0.05) than BEP subjects. The groups were, however, similar as far as the anthropometric and bioelectrical characteristics are concerned.
The changes in anthropometric and bioelectrical characteristics after the Wt reduction programme are given in Table 2.
Absolute and percent Wt reduction was significantly higher in CSP than BEP subjects (p<0.05) and the same hold for the changes in Z at all frequencies (p<0.05). The change in the Z_5/Z_{100} ratio did not show however any between-group difference.
In Figure 1, the average changes in Z of each group are plotted as a percentage of those observed in the BEP group. The values were 1.5 to 2 times higher in CEP and 5.0 to 5.5 times higher in CSP than BEP subjects.

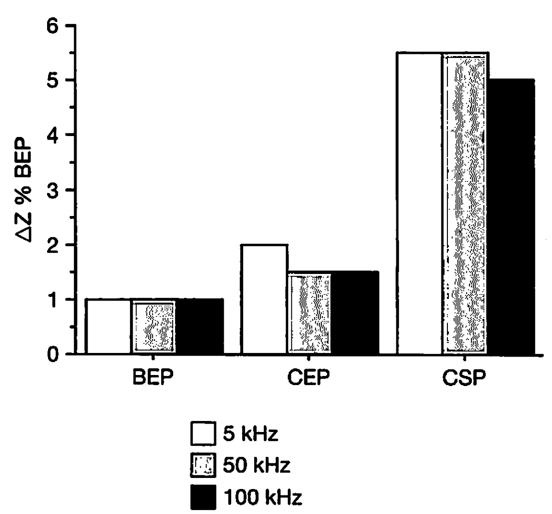

Fig. 1 - *Changes of impedance at 5, 50 and 100 kHz in CSP and CEP as compared to BEP subjects. ΔZ=change in impedance; BEP=basal exercise programme; CEP=cardiovascular exercise programme; CSP=cardiovascular and strength programme.*

DISCUSSION

This study corroborates the hypothesis that exercise does contribute to the changes of Z observed in severely obese subjects undergoing a Wt reduction programme based on energy restriction, physical activity and psychological counselling.

Obese subjects given the same diet and psychological support did show in fact different changes in Z depending from the type of exercise performed. The absolute and percent changes of Z were similar within each group (BEP, CEP and CSP) and no change in the Z_5/Z_{100} ratio was observed. This confirms the results of our previous study, conducted on subjects performing a programme similar to that of BEP subjects (1). However, the dimension of change showed a substantial between-group variability. CSP subjects had 5.0 to 5.5 times the values of BEP subjects, while CEP subjects had only 1.5 to 2.0 times the values of BEP subjects. Since CSP subjects differed from CEP subjects for having performed strength exercises and these latter differed from BEP subjects for having performed cardiovascular training, it is likely that the greater changes of Z observed in CSP subjects do reflect their specific muscular training. An increase in Z signals a decrease in the compartment investigated by the given frequency (2). Thus, the observed increase in Z_{100} signals a decrease in TBW and the increase in Z_5 a decrease in ECW. Since these decreases were similar, the ECW/TBW ratio as detected by the Z_5/Z_{100} ratio did not change.

On the basis of the available knowledge, the most likely explanation for the higher changes of Z observed in CSP patients is that they had a higher absolute loss of TBW and ECW as compared to BEP and CEP patients (7). The muscular training of CSP patients may have in fact increased their energy expenditure and promoted a greater loss of water as compared to CEP and BEP subjects. The greater weight loss of CSP as compared to CEP and BEP subjects may be a reflection of this fact.

At least another explanation should however be considered. Arms and legs do contribute substantially to total body Z since, according to Ohm' s law, Z is inversely proportional to the transversal area of the conductor (1). The muscular training of CSP patients may have modified the bioelectrical properties of their muscle fibres with a resulting different contribution to total body Z. Segmental BIA, which allows to measure the impedance of trunk, arms and legs and monitor their changes with time (8), could be employed in further studies to test this latter hypothesis.

In conclusion, the type of exercise performed does influence the absolute changes of TBW and ECW but not BWD in obese subjects undergoing Wt loss by means of a Wt reduction programme based on energy restriction, physical activity and psychological counselling.

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REFERENCES

1. Sartorio A., Conte G., Morini P., Battistini N., Faglia G., Bedogni G.: Changes of bioelectrical impedance after a body weight reduction program in highly obese subjects. *Diab. Nutr. Metab.* 13: 186-191, 2000.
2. Deurenberg P., Yap M: Bio-electrical impedance and the five level body composition model. In: Morini P. (Ed), *The new clinical approach to bioelectrical impedance analysis.* EDRA, Milano, 1998, pp. 30-36.
3. De Lorenzo A., Andreoli A., Deurenberg P: Impedance ratio as a measure of water shifts. *Ann. Nutr. Metab.* 41: 22-28, 1997.
4. Lohman T.G., Roche A.F., Martorell R.: *Anthropometric Standardization Reference Manual.* Human Champaign IL, Human Kinetics Books, 1988.
5. World Health Organization: *Obesity: preventing and managing the global epidemic.* Geneva, World Health Organization, 1998.
6. Deurenberg P: International consensus conference on impedance in body composition. *Age Nutr.* 5: 142-145, 1994.
7. Bedogni G., Borghi A., Battistini N.: Body water distribution and obesity. In: *Nutritional Assessment in Obesity: theoretical and practical issues.* EDRA, Milano, 1999, pp. 29-36.
8. Pietrobelli A., Morini P., Battistini N., Chiumello G., Nunez C., Heymsfield S.B.: Appendicular skeletal muscle mass: prediction from multiple frequency segmental bioimpedance analysis. *Eur. J. Clin. Nutr.* 58: 507-511, 1998.