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The prediction of extracellular and total body water from bioelectric impedance in a non-Caucasian population from Central Asia

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Summary. The availability of only a small number of studies on bioelectric impedance analysis (BIA) in non-Caucasian ethnic groups appears to limit reliable utilization of this method in anthropological field studies. In this study, 28 male Turkish–Mongolian subjects native of Kazakhstan (Central Asia) underwent total body water (TBW) and extracellular water (ECW) assessment by deuterium oxide (D_2O) and sodium bromide (NaBr) dilution respectively. Bioelectric impedance (BI) was recorded at multiple frequencies. ECW and TBW were calculated from BI at 1 and 100 kHz respectively by applying formulae developed on a sample of Caucasian subjects with a hydration status similar to that of the study population. TBW predicted from BI at 100 kHz ($37 \cdot 5 \pm 3 \cdot 3$ l) was highly correlated and not significantly different from that obtained by D_2O dilution ($39 \cdot 0 \pm 4 \cdot 1$ l, $r = 0 \cdot 894$, $p < 0 \cdot 0001$, SEE = $1 \cdot 9$ l). Similarly, ECW predicted from BI at 1 kHz ($15 \cdot 1 \pm 1 \cdot 2$ l) was highly correlated and not significantly different from that obtained by NaBr dilution ($15 \cdot 0 \pm 1 \cdot 6$ l, $r = 0 \cdot 847$, $p < 0 \cdot 0001$, SEE = $0 \cdot 8$ l). It is concluded that selected predictive formulae developed on Caucasian subjects may provide a precise and accurate assessment of ECW and TBW in Turkish–Mongolian populations.

1. Introduction

Bioelectric impedance analysis (BIA) is an expedient and precise technique for the assessment of body composition. In recent years BIA has been extensively validated and utilized in studies of children, adults and the elderly of both sexes (Kushner 1992). Some uncertainties are still open to discussion in that, as Chumlea and Guo (1994) have pointed out, the majority of studies were carried out on white ethnic groups. To date only a few studies of BIA have been performed among non-white ethnic groups (Rising, Swinburn, Larson and Ravussin 1991, Zillikens and Conway 1991, Schultink, Lawrence, van Raji and Hautvast 1992, De Waart, Li and Deurenberg 1993, Stolarczyk, Heyward, Hicks and Baumgartner 1994). On these bases it appears clear that BIA cannot be reliably used for predicting body composition in the vast majority of non-white ethnic groups. On the other hand, in the few studies available on non-white populations, bioelectric impedance has been determined only at the frequency of 50 kHz. Multiple frequency BIA (MFBIA) has been reported to predict the distribution of body water accurately, between extracellular (ECW) and intracellular (ICW) spaces (Segal, Burastero, Chun, Coronel, Pierson and Wang 1991). Also in this context, no data are at present available to corroborate the utilization of this methodology in non-white populations.

During the course of a larger research study on human adaptability to high altitudes, carried out in collaboration with the Laboratory of Anthropology of the Academy of Sciences of Alma-Ata (Kazakhstan), we have tested MFBIA for predicting TBW and ECW in Kazakh subjects. In this short report we have compared the prediction of both TBW and ECW from MFBIA utilizing formulae developed on a white Caucasian population (Deurenberg, Schouten, Andreoli and De Lorenzo

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1993) with those measured by deuterium and bromide dilution. These dilution methods can be considered the reference for the measurement of hydration status. The predictive formulae of Deurenberg and colleagues (Deurenberg *et al.* 1993) have been chosen from among the wide list of prediction formulae available in the international literature because they have been developed using the same impedance plethysmograph employed in the present study.

2. Materials and methods

Twenty-eight male subjects aged 31·0±7·0 years were randomly selected for this comparison among participants to the above-mentioned study on human adaptability to high altitudes. All subjects were natives of the Kegen Valley, located in the Tien-Shan region of Kazakhstan, Central Asia. All subjects were in good health according to medical history, physical examination and blood and urine analysis. According to their somatic features all subjects were classifiable within the Turkish–Mongolian ethnic group (Alekseev and Gochman 1983). The aim of the study was explained to all subjects, and their informed consent was obtained before participation. The experimental protocol was approved by the Ethical Committee at the University of Modena, Italy.

Body weight and height were measured following the *Anthropometric Standardization Reference Manual* (Lohman, Roche and Martorell, 1988).

TBW and ECW were measured by deuterium oxide (D_2O) and sodium bromide (NaBr) dilution techniques, respectively. Subjects fasted for at least 8 hours and voided the bladder before receiving orally a precisely weighed solution made up of D_2O, NaBr and drinkable water. A detailed description of deuterium bromide load and body fluid collection is given elsewhere (Battistini, Brambilla, Virgili, Simone, Bedogni, Morini and Chiumello 1992, Battistini, Virgili and Bedogni 1994). The deuterium load was sufficient to increase the isotopic excess to approximately 500% over the background. Deuterium enrichment in plasma samples was measured by FT-IR spectrophotometry according to the method of Lukaski and Johnson (1985). TBW was calculated as deuterium dilution space ×0·95, taking into account non-aqueous distribution of D_2O. Bromide concentration in plasma was measured by high performance liquid chromatography according to the method of Wang, Sheng, Morkenberg, Kosanovich, Clarke and Klein (1989). ECW was calculated as bromide dilution space ×0·90 ×0·95, taking into account non-extracelluar distribution of bromide and Donnan's effect, respectively. The final concentration in plasma was below one-tenth of the value regarded as toxic (6 mM) (Goodman and Gillman 1970).

The determination of bioelectric impedance (Z) was made with a tetrapolar impedance plethysmograph (Human IM Scan, Dietosystem, Milan, Italy) at frequencies of 1, 5, 50 and 100 kHz, as described by Segal *et al.* (1991). TBW and ECW were calculated from the impedance index (height$^2/Z$ or ZI) at frequencies of 100 (ZI_{100}) and 1 (ZI_1) kHz, respectively by applying the formulae developed by Deurenberg *et al.* (1993) in a white Caucasian population.

Statistical analysis (mean, standard deviation, ANOVA, linear regression) was performed on an Apple Macintosh computer using the Statview 4·01 package. The level of significance was set to $p<0·05$. Results are expressed as mean±standard deviation.

3. Results and discussion

Age, weight, height, BMI, total body water standardized per kilogram of body

Table 1. Mean ± SD (and range) of age, weight, height, BMI, total body water standardized per kilogram of weight (TBW%), extracellular water standardized per litre of TBW, extracellular to intracellular ratio (ECW : ICW) and bioelectric impedance (Z) at frequencies of 1, 5, 50 and 100 kHz of the study sample.

	$x \pm SD$	Range
Age (years)	31·0 ± 7·0	20·0–42·0
Weight (kg)	65·1 ± 7·1	50·0–76·0
Height (cm)	167·8 ± 6·0	152·9–180·6
BMI (kg/cm^2)	23·1 ± 2·1	20·3–28·1
TBW%	60·0 ± 1·2	57·1–61·8
ECW%	38·5 ± 0·8	37·2–40·3
ECW/ICW	0·63 ± 0·02	0·59–0·67
$Z_1(\Omega)$	613 ± 48	538–702
$Z_5(\Omega)$	594 ± 48	516–680
$Z_{50}(\Omega)$	511 ± 44	428–585
$Z_{100}(\Omega)$	472 ± 40	396–548

weight (TBW%), extracellular water standardized per litre of TBW (ECW%), extracellular to intracellular water ratio (ECW : ICW) and Z values of the subjects are presented in table 1. The anthropometrical parameters of the subjects are comparable with those reported by Deurenberg *et al.* (1993) for the subjects generating the formulae utilized for predicting TBW and ECW.

Table 2. Mean ± SD (and range) of total body water (TBW) and extracellular water (ECW) measured by D_2O and NaBr dilution and predicted from the impedance index (ZI, height^2/impedance) at 100 (ZI_{100}) and 1 (ZI_1) kHz (Deurenberg *et al.* 1993).

	$x \pm SD$	Range
TBW D_2O (l)	39·0 ± 4·1	30·5 - 45·4
TBW ZI_{100} (l)	37·5 ± 3·3	30·5 - 41·7
ECW NaBr (l)	15·0 ± 1·6	11·9 - 18·3
ECW ZI_5 (l)	15·1 ± 1·2	12·2 - 16·6

Table 2 presents the values of TBW and ECW both measured by dilution and predicted from ZI_{100} and ZI_1 following application of Deurenberg's formulae (Deurenberg *et al.* 1993). The means of the measured values of both TBW and ECW actually overlap those obtained from BIA associated to the selected predictive formulae.

Figures 1 and 2 show individual values of TBW and ECW predicted from ZI_{100} and ZI_1 plotted against the corresponding individual values obtained by deuterium and bromide dilution respectively. TBW predicted from ZI_{100} is highly correlated with TBW measured by deuterium dilution ($r = 0{\cdot}894$, $p < 0{\cdot}0001$). Similarly, ECW predicted from ZI_1 is highly correlated with ECW obtained by bromide dilution ($r = 0{\cdot}847$, $p < 0{\cdot}0001$). The difference between predicted and measured values is $-1{\cdot}5 \pm 1{\cdot}91$ for TBW and $0{\cdot}1 \pm 0{\cdot}81$ for ECW. For both TBW and ECW the SEE is rather low (1·9 and 0·81, respectively). These SEE values are slightly lower than those associated with the original prediction formulae (2·27 kg for TBW and 1·14 kg for ECW). In both cases, as determined by the comparison of the slope and intercept of the regression lines, the predicted values lie on the line of identity, indicating the absence of bias in the prediction of both TBW and ECW from body impedance (figures 1 and 2).

The availability of only a small number of studies on BIA in non-white ethnic

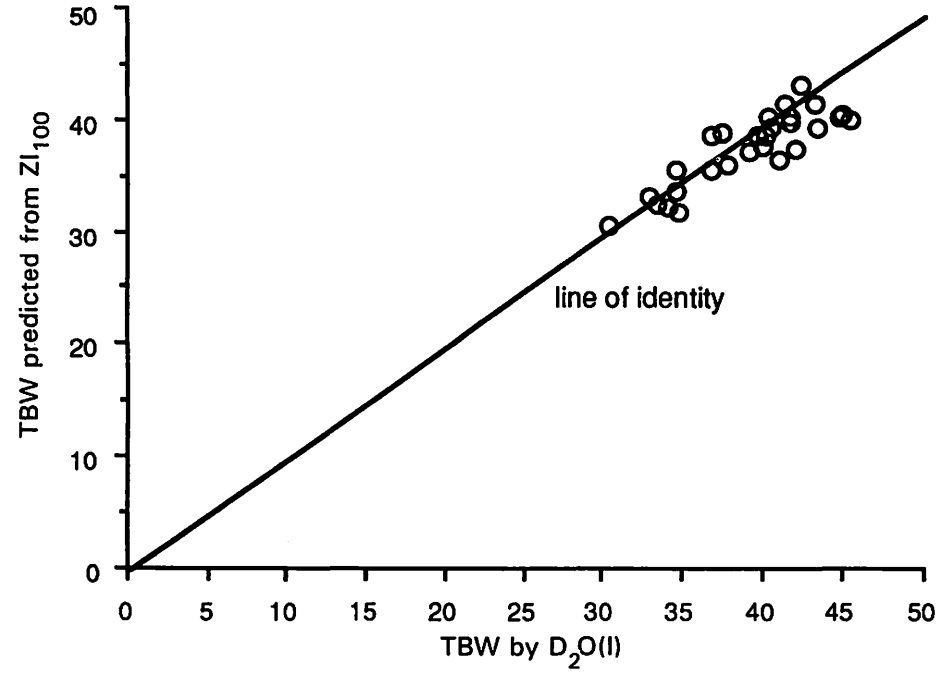

Figure 1. TBW predicted from height$^2/Z_{100}$ (Zl_{100}; Deurenberg *et al.* 1993) against TBW obtained from D_2O dilution ($r = 0{\cdot}894$).

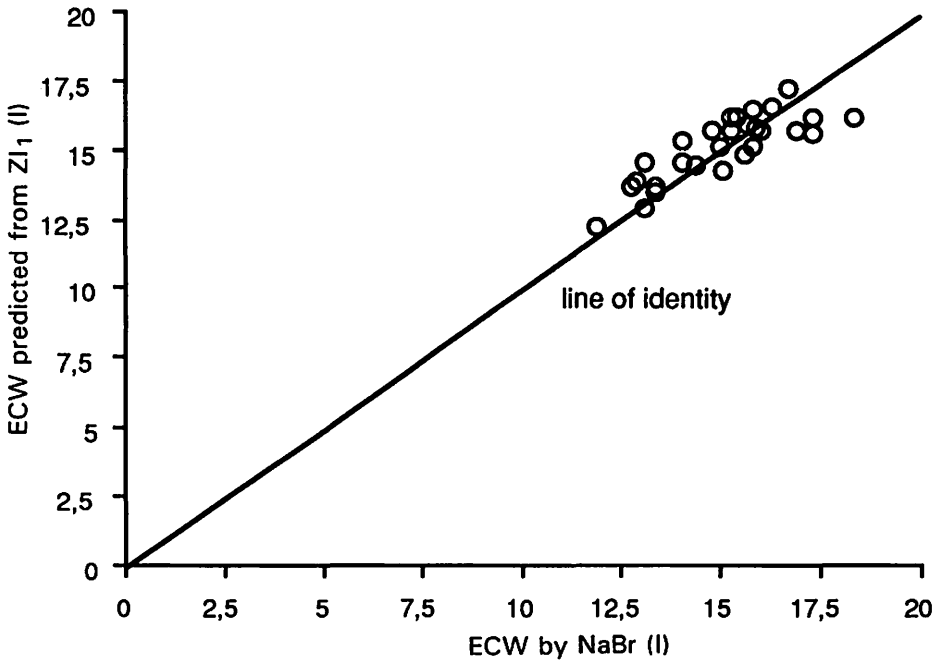

Figure 2. ECW estimated from height$^2/Z_1$ (Zl_1; Deurenberg *et al.* 1993) against ECW obtained from NaBr dilution ($r = 0{\cdot}847$).

groups appeared to limit reliable utilization of this method in field studies (Chumlea and Guo 1994). Furthermore, the accuracy of MFBIA for predicting TBW and ECW has never been investigated in non-white individuals. In this study formulae developed on a sample of Caucasian white subjects were used for predicting TBW and ECW in Turkish–Mongolian individuals. Although our subjects were slightly older (31·0 vs 25·5 years) than those studied by Deurenberg *et al.* (1993), and their weight and height were lower (65·1 vs 73·1 kg and 167·8 vs 183·0 cm, respectively), their TBW% (60 vs 61%) and ECW : ICW ratio (0·63 vs 0·66) were comparable. Since body impedance is largely influenced by the intracellular and extracellular distribution of water (Deurenberg, van der Kooy, Leenen and Schouten 1989), it is reasonable that the formulae developed by Deurenberg *et al.* (1993) would give reliable results in non-Caucasian subjects with values of TBW% and ECW : ICW ratio similar to those of the original population. In conclusion our study suggests that TBW and ECW of non-Caucasian subjects from Central Asia can be adequately predicted from MFBIA by using predictive algorithms generated on white Caucasian subjects with similar body-water distribution. The fact that the Turkish–Mongolian ethnic group is characterized by a mixture of Caucasoid and Mongolian features (Bernhard 1993) should also be taken into account when considering the results of the present study. However, within the scope of this study it appears that the utilization of selected formulae provides precise and accurate prediction of body hydration and water compartmentalization between extracellular and intracellular spaces in different ethnic groups. Thus, due to its portability, BIA appears to be an expedient and reliable technique for on-field assessment of hydration status in different ethnic groups such as Turkish–Mongolian individuals.

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Zusammenfassung. Die Tatsache, daß nur eine geringe Zahl von Untersuchungen zur Bioelektrischen Impedanzanalyse (BIA) an nicht kaukasischen Bevölkerungsgruppen vorliegt, scheint die verlässliche Nutzung dieser Methode in anthropologischen Feldstudien zu limitieren. In der vorliegenden Untersuchung wurde an 28 männlichen aus Kasachstan (Zentralasien) stammenden türkisch-mongolischen Individuen das Gesamtkörperwasser (TBW) und das extrazelluläre Wasser (ECW) mit der Deuteriumoxid (D_2O)- bzw. der Natriumbromid (NaBr)- Verdünnungsmethode bestimmt. Die bioelektrische Impedanz (BI) wurde bei variierenden Frequenzen bestimmt. Unter Anwendung von Formeln, die für eine Stichprobe von kaukasischen Individuen, mit einem dem der Probanden der vorliegenden Studie ähnlichen Hydrationsstatus, entwickelt wurden, konnten aus der BI für 1 und 100 kHz ECW und TBW berechnet werden. Der aus der BI bei einer Frequenz von 100 kHz geschätzte Wert für TBW ($37{\cdot}5 \pm 3{\cdot}3$ l) war mit dem aus der D_2O-Verdünnungsmethode resultierenden Wert hoch korreliert und unterschied sich nicht statistisch signifikant ($39{\cdot}0 \pm 4{\cdot}1$ l, $r = 0{\cdot}894$, $p < 0{\cdot}0001$, SEE = $1{\cdot}9$ l). Analog war der aus der BI bei einer Frequenz von 1 kHz geschätzte Wert für das ECW ($15{\cdot}1 \pm 1{\cdot}2$ l) mit dem aus der NaBr-Verdünnungsmethode resultierenden Wert hoch korreliert und unterschied sich statistisch nicht signifikant ($15{\cdot}0 \pm 1{\cdot}6$ l, $r = 0{\cdot}847$, $p < 0{\cdot}0001$, SEE = $0{\cdot}8$ l). Daraus wird gefolgert, daß ausgewählte Prädiktionsgleichungen, die für kaukasische Individuen entwickelt wurden, eine präzise und akkurate Bestimmung von ECW und TBW in türkisch-mongolischen Bevölkerungen ermöglichen könnte.

Résumé. L'utilisation de la méthode d'analyse par impédance bioélectrique dans les études de terrain en anthropologie, présente une fiabilité limitée par suite du petit nombre d'études disponibles pour les groupes ethniques non caucasiens. Dans cette études, 28 sujets masculins turco-mongols natifs du Kazakhstan (Asie centrale) ont subi un examen d'estimation de leur eau corporelle totale (ECT) et de leur eau corporelle extracellulaire (ECE) par deux techniques: dilution du dioxide de deuterium (D_2O) et du bromide de sodium (NaBr). L'impédance bioélectrique (IB) a été enregistrée à des fréquences multiples. l'ECE et l'ECT ont été calculées à partir de l'IB à 1 et 100 kHz respectivement, en appliquant les formules développées sur un échantillon de sujets caucasiens présentant un statut hydrique semblable à celui de la population étudiée. L'ECT estimée par l'IB à 100 kHz ($37{\cdot}5 \pm 3{\cdot}3$ l) était hautement corrélée et ne différait pas significativement de celle obtenue par dilution de D_2O ($39{\cdot}0 \pm 4{\cdot}1$ l, $r = 0{\cdot}894$, $p < 0{\cdot}0001$, SEE = $1{\cdot}9$ l). De manière similaire, l'ECE prédite à partir de l'IB à 1 kHz ($15{\cdot}1 \pm 1{\cdot}2$ l) était hautement corrélée et ne différait pas significativement de celle obtenue par dilution du NaBr ($15{\cdot}0 \pm 1{\cdot}6$ l, $r = 0{\cdot}847$, $p < 0{\cdot}0001$, SEE = $0{\cdot}8$ l). On conclut qu'une sélection de formules développées sur des sujets caucasiens peut fournir des estimations précises de l'ECE et de l'ECT dans les populations turco-mongoles.