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Original article

Bioimpedance index for measurement of total body water in severely malnourished children: Assessing the effect of nutritional oedema

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SUMMARY

Background & objectives: Restoration of body composition indicates successful management of severe acute malnutrition (SAM). Bioimpedance (BI) index (height^2/resistance) is used to predict total body water (TBW) but its performance in SAM, especially with oedema, requires further investigation.

Subjects/Methods: Children with SAM (mid-arm circumference <11.0 cm or weight-for-height <70% of median of NCHS reference and/or nutritional oedema) admitted to Jimma University Hospital were included. Tetrapolar-whole-body impedance (Z), resistance (R) and reactance (Xc) were measured at 50 and 200 kHzs. Pre- and post-deuterium dose saliva samples were analysed using isotope-ratio mass spectrometry. TBW was regressed on H^2/Z. Xc and R were height (H)-indexed, and Xc/H plotted against R/H.

Results: Thirty five children (16 non-oedematous and 19 oedematous) with median (interquartile range) age of 42 (26–54) months were studied. Height-for-age z-score (mean ± SD) was low in both non-oedematous (−3.9 ± 2.8) and oedematous (−3.6 ± 1.7) children. Oedematous children had lower BI parameters than non-oedematous ($p < 0.001$) and hence higher H^2/Z for a given amount of TBW. At both 50 and 200 kHz, association between H^2/Z and TBW was stronger in non-oedematous children than oedematous (60% higher coefficient of determination and 20% lower standard error of estimate). Intercepts and regression estimates at 50 and 200 kHz were similar, in both oedematous and non-oedematous children.

Conclusions: In children with oedematous SAM, BI index was weak in predicting TBW. Moreover, predicted TBWs at 200 kHz and 50 kHz did not differ and hence BI measurement at 50 kHz is still practical for TBW estimation.

1. Introduction

Restoration of body composition indicates successful management of severe acute malnutrition (SAM), but no easy and accurate method is available [1–3]. Bioimpedance method (BIM), whole-body [4] or segmental [5], is a safe, rapid and easy technique often used to predict total body water (TBW) and lean mass can in healthy individuals. However, its conventional application, commonly referred to as bioimpedance analysis (BIA), requires population-specific equations [6,7], and its accuracy is limited in general [8]. This is due in part to inter-individual variability in body proportions (e.g. limb lengths), as narrow cylinders such as limbs contribute disproportionately to total body impedance [9]. In healthy children, age or body size-to-age variation in impedance (Z in Ohm) could affect accuracy of TBW prediction [10]. Stunted children with some degree of wasting produce higher R compared with anthropometrically normal children [11] and thus reflects the influence of abnormal body composition and/or body proportion.

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The poorer the ability of BIA to predict TBW, the less suitable it will be for clinical monitoring of body composition.

In most four-electrode (tetrapolar) measurements, Z is measured with 800 μA alternating current at 50 kHz passing through the body, between the wrist and ankle [12]. Two relationships between the Z of the body and its volume (V) are central to this method [4]. First, derived from Ohm's Law, V is inversely related to Z and directly to conductive distance, approximated by height or length (H):$V = \rho H^2/Z$. Tissue specific resistivity, ρ, is a frequency-dependent constant inversely related to the number of free ions per V [13]. Theoretically it is independent of body size, shape and age but could be affected by abnormal tissue hydration and/or osmolality [10–12]. Second, at low frequencies electric current flows around the cell without penetrating into the cell, whereas at high frequencies the membrane capacitance is no impediment to the current and it flows indiscriminately through both intracellular and extracellular space, and thus assumed to reflect TBW better [4].

Decreased total body potassium, increased total body sodium and increased TBW are well recognized and common features of SAM, and often indicate diminished body cell mass and expanded extracellular fluid [1,2,16]. Yet, how these abnormalities, particularly oedema, affect the performance of BIA is little studied. This study explores the performance of BIA in estimating TBW in children with SAM and the influence of oedema, using deuterium dilution method as a reference.

2. Subjects and methods

2.1. Study setting and subjects

Children 0.5–14 years of age with SAM (MUAC <11.0 cm or weight-for-height <70% of the median of the NCHS growth reference and/or nutritional oedema) admitted to Jimma University Hospital were included after informed consent. Children with life threatening conditions such as shock were excluded.

2.2. Data collection

Weight was measured to the nearest 10 g using a digital scale (Tanita BD 815 MA, Tokyo, Japan) and length to nearest 0.1 cm using a length board (SECA 416, Hamburg, Germany) for children less than 2 years of age. For older children, height was measured using stadiometer (SECA 214, Hamburg, Germany) to nearest 0.1 cm. Pitting oedema was checked by gentle pressure with the thumb on the feet for 3–5 s.

TBW was determined by deuterium dilution at a dose of 0·5 g of ^2H_2O (Sercon, Crewe, UK) per kg body weight diluted in 5 ml of sterile water. Older children drank the deuterium whereas for younger children it was dripped into the mouth using a plastic tube attached to a syringe. Any spillage was collected in a tissue, weighed and subtracted from the dose. Pre-dose, and 3-h post-dose samples of saliva were collected in all children. An additional 4-h post-dose sample was collected in 15 children. In two children (1 with oedema), samples were collected hourly till 8-h post-dose. Children were not given feeds 30 min before and 15 min after deuterium dosing. Saliva samples were kept at −20 °C before shipment to the UK for analysis. Though the dose used was based on Fourier transform infrared (FTIR) protocol, it was difficult to get the minimum (2 ml) saliva volume required for this method [17] and analysis was therefore undertaken at Institute of Child Health, UK using isotope-ratio mass spectrometry (Delta Plus XP; Thermofisher Scientific, Bremen, Germany). Samples were analysed in duplicate, with all enrichments normalized to values for international standard water samples, and the average value used in subsequent calculations. The mean precision of ^2H analyses was, 9.4 deltas, inducing imprecision on TBW of 0·8%. For calculating TBW, it was assumed that ^2H dilution space overestimated TBW by a factor of 1·044 (Ref. [16]).

A tetrapolar portable bioimpedance (BI) analyser (BODYSTAT QuadScan 4000, British Isles, England), emitting 200 μA root mean square alternating current at 5, 50, 100 and 200 kHzs, was used to measure resistance (R), reactance (Xc) and Z. Self-adhesive disposable electrodes were attached at the right hand and foot, injecting leads were connected to the electrodes just behind the finger and toe and the measuring leads were then connected to the electrodes on the right wrist and right ankle. Measurement was done after deuterium dosing and in triplicate, 5 min apart, while children were calm and supine on stretcher with limbs abducted from the body. Triplicate values were averaged for each subject.

Among 7 oedematous children with TBW data at 3 and 4 h, there was an average increase in isotopic enrichment, which indicated a delayed deuterium equilibration time. The calculated TBW values therefore decreased during this period by 3.5% (95% CI: -10.6, 3.4). Among 7 non-oedematous children, there was no average change in TBW calculated from 3- and 4-h post dose samples (average difference −0.2%, 95%CI -5.4, 5.0). Data on deuterium enrichment up to 8 h in two children are shown in Fig. 1. In the non-oedematous child, enrichment declined from 3 h, indicating equilibration by 3 h and subsequent dilution of body water by fluid intakes. In the oedematous child, enrichment increased between 3 and 4 h, and then declined. This suggests that equilibration was complete by 4 h in this child. On this basis, we assumed that all oedematous children were equilibrated by 4 h. Therefore, 3-h TBW values were

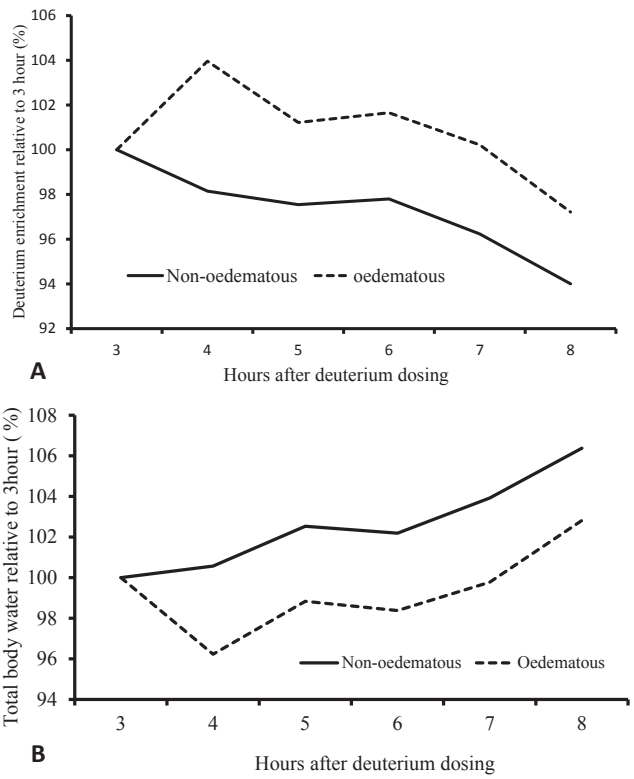

Fig. 1. Patterns of deuterium enrichment (A) and corresponding calculated total body water (B) in two children with severe acute malnutrition. In Fig. 1A, declines in enrichment can be attributed to post-equilibration fluid intake, whereas increases in enrichment indicate continuing isotopic equilibration. The data therefore indicate that the non-oedematous child was equilibrated by 3 h, and the oedematous child by 4 h.

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