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**Comparison of Total Body  
Water Estimates From  $^{18}\text{O}$   
and Bioelectrical Response  
Prediction Equations**

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## INTRODUCTION

Measurement of total body water (TBW) during extended-duration spaceflight may be performed to evaluate exercise and cardiovascular countermeasures to microgravity-induced deconditioning. Quantification of TBW can be performed through the use of water enriched with a stable isotope of oxygen,  $^{18}\text{O}$  [1,2]. A sample of  $\text{H}_2^{18}\text{O}$  is ingested orally and, after 3 to 5 hours of equilibration with the body's water compartments, saliva samples are obtained to measure  $\text{H}_2^{18}\text{O}$  dilution. This method of TBW measurement is noninvasive, requires little effort on the part of the subject, and has a precision of 0.8-1.5% when compared to serum samples [1]. Traditionally, isotope dilution using deuterated ( $^2\text{H}_2\text{O}$ ) or tritiated ( $^3\text{H}_2\text{O}$ ) water has been used as the reference for TBW measurement. Use of deuterated water, however, can cause metabolic side effects when given in high doses; and tritiated water is radioactive, which limits its use in many circumstances. Analysis of hydrogen isotope dilution also requires use of very precise and expensive spectrometric equipment [2]. Finally, hydrogen isotopes can overestimate the TBW measurement due to hydrogen exchange with protein. The use of  $^{18}\text{O}$ , a naturally occurring stable isotope of oxygen, is much more desirable than the use of hydrogen isotopes; but it is not without drawbacks, which are: (1) expensive generation (\$500-\$1000/dose), (2) limited availability (i.e., approximately 1 year to obtain), and (3) need for costly spectrometric analyzers to evaluate the saliva samples. For these reasons, many clinical and research facilities estimate TBW indirectly through hydrostatic weighing techniques. Total body immersion is used to calculate the body density

from which percent body fat and fat-free mass (FFM) are derived. TBW represents a fixed fraction (73.2%) of FFM [7].

Bioelectrical responses have been shown to estimate human body composition accurately [3-6]. Bioelectrical response devices measure resistance (R) and reactive capacitance (reactance) responses to an excitation current of 800  $\mu\text{A}$  at a signal frequency of 50-120 kHz. The subthreshold current is applied through electrodes at the wrist and ankle, and bioelectrical measurements are made immediately. A clear linear relationship ( $r = -0.86$ ) exists between TBW (from deuterium-labeled water) and bioelectrical resistance [5]. This relationship is strengthened when TBW is correlated with height (Ht) and bioelectrical resistance (R) in the factor  $\text{Ht}^2/\text{R}$  [3,5].

Numerous prediction methods exist for estimating body composition and TBW. Identification of a method that is rapid, accurate, and cost-effective is necessary so that the procedure may be used during extended-duration spaceflight to monitor countermeasure therapy. The purpose of this investigation was to compare TBW estimates from three established bioelectrical response prediction equations [2,3,8] with two standard methods—hydrostatically derived FFM and  $^{18}\text{O}$ .

## METHODS

Twenty-seven subjects (14 females and 13 males) were recruited through the NASA Health Screening Facility at the NASA/Johnson Space Center and gave written informed consent to participate in the study (Table 1).

TABLE 1. *Subject characteristics (mean  $\pm$  SD)*

n	27	
Mean Age (yr)	32	$\pm$ 6
Mean Height (cm)	168.5	$\pm$ 6.0
Mean Weight (kg)	67.8	$\pm$ 12.2
Mean Body Fat (%)	21.0	$\pm$ 6.7

All testing was completed between 7:00 a.m. and 1:00 p.m. on the same day. Subjects were asked to fast for at least 4 hours, with no consumption of caffeine or alcohol within 24 hours of testing. Upon arrival, a background saliva sample was collected to establish existing levels of  $^{18}\text{O}$  in the body. Subjects then were given a bagel and juice prior to ingesting 40-45 g of  $\text{H}_2^{18}\text{O}$  (6-7 g of  $^{18}\text{O}$ ). To ensure that the entire amount of  $^{18}\text{O}$  was ingested, the bottle containing the  $\text{H}_2^{18}\text{O}$  was rinsed twice with approximately 50 mL of tap water and was given to the subject to drink. Subjects then gave approximately 5 mL of saliva at 3, 4, and 5 hours after initial  $\text{H}_2^{18}\text{O}$  consumption. Saliva samples were immediately frozen and later analyzed by the Stable Isotope Laboratory, Children's Nutrition Research Center at the Baylor College of Medicine.

Bioelectrical response testing was completed between the 3- and 4-hour  $^{18}\text{O}$  saliva collection times. Skin sites on the distal surface of the metacarpals and metatarsals, between the medial and lateral malleoli of the ankle, and between the distal prominences of the radius and ulna, were cleansed with alcohol before applying four silver/silver chloride ECG electrodes (Fig. 1).

Tetrapolar bioelectrical resistance readings were taken immediately upon resuming the supine position, and measurements were made of the subject's right side. Bioelectrical resistance responses to input frequencies of 50-300 kHz were simultaneously obtained from a modified 4284A Hewlett-Packard Precision LCR Meter (Fig. 2).

Three bioelectrical response prediction equations were used to estimate TBW (Table 2).

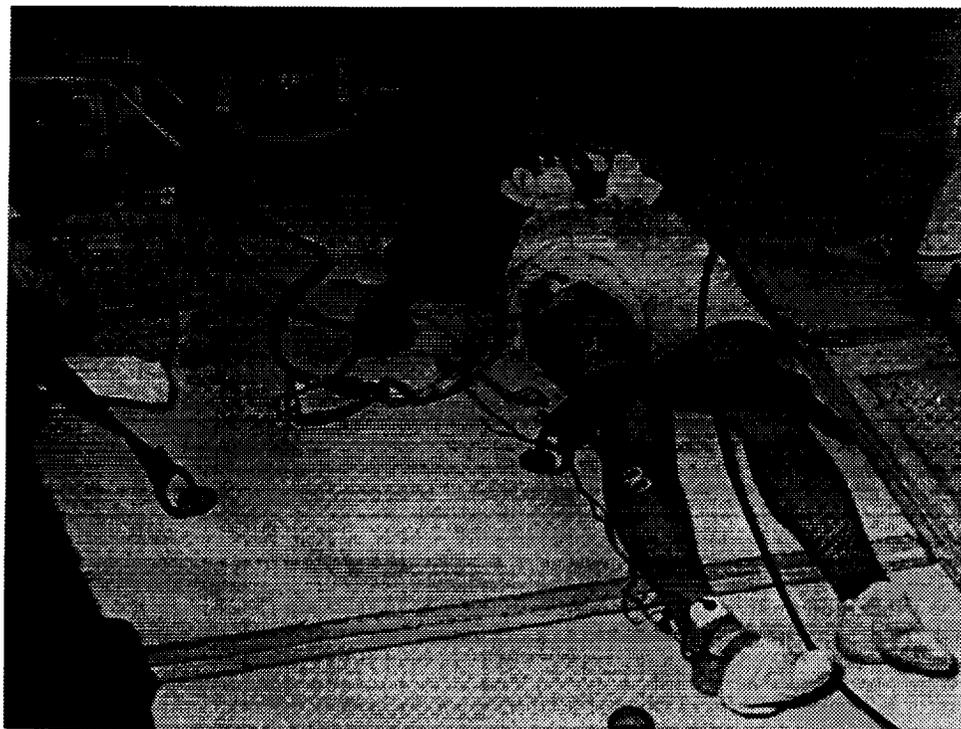


FIG. 1. Bioelectrical resistance test conducted in the supine position. Electrodes being used for measuring—found on the subject's right hand and right foot—are covered with cloth to keep them temperature constant.

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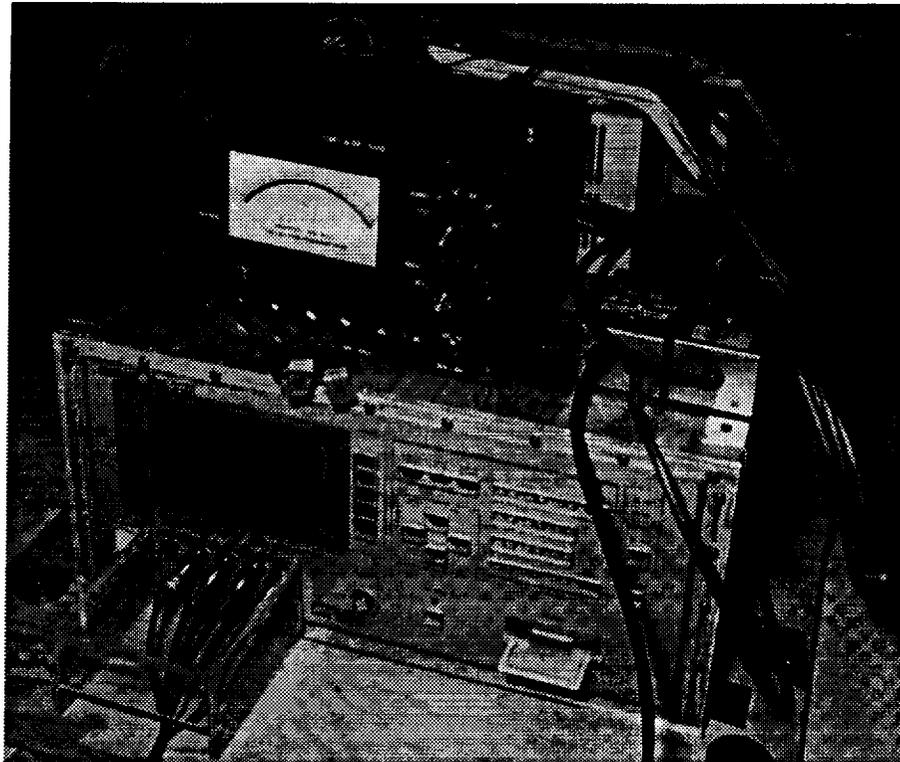


FIG. 2. Hewlett-Packard Precision LCR meter and YSI skin temperature probe apparatus.

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TABLE 2. *Bioelectrical response prediction equations used to estimate TBW*

- 
1. Lukaski & Bolonchuk [4]  

$$TBW (L) = 0.337 \cdot (Ht^2/R) + 0.14 \cdot Wt - 0.08 \cdot Age + 2.9 \cdot Gender + 4.65$$
 where R at 50 kHz  
 Gender: Male = 1, Female = 0
  
  2. Kushner & Schoeller [3]  
 Males:  $TBW (L) = 0.396 \cdot (Ht^2/R) + 0.143 \cdot Wt + 8.399$   
 Females:  $TBW (L) = 0.382 \cdot (Ht^2/R) + 0.105 \cdot Wt + 8.315$   
 where R at 50 kHz
  
  3. Segal et al. [8]  

$$TBW (L) = 3.43 + 0.14 \cdot Wt + 0.45 \cdot (Ht^2/R)$$
 where R at 100 kHz
-

Body density determination through hydrostatic weighing was conducted immediately after ingesting the  $H_2^{18}O$ . Each subject was completely submerged in a tank of water (30-35°C) and was allowed to perform normal tidal breathing through a snorkel-like device (Fig. 3).

Ten maximal exhalations were performed, at which time weights were recorded. Body volume was corrected for lung residual volume using an oxygen dilution technique [9] that was performed at the end of the test period. Percent body fat [10], FFM, and TBW (73.2% of FFM) were then calculated from body density using a two-compartment model.

TBW (kg) mean, standard deviation (SD), and standard error of estimate as a percent of the  $^{18}O$  mean (SEE), were calculated for TBW

measurements from  $^{18}O$ , FFM from hydrostatic weighing, and the three bioelectrical response prediction equations (Table 2). Pearson product-moment correlation coefficients ( $r$ ) were calculated to determine the relationship between each method and  $^{18}O$ . A repeated measures MANOVA with post-hoc Dunnett's Test was used to determine significant differences between bioelectrical response prediction and  $^{18}O$ .

## RESULTS

The equation from Segal et al. [8] yielded mean TBW estimates that were significantly ( $p < 0.05$ ) greater than the mean TBW measurement given by  $^{18}O$ . The bioelectrical response prediction equation from Lukaski &

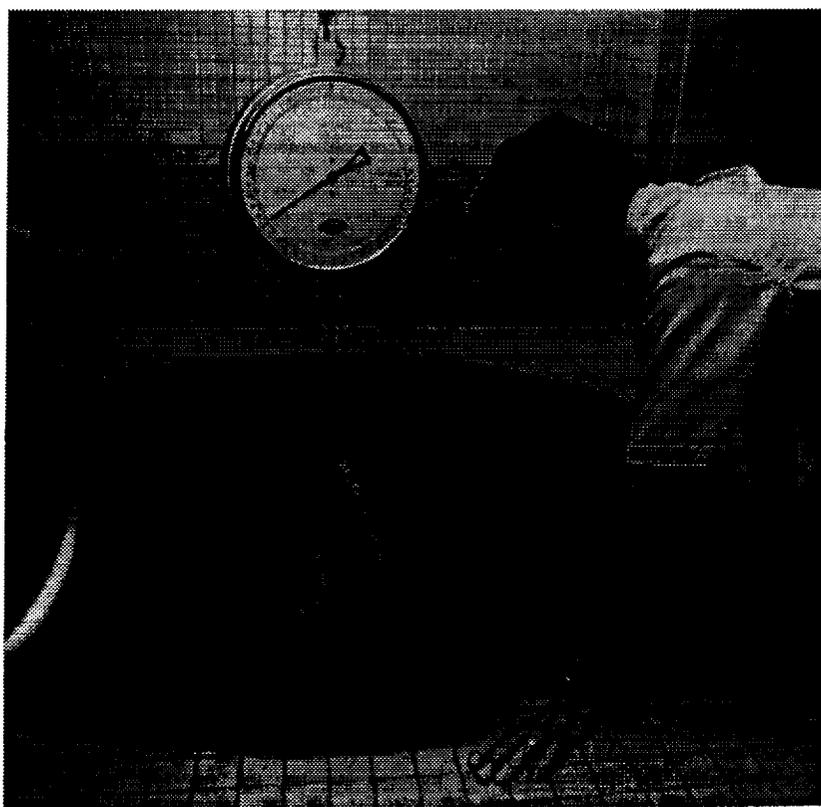


FIG. 3. Body volume determination by hydrostatic weighing using a snorkel-like device and tidal breathing

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Bolonchuk [4] significantly ( $p < 0.05$ ) under-predicted TBW. TBW estimates from FFM and the bioelectrical response prediction equation of Kushner & Schoeller [3] were not significantly ( $p > 0.05$ ) different than those given by  $^{18}\text{O}$  (Table 3, Fig. 4). Standard errors identified through regression analyses were, however, higher for all bioelectrical response prediction equations when compared to those derived from FFM (Table 3). Strong correlation coefficients

were found between each prediction method and  $^{18}\text{O}$ .

Findings reported here are for all subjects combined (Table 3). When the findings for males ( $n = 13$ ) and females ( $n = 14$ ) were analyzed separately, the mean, SD, SEE, and  $r$  were altered but statistical findings were unchanged. Results are, therefore, presented for all 27 subjects.

TABLE 3. Total body water estimates from three bioelectrical response prediction equations and hydrostatically derived FFM compared to total water measured from  $^{18}\text{O}$  ( $n = 27$ )

Method	Mean	SD	r	SEE (%)
$^{18}\text{O}$	39.29	7.31	--	--
FFM	39.16	7.44	0.98	3.5
Kushner & Schoeller [3]	39.81	7.96	0.93	6.7
Lukaski & Bolonchuk [4]	32.81*	7.09	0.94	6.4
Segal et al. [8]	41.56*	8.22	0.93	7.2

\*Significantly, ( $p < 0.05$ ) differs from  $^{18}\text{O}$ .

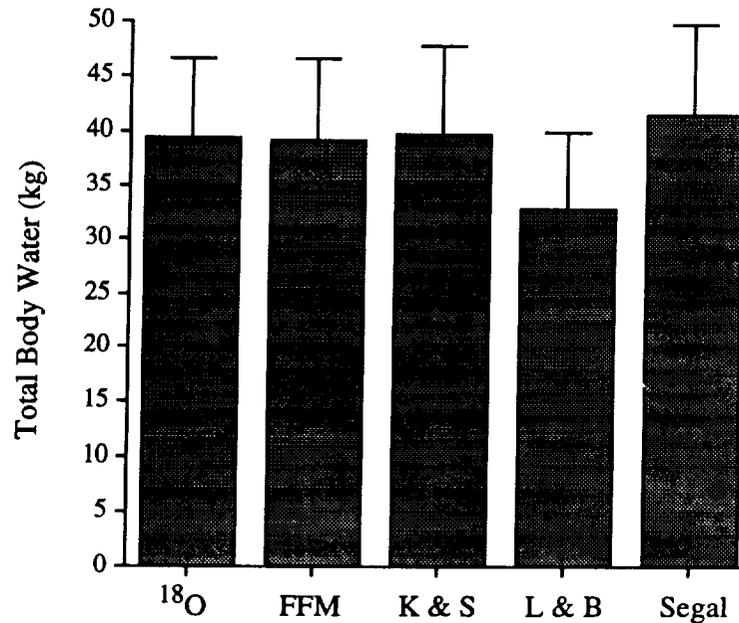


FIG. 4. Comparison (mean  $\pm$  SD) of TBW prediction methods with  $^{18}\text{O}$

## CONCLUSION

Bioelectrical response testing requires minimal equipment and effort, and produces results quickly. If accurate, this method would be ideal for use during spaceflight to monitor hydration status and perhaps improve countermeasure application and orthostatic tolerance upon return to one-g. The bioelectrical response prediction equation from Kushner & Schoeller [3] provided the most valid measure of TBW in this study when compared to the reference value given by  $^{18}\text{O}$ . The Kushner & Schoeller equation, unlike

the other two bioelectrical response prediction equations examined, uses separate numerical constants depending upon gender. All three prediction equations had greater variability in measuring TBW than that found with FFM, which is commonly used in laboratories as a reference to assess body composition (Table 3). It is suggested that, before using the impedance method to measure TBW during spaceflight, other bioelectrical response prediction equations with lower variability should be identified.

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