International Journal of Obesity (1992) **16**, 207–212
Received 30 April 1991; accepted 15 October 1991

The prediction of total body water from body impedance in young obese subjects

Nino Battistini,[1] Paolo Brambilla,[2] Fabio Virgili,[3] Paolo Simone,[2] Giorgio Bedogni,[1] Pietro Morini[1] and Giuseppe Chiumello[2]

[1]Cattedra di Fisiologia della Nutrizione, Università di Modena, Modena [2]Paediatric Department, Endocrine Unit, Scientific Institute H, San Raffaele, Milan and [3]Istituto Nazionale della Nutrizione, Roma, Italy

Summary

Almost all formulae for the prediction of total body water (TBW) from body impedance are based on the assumption of a constant conductor configuration — i.e. a constant subject section. In this paper we report on data obtained for a group of 19 young obese subjects (relative weight > 120%) and 10 young normal subjects (relative weight 80–110%). In obese subjects, the application of two different formulae generated from normal children gave biased results and led to an underestimation of TBW with respect to the reference value obtained by deuterium oxide dilution. Body mass index accounted for more than 40% of the inter-individual variability, suggesting that body size was not taken sufficiently into consideration by the predictive formulae used. We have used the body surface area as the anthropometrical parameter for the prediction of TBW from body impedance. The regression formula that we propose (TBW = 1.156 × (surface area/body impedance) − 2.356; R = 0.96), although requiring further validation on external populations, seems to provide a more realistic assessment of TBW in young obese subjects. We therefore suggest that the assessment of TBW in young obese subjects requires specifically designed prediction formulae.

Keywords: children, deuterium oxide, total body water, impedance.

Introduction

The prediction of total body water (TBW) and possibly the fat free mass from bioelectrical impedance (BI) has been extensively validated in both adult and pediatric populations[1–3] and is now used as an alternative to isotopic dilution techniques, which are difficult in field conditions and require expensive instrumentation for isotope enrichment analysis.

The prediction of TBW from bioelectrical impedance measurements is based on the principle that the impedance of a geometrical system is related to the conductor length and configuration, its cross-sectional area and signal frequency. At a constant frequency, and assuming a constant conductor configuration, the bioelectrical impedance (or resistance) to the flow of current can be related to the volume of the conductor, following the formula: [4]

$$\text{Volume} = a \times \text{length}^2/\text{impedance} + b$$

The two terms, impedance and resistance, are considered equivalent here. This is due to the mathematical relationship between impedance and resistance and to the assumption that the reactance is irrelevant in comparison to the impedance at the frequency and current of the instrument.[3]

On this basis, a number of predictive formulae

Correspondence to: Nino Battistini, Cattedra di Fisiologia della Nutrizione, Università di Modena, via Campi 287, 41100 Modena, Italy.

have been generated for adult and pediatric populations by regressing the impedance against total body water (or the fat free mass) obtained by classical methods.[3] If we focus attention on the statement 'Assuming a constant conductor configuration' we could point out that the use of predictive formulae could not apply to obese subjects who probably present a body shape (body cross-sectional area) significantly different from the normal population. Thus, the reliable use of BI in young obese subjects probably requires further validation, since one of the basic assumptions from which predictive formulae have been generated could be violated.

In this paper we present the data from a study conducted on a group of young subjects classified as obese, and on a group of normal young subjects. TBW was estimated by means of deuterium oxide dilution technique and by BI.

Materials and methods

Nineteen subjects (nine boys and ten girls) were classified as obese on the basis of two parameters as suggested by Paige[5] i.e. weight/height $\geqslant 90$ percentile and relative body weight > 120%. Ten subjects (seven boys and three girls) classifiable as normal (i.e. relative weight 80–110%) were also included in the study as a control group.

The subjects in fasting conditions received orally a dose of deuterium oxide calculated on the basis of body weight to increase the enrichment by 300 ppm. This is an increase relative to standard mean ocean water (V-SMOW) of about 1000 δ units.

The experimental protocol required the fasting subject to void the bladder before drinking the dose, to wait at least three hours, then void the bladder again. This second sample urine of was considered 'contaminated' by pre-equilibration urines and not used for the analysis. The subsequent urination, which was usually obtained about 30 minutes from the previous one, was considered representative of the equilibrium and used for spectrometrical analysis. Pre-dose and post-equilibration isotope enrichments were measured in sublimated urine by FT-IR spectrophotometry as described by Lukaski and Johnson[6] with minor modification. Dilution space (g) was calculated using the following formula:

$$g=[T(g) \times D(g)/A(g)] \times (E_a - E_t)/(E_s - E_p)$$

where T is the amount of tap water used to dilute an aliquot A of the administered dose; D is the amount of adminstered dose; E_a, E_t, E_s and E_p are the enrichments (in δ m units) of the administered dose, tap water, post-dose and pre-dose urine sample respectively.

TBW was calculated as the dilution space divided by 1.03. This factor has been determined on the basis of theoretical calculations regarding the amount of exchangeable hydrogen available during equilibration and on the basis of comparison between desiccation and dilution spaces in animals.[7]

On the same day as the isotope load (during the equilibration time) the subjects underwent measurement of body impedance at 800μ A and 50 KHz (Human-Im®, Dietosystem, Milan, Italy) on the right side of the body as described by Lukaski *et al.*[8] Body impedance was converted to TBW using two different formulae which take into account impedance and height and impedance, height and weight of subject respectively:

(i) as reported by Davies *et al.*[9] for the prediction of TBW in young subjects:
$$\text{TBW(l)} = 0.6 \times (\text{height}^2/\text{impedance}) - 0.5$$
(ii) as described by the manufacturer (Dietosystem, Milan, Italy) for pediatric purposes:
$$\text{TBW(l)} = 0.75 \times (\text{height}^2/\text{impedance}) - 0.062 \times \text{weight}$$

Anthropometric measurements, including waist, hip and thigh circumferences, skinfold thickness at the biceps, triceps, sub-scapular and supra-iliac sites, were measured by a trained operator following the directions of the *Anthropometric Standardization Reference Manual.*[10]

The experimental protocol was approved by the Ethical Committee of San Raffaele Hospital (Milan). The informed consent of the subjects' families was obtained.

Statistical analysis (mean, standard deviation, correlation, linear regression, mean t test, ANOVA) was performed using a Statview® package for the Macintosh® PC.

Results and discussion

The mean (±s.d.) and the range for body weight and height, the relative weight, the impedance and the total body water from deuterium oxide dilution, of both obese and control subjects, are given in Table 1. The mean age is similar to that reported by Davies *et al.*[9] while body weight of obese subjects is significantly higher. The relative weights (157.4±23.7) of obese subjects indicate a body weight about 60% greater than the ideal weight for their height. TBW represents about 45% of body weight (45.0±6.0%) of obese subjects.

Table 1 Mean ± s.d. (and range) of age, weight, height, relative weight, body mass index (BMI), TBW and impedance of the study subjects

	obese (n=19)		*control (n=10)*	
	mean ± s.d.	*range*	*mean ± s.d.*	*range*
age (years)	12.1 ± 1.8	8 - 15	12.4 ± 1.7	9 - 15
weight (kg)	65.3 ± 15.8	36.0 - 96.2	40.2 ± 10.8	31.0 - 68.0*
height (cm)	152.1 ± 12.8	125.7 - 179.2	149.5 ± 10.9	136.1 - 173.4
relative weight	157.4 ± 23.7	120 - 205	101.9 ± 11.9	80.7 - 111.7*
BMI (kg/m^2)	27.4 ± 3.1	21.0 - 32.9	17.7 ± 2.3	14.3 - 22.6*
TBW (l)	29.2 ± 7.1	17.0 - 39.9	24.4 ± 4.4	19.8 - 32.7
impedance (Ω)	592 ± 56	490 - 692	626 ± 54	529 - 710

* $P < 0.001$ *vs.* obese

The control group shows age, height, TBW and impedance similar to those of the obese sub-sample. Height, BMI and relative weight are significantly lower than in the obese group ($P < 0.001$). In the control group TBW represents about 60% of body weight (62.0 ± 9.2%) ($P < 0.0001$ *vs.* obese)

Figure 1 shows the values of TBW predicted from BI utilizing the formula of Davies *et al.*,[9] plotted against the reference values obtained by deuterium oxide dilution. When applied to obese subjects (o), the formula of Davies *et al.*[9] is highly correlated with the reference values ($r=0.93$) but the values do not lie on the line of unity, indicating the presence of bias in the prediction. The mean of predicted values (23.5 ± 5.4) is significantly lower ($P < 0.001$ by ANOVA) than that obtained by deuterium oxide dilution (29.1 ± 7.1) (see Table 2).

When applied to normal subjects (●), the formula of Davies *et al.*[9] provides values with a bias lower than in obese subjects, but the level of correlation is also lower ($r=0.89$). Also, in the control group, the mean of values predicted from BI (21.2 ± 3.7) is significantly lower ($P < 0.001$ by ANOVA) than that obtained by the deuterium oxide dilution technique (24.4 ± 4.4) (see Table 2).

Figure 2 shows individual values of TBW predicted from body impedance plotted against the reference TBW values obtained by deuterium oxide dilution, in obese and normal subjects.

Table 2 Mean ± s.d. of TBW, measured by deuterium oxide dilution and by BI using the formula of Davies *et al.*[9] and the manufacturer's formula in obese and normal children

	obese	*normal*
TBW by deuterium oxide	29.1 ± 7.1	24.4 ± 4.4
TBW by Davies *et al.*[9]	23.4 ± 5.4*	21.2 ± 3.7*
TBW by manufacturer	26.4 ± 5.6*	24.7 ± 4.2

* ANOVA $P < 0.0001$ from TBW by deuterium oxide

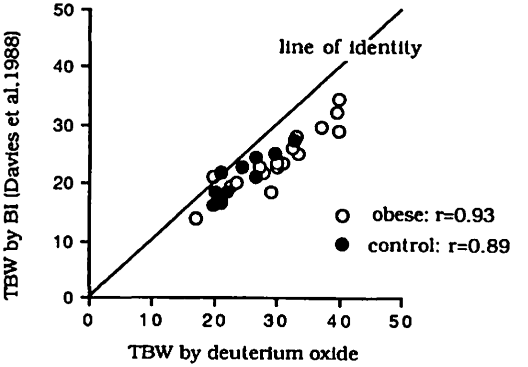

Figure 1 TBW estimated from body impedance by the formula of Davies et al.[9] against TBW obtained from deuterium oxide dilution in obese (o) and control (●) subjects.

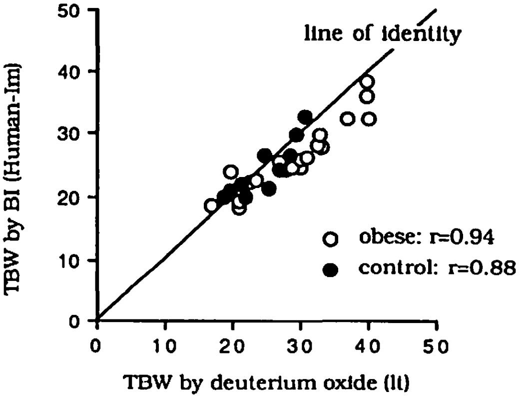

Figure 2 TBW estimated from body impedance (manufacturer's formula) against TBW obtained from deuterium oxide dilution in obese (o) and control (●) subjects.

Values were calculated utilizing the formula described by the manufacturer, which also includes the weight of the subject. Using the manufacturer's formula, TBW values by BI and deuterium oxide dilution in of obese subjects are highly correlated ($r=0.94$) but values do not lie on the line of unity. The average value obtained from the impedance (26.4 ± 5.6) significantly underestimates ($P < 0.001$ by ANOVA) the TBW of the sample of obese subjects with respect to the reference method (see Table 2).

In the control group, the inclusion of body weight into the prediction formula significantly improves the estimate of TBW from BI, the mean value (24.7 ± 4.2) being not significantly different from that obtained by deuterium oxide dilution (see Table 2). Thus, the plot presents a quite large scatter of values and the level of correlation is lower than that obtained in obese subjects ($r=0.88$).

Two points emerge from the results. Firstly, the formula of Davies *et al.*,[9] generated from data obtained from a normal population and including the impedance only, is highly correlated with the reference method but seems to provide a biased estimate of TBW when applied to obese and normal young subjects. Secondly, the inclusion of body weight into the predictive formula significantly improves the agreement between the means of estimates using BI and deuterium oxide dilution in normal subjects, but does not produce a consistent improvement in obese subjects. With respect to deuterium oxide dilution technique, both Davies *et al.*[9] and the manufacturer's formulae show very high correlation coefficients in obese subjects ($r=0.93$ and $r=0.94$ respectively) and rather low correlation coefficients in the control group ($r=0.89$ and $r=0.88$ respectively).

The fact that the formula including body weight underestimates TBW of obese subjects seems to be entirely attributable to the obesity of the study population, since the utilization of the same formula on normal subjects leads to reasonable results (see Table 2).

The construction of a formula on the basis of our own raw data, and including the same variables (i.e. height, weight and impedance), did not significantly improve the coefficient of correlation between TBW and the predicted value. The resulting formula from a multiple regression analysis is: TBW (l)$=0.67 \times (\text{height}^2/\text{impedance}) + 0.03 \times \text{weight} + 0.13$ ($r=0.93$; s.e.e $=0.7$ kg)

As suggested by others,[3,11,12] it is possible that the accurate assessment of body compartments from body impedance requires the utilization of group-specific regression equations, possibly including other variables.

In order to explore the nature of the bias and the individual discrepancy in the prediction of TBW from body impedance in obese subjects using both the manufacturer's formula and the formula suggested by Davies *et al*, we have plotted the residuals of the regressions against other variables related to body composition for body fatness (e.g. age, gender, single skinfolds, the sum of skinfolds, body weight, waist to hip ratio, waist to thigh ratio, BMI etc.).

None was found to be significantly associated with the residuals, with the exception of BMI which accounted for about 40% of the inter-individual variability of the prediction obtained from the manufacturer's formula and the formula suggested by Davies.

The fact that a significant percentage of the inter-individual variability is accounted for by BMI suggests that body size of obese subjects was not taken into sufficient consideration in the formulae generated from a normal population. In other words, it is possible that the 'configuration of the conductor' should not be considered constant. Moreover a different water distribution between the intracellular and extracellular water due to the large amount of adipose tissue could affect the measurement of body impedance.[12]

One of the simplest ways to introduce the size and the shape of the subject into the formula, is to calculate the body surface area (SA) from height and weight using classical prediction formulae, such as that described by DuBois and DuBois.[13] Furthermore, SA has been already reported as a good predictor of TBW in obese subjects.[14] Thus, we have attempted to generate a predictive formula on our sample where the parameter height^2 is replaced by the SA calculated using the formula of DuBois and DuBois:

$$SA = \text{weight}^{0.425} \times \text{height}^{0.725} \times 71.84.$$ [13]

Figure 3 shows the regression of the SA/impedance parameter against TBW obtained by deuterium oxide dilution. The ability of bioelectrical impedance to predict total body water is improved by including SA ($r=0.96$). The resulting formula that we propose for the prediction of TBW from body impedance in young obese subjects is:

$$\text{TBW (l)} = 1.156 \times [\text{SA (cm}^2\text{)/body impedance}(\Omega)] - 2.36$$
($r=0.96$; s.e.e. $=0.41$)

The 95% interval of confidence of the slope of the regression line is between 0.98 and 1.38.

adults is strongly age dependent. *Eur J Chin Nutr* **44**, 261–268.
12 Deurenberg, P., Kooy, K., Leenen, R. & Schouten, F. (1989): Body impedance is largely dependent on the intra and extra-cellular water distribution. *Eur J Clin Nutr* **43**, 845–853.
13 DuBois, D. & DuBois, E.F. (1916): A formula to estimate the approximate surface area if height and weight be known. *Arch Intern Med* **17**, 863–871.
14 Hume, R. & Weyers, E. (1971): Relationship between total body water and surface area in normal obese subjects. *J Clin Pathol* **24**, 234–238.

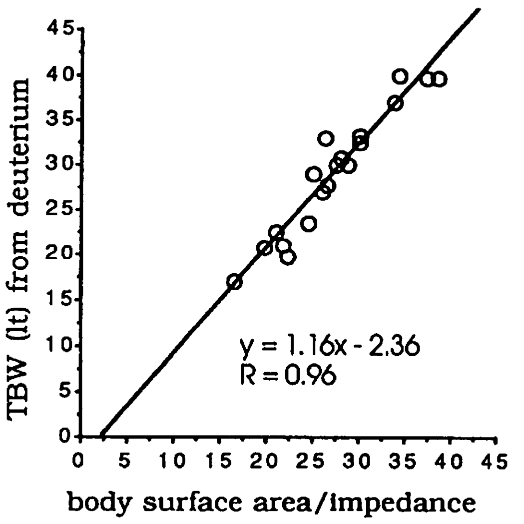

Figure 3 Regression of SA/impedance *vs.* TBW by deuterium oxide dilution.

This formula, as with all predictive formulae, must be cross-validated, but the utilization of the parameter SA/impedance to predict TBW from body impedance seems to provide a more realistic estimate of TBW than the height^2/impedance parameter in young obese subjects. It is possible that the relationship between height^2/impedance, weight and TBW is not simple in obese subjects and should be described using transformed (anthropometrical) parameters such as those used in the prediction of surface area. Another point is that we could consider an obese subject as a system of two (or more) different resistors 'in parallel': the lean body mass and the adipose tissue, each with different resistance and electrical characteristics. In this case, neither the simple height^2/impedance variable, nor the inclusion of more additional variables (weight, age, height etc.) in the prediction formula would be sufficient for the description of the electrical flow.

In other words, even after introducing the parameter height^2/impedance derived from a rearrangement of Ohm's law, the body surface area in obese people could better describe the current flow across the body than height^2. In conclusion, the improvement in the predictive capacity of body impedance in our sample of young obese subjects can be explained by the fact that previously published formulae were generated using the parameter height^2 /impedance on the assumption of a constant conductor configuration. The utilization of body surface area/impedance as parameter for the prediction of TBW seems to overcome this assumption. More studies and a cross-validation, are needed to confirm this hypothesis.

Our data confirm that body impedance can be considered a valid alternative to deuterium oxide dilution for the assessment of TBW in pediatric populations, even though to be reliable its use in obese subjects requires specifically designed prediction formulae.

Acknowledgements—This work was supported by grants CNR (National Council of Research), Target Project 'Prevention and Control of Disease Factors' (FATMA), and sub-project 'Feeding Operating Unit Study of the Alcohol-related Pathologies'.

References

1 Segal, K.R., Van Loan, M., Fitzgerald, P.I., Hodgdon, J.A. & van Itallie, T.B. (1988): Lean body mass by bio-electrical impedance analysis. A four-site cross-validation study. *Am J Clin Nutr* **47**, 7–14

2 Houtkooper, L.B., Lohoman, T.G., Going, S.B. & Hall, M.C. (1989): Validity of bio-electrical impedance for body composition assessment in children. *J Appl Physiol* **66**, 814–821

3 Lukaski, H.C. (1990): Applications of bioelectrical impedance analysis: a critical review. In *Advances in* in vivo *body composition studies*, eds S. Yasumura *et al.* pp. 365–374. New York, Plenum Press.

4 Van Loan, M. & Maycin, P. (1987): Bioelectrical impedance: is it a reliable estimator of lean body mass and total body water? *Hum Biol* **59**, 299–306.

5 Paige, D.M. (1985): Obesity and children. In *Dietary treatment and prevention of obesity*, eds R.T. Frankle, J. Dewyer, L Moragne, A. Owen, pp. 193–201. London: John Libbey.

6 Lukaski, H.C. & Johnson, P.E. (1985): A simple inexpensive method of determining total body water using a tracer dose of D_2O and infra-red absorption of biological fluids. *Am J Clin Nutr* **41**, 363–370.

7 Sheng, H. & Huggins, R. (1979): A review of body composition studies with emphasis on total body water and fat. *Am J Clin Nutr* **32**, 630–643.

8 Lukaski, H.C., Johnson, P.E., Bolanchuk, W.W. & Lykken, G.I. (1985): Assessment of fat-free mass using bioelectrical impedance measurements of the human body. *Am J Clin Nutr* **41**, 810–817.

9 Davies, P.S.W., Preece, M.A., Hicks, C.J. & Halliday, D. (1988): The prediction of total body water using bioelectrical impedance in children and adolescents. *Ann Hum Biol* **15**, 237–240.

10 Lohman, T.G., Roche, A.F. & Mortarell, R. (1988): In *Anthropometric Standardization Reference Manual*, pp. 1–171 Champaign, Illinois: Human Kinetic Books.

11 Deurenberg, P., Kusters, C.S.L. & Smit, H.E. (1990): Assessment of body composition by bioelectrical impedance in children and young