Original Research

Validity of the Bottle Buoyancy Model for Body Fat Determination

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ABSTRACT

International Journal of Exercise Science V(i): X-Y, YEAR. **Purpose:** We investigated a modification of the bottle buoyancy (BB) method in comparison to single frequency, bioelectric impedance analysis (BIA) as a valid noninvasive method of percent body fat (%BF) determination. **Procedures:** Twenty eight participants (15 men, 13 women), in counterbalanced-order, completed the BB, BIA, and computerized hydrostatic densitometry (HD) methods. We elected to modify the BB method using a 12.15 L container with participants hugging the container in an upright position. Consistency measures of intraclass correlation coefficient (ICC), typical error (TE), coefficient of variation (CV) and total error of measurement (TEM) are reported. **Main Findings:** Our modification of the BB resulted in less "bobbing" than described in the previous method, and took ~5 to 15 min per participant to complete. Group values (%BF) did not differ ($p > 0.05$) for BB (20.7 ± 6.6), BIA (21.0 ± 9.7), and HD (20.2 ± 7.2). Strong measurement agreement was observed between BB and HD (ICC: 0.95, TE: 1.80 %BF, CV: 10.7%, TEM: 1.77 %BF). Agreement between BIA and HD (ICC: 0.85, TE: 3.35 %BF, CV: 19.6%, TEM: 3.29 %BF) was lower than BB. **Conclusion:** Our modification of the BB method resulted in similar measurement consistency with the originating method. The BB method appears to represent a valid surrogate measure of %BF, superior to that observed with BIA.

KEY WORDS: bioelectrical impedance analysis, body composition, body fat percentage, hydrostatic densitometry

INTRODUCTION

Body composition is a measurement of percent osseous, muscle, and adipose tissue that composes the body (11, 16). Maintaining fat free mass rather than fat mass can provide competitive edge (1, 12). A certain percentage of body fat (%BF) is necessary for optimum performance (e.g., storage/release of fat soluble vitamins, storage/release of a lipid reservoir as substrate during exercise and recovery); however, an excessive %BF may hinder total work capacity (i.e., reduce power relative to total mass (1). Many athletes are encouraged by coaches and medical staff to maintain a specific %BF. Thus, a functioning performance facility must have access to valid methods for determining %BF (1, 12).

Several standard methods are utilized to assess %BF in athletes, including

but not limited to dual-energy X-ray absorptiometry scan (DEXA), hydrostatic densitometry (HD), air displacement plethysmography, bioelectrical impedance analysis (BIA), and skin fold assessment (1, 4). DEXA is an expensive and time-intensive method (2, 7). Air displacement plethymography and HD also are costly and require considerable training to operate. Conversely, single frequency BIA and skin folds assessment can be more affordable and portable methods; however, the skin fold assessment method requires experience and necessitates the participant's willingness to expose their skin. Moreover, the validity of both of these surrogate measures of %BF has been questioned (15).

Katch et al. (11) proposed an inexpensive alternative procedure for predicting body density by having participants float on a partially-filled water container within a tank of water: a method later termed the bottle buoyancy (BB) method. The BB method involves sealing a partially-filled container with a sufficient volume of water and air such that the participant holding onto the bottle neither floats nor sinks, but remains neutrally buoyant underwater. Underwater weight is determined simply by measuring the remaining volume of water needed to fill the bottle, whereby a filling volume of 1 L of water is equivalent to 1 kg of underwater body weight. The BB method utilizes *Archimedes' Principle of Buoyancy*, and is related inversely to how the HD method is determined. Specifically, where the HD method physically measures a participant's weight underwater while suspended on a scale, the BB method determines the volume of air necessary to float a participant. The BB method is exciting as it represents an inexpensive surrogate measure of %BF with the promise of having better validity than the other noninvasive methods, namely, BIA. Unfortunately, little empirical data exists on the BB method. We are only aware of three prior studies (6, 8, 11), with 12 years passing since the last publication on the topic. Moreover, none of these prior studies compared the validity of the BB method to BIA on the same sample of participants. Single frequency BIA is a valid (4), common and cost-effective method for assessing %BF in non-clinical settings. Thus, we felt it was important to compare the BB method to the BIA to determine if it has the potential to be a valid alternative for %BF determination on a limited budget.

When Katch et al. (11) introduced the BB method, they used a 7.57 L (2 gal) rigid plastic container. Both Carey and Serfass (6) and Gulick and Geigle (8) used 11 L containers. Positioning on the bottle in the BB method is not clear. Gulick and Geigle (8) depicted a representative participant attempting to lay prone on the bottle underwater. In pilot testing, we found participants had a tendency to roll or flip on an 11 L container. We switched to a 12.15 L container and found participants could more easily comply by remaining upright, and simply hugging the container as they submerged. Thus, the purpose of the study was to observe the validity of our modified procedure for the BB method against the single frequency BIA for estimating %BF as determined using HD.

METHODS

Participants

Twenty-eight individuals (all Caucasian) were tested for this study (men: n = 15,

women: n = 13). Age, body mass out of water, height and body mass index (BMI) for the men were 24.7 ± 3.2 y, 84.4 ± 13.9 kg, 1.6 ± 0.1 m, and BMI = 27.2 ± 4.0 kg/m^2, respectively. Demographic data for the women were 24.8 ± 6.3 y, 74.0 ± 12.9 kg, 1.7 ± 0.1 m, and BMI = 25.0 ± 3.1 kg/m^2, respectively. Participants were asked to refrain from exercise 24 hours prior to testing, consumption of food 4 hours prior to testing, and to remain hydrated prior to their designated testing times. All data collection took place between 11:00 am and 1:00 pm during the week. Men wore tight fitting spandex shorts and women wore tight fitting two-piece swim suits. To enhance participant compliance, we provided the following preliminary instructions to the participants: "the baggier the swimwear, the more buoyant you will be underwater, increasing the likelihood of the test indicating your %BF is higher than it actually is." All participants confirmed they were comfortable swimming in deep water; however, a certified lifeguard was present for all testing. All procedures for this study were pre-approved by our institutional review board and all participants signed an informed consent to volunteer for this study.

Protocol

Participants engaged in BIA method of %BF first to avoid biasing the measure with a wet swim suit worn. Subsequently, the HD and BB methods were conducted in counterbalanced fashion to avoid an order-effect. All testing was conducted on the same day and within a two-hour time period to avoid variations in hydration (12). All testing procedures were standardized and conducted by the same investigators to eliminate errors associated with inter-rater reliability. Body weight on land was measured using a Tanita scale (TBF-215, Tokyo, JAP) and standing height was measured using a wall mounted height rod preceding each test (Detecto, Webb City, MO, USA). Water temperature was measured with a standard thermometer in degrees Celsius (°C). The equipment utilized for the BIA was a leg-to-leg 50kHz Tanita Body Composition Analyzer (Model TBF-215, Tokyo, JAP). Equipment utilized for HD measure was Exertech™ Body Density Measuring System, including Flotaweigh™ Floating Wireless Underwater Weighing System (Exertech™ WD4 Software, Malvern, PA, USA). The BB method equipment included a standard water cooler container of 12.15 L (3 gal) in dimension with a screw on cap (Culligan® , Rosemont, IL, USA). To expedite filling and removal of water, we marked the container in 0.5 L increments. We used a 1 L graduated cylinder to fill and remove water from the container to ensure accuracy.

Single Frequency Bioelectrical Impedance Analysis

The participant's demographic information (age, sex, and height) was entered into the BIA apparatus. The body type (athletic or standard) was then selected based on the participant's athletic background per manufacturer's recommendations. The participant stepped onto the platform scale of the BIA with clean, bare feet, facing forwards and remained completely still during the measurement. The %BF was calculated using Tanita Body Composition Analyzer's proprietary equation.

Hydrostatic Densitometry

Prior to commencing the study, the manufacturer of the HD apparatus used in the study validated the sensors and tare weight with a set of calibrated weights. For each participant, the HD apparatus was calibrated by taking repeated measurements of a known mass. The participants all wore a rubber swimming cap and nose plugs during testing and patted down their attire to reduce air pockets. Researchers patted down the participant's swimming cap. Water temperature was kept at ~30-32 °C; however the precise temperature during testing was recorded. Participants sat on platform attached to the scale either cross-legged, with their feet in front of them, or on their knees, depending on range of motion through hip flexion for full submersion ability. Participants held the handles on the scale and exhaled their forced vital capacity. When the force on the sensors of scale reached equilibrium, a measure was taken and a knock on the tank prompted the participant to come up for air. Three to five trial runs were conducting to familiarize the participant with the HD procedures. Full submersion was required for a period of five seconds. Ten trials were conducted to gain an array of measures. The mean of the two highest body densities (D_b) were taken and entered into the Siri equation (14) (Figure 1) to determine our criterion measure of %BF.

Bottle Buoyancy

Pool temperature was taken at the beginning of each test to determine water density. Participants used a rubber swimming cap and nose plugs. Before entering the pool, the researchers patted down the participant's swimming cap to seek out any pockets of air and participant's patted down their attire to reduce air pockets.

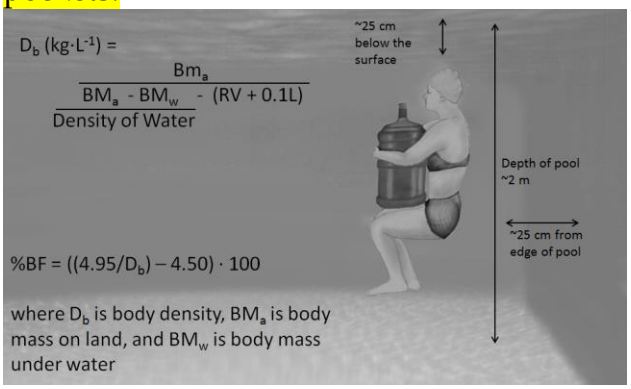

Figure 1. Illustration of the Bottle Buoyancy Method

Goggles were not permitted due to the unknown effect they would have on the measurement and no other persons were allowed in the pool at the time of testing. Participants entered the pool at a water depth of ~2 m and remained next to the edge of the pool, away from any underwater jets. Participants practiced exhaling maximally while submerging in order to acquaint themselves with the procedures of the BB method. Based on the gender, the 12.15 L container was filled either to 8 L for men and 10 L for women as a preliminary measure (i.e., 4.15 of 2.15 L of dead air within the plastic container, respectively). While hugging the container and staying afloat by holding onto the poolside, participants were instructed to take a deep breath in and exhale. After the participant exhaled almost completely, they were then instructed to gently let go of the pool without pushing off to avoid bobbing up and down. If the participant sank, water was removed in 0.5 L increments. Conversely, water was similarly added if the participant floated above the water surface. These steps were repeated until the participant was neutrally buoyant with

~25 cm of water over their head confirmed visually overhead (6) (Figure 1). Three verification trials were conducted with participants being instructed to try and expel out more air in an attempt to sink the bottle. If neutral buoyancy was confirmed, testing was completed.

The volume of water remaining in the bottle was subtracted from the total bottle volume. A volume of 83 mL was added to that value to correct for the volume air needed to maintain neutral buoyancy of the bottle itself. Residual lung volume (RV) in liters was estimated using height and age with separate equations for men [(0.033 ·height) + (0.022 ·age) – 1.232] and women [(0.046 ·height) + (0.016 ·age) – 2.003] (13). The Siri equation was used to estimate %BF (14) (shown in Figure 1), where BM_a is body mass in air, BM_w is body mass under water, and D_w (water density) was calculated using water temperature (C°) ·-0.003 + 1.004627.

Statistical Analysis

The dependent variable of %BF between gender and the three different methods was evaluated using a 2 X 3 analysis of variance (ANOVA) with repeated measures. To facilitate comparison of our results with the original method conceived by Katch et al. (11), we compared the dependent variable of D_b between HD and the BB method using *t* test, r^2, and standard error of estimate (SEE). The level for rejecting the null hypothesis was set at $p < 0.05$ and the data from each trial were screened preliminarily for normality, skewness, and outliers. Measurement consistency between %BF methods was evaluated using typical error (TE), intraclass correlation coefficient (ICC), and coefficient of variation (CV) (9) along with the total error of measurement (TEM). Although considered a proportionally-biased statistic (9), Bland-Altman plots (3) were provided in an effort to display the distribution of error between methods across the range of %BF values evaluated. Summary statistics are reported using mean ± SD and all data analyses were conducted using SPSS version 12.0 (SPSS Inc., Chicago, IL, USA)

Results

All twenty eight participants' data collected from the three apparatuses were analyzed. There was no significant main effect ($F = 0.97$, $p = 0.39$, $\eta_p^2 = 0.07$) between methods nor sex-differences in %BF observed ($F = 3.09$, $p = 0.06$, $\eta_p^2 = 0.19$). Table 1 provides summary statistics of each measurement. Highly consistent measures of D_b between HD and the BB method were observed (ICC = 0.95, TE: 0.004 g ·ml^{-1}, CV = 0.37%), with no significant difference (mean difference = 0.0008 g ·ml^{-1}, $t = 0.73$, $p = 0.47$). A strong correlation between Db between HD and the BB was observed ($r^2 = 0.952$) with a SEE of 0.0054 kg ·L^{-1}.

Analysis of the two trials for the HD measurement was highly reliable (Table 2, top rows), providing a stable criterion measurement. For both genders, along with the total sample, the typical error of measurement was nearly twice as large for BIA in comparison to the BB method. Limits of agreement for the BIA also were >2 times the limits of agreement with the BB method (Figure 2). The correlation between BIA and HD was r = 0.77 with a SEE of 4.66 %BF. Also shown in Figure 2, the distribution of error was similar between 7 to 35% BF for a given participant.

Table 1. Summary statistics of percentage body fat (%BF)

		Mean	SD	N
Hydrostatic Densitometry	Men	16.5	6.5	15
	Women	24.4	5.6	13
	Total	20.2	7.2	28
Bioelectric Impedance	Men	15.6	7.8	15
	Women	27.3	7.8	13
	Total	21.0	9.7	28
Bottle Buoyancy	Men	17.1	7.3	15
	Women	22.8	8.2	13
	Total	20.7	8.1	28

Table 2. Measurement consistency of the bottle buoyancy and bioelectric Impedance analysis (BIA) methods of estimating percentage body fat (%BF) determined using hydrostatic densitometry (HD)

Comparisons	Typical Error (%BF)	ICC (α)	CV (%)	TEM (% BF)
	OVERALL (*N* = 28)			
Trial 1 – Trial 2 HD	0.09	1.00	0.6	0.10
HD – Bottle Buoyancy	1.80	0.95	10.7	1.77
HD – BIA	3.35	0.85	19.6	3.29
	MEN (*n* = 15)			
Trial 1 – Trial 2 HD	0.08	1.00	0.6	0.10
HD – Bottle Buoyancy	1.24	0.97	10.8	1.27
HD – BIA	2.39	0.89	19.7	2.40
	WOMEN (*n* = 13)			
Trial 1 – Trial 2 HD	0.10	1.00	0.4	0.10
HD – Bottle Buoyancy	2.25	0.91	13.5	2.27
HD – BIA	3.78	0.69	15.4	4.19

ICC-Intraclass Correlation Coefficient
CV-Coefficient of Variation
TE-Total Error of Measurement

Larger inconsistencies between the predictive measures were observed for the BIA in women vs. men. Overall, the statistical differences between methods and gender were not observed (i.e., no interaction, see Table 1 and 2).

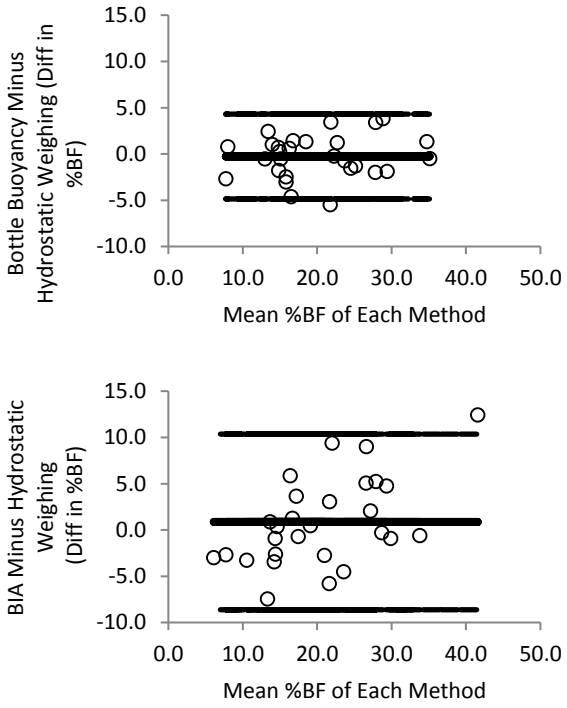

Figure 2. Measurement agreement between our criterion measure of hydrostatic densitometry (HD) versus the BIA and bottle buoyancy methods (Note the deliberate use of an identical scale for the *x* and *y* axes). Solid lines represent the mean difference between methods whereas the dashed lines represent the limits of agreement within ± 2 SD.

DISCUSSION

The present study evaluated the validity of two surrogate measures of %BF using HD method as the criterion measurement. The HD method requires access to a tank along with a scale for measuring underwater body weight. The measurement of underwater body mass is more precise when using digital sensors interfaced with a microcomputer. Unfortunately, HD is cost prohibitive in non-clinical settings and

therefore valid surrogate measures of %BF are needed.

The BIA scale is a very common non-invasive method of %BF determination; however, several researchers have questioned the validity of the single frequency BIA (10, 15). In the case of Jackson et al. (10), SEE ranging of 4.6 to 6.4%BF were observed for the BIA method. The SEE for estimating %BF with HD in the present study was comparable to the results of Jackson et al. (i.e., SEE = 4.7%BF).

Similar to single frequency BIA, the BB method represents an alternative inexpensive and non-invasive method of %BF determination, yet very little research exist on the method. The present investigation determined that the absolute validity of the BB method, as determined using LOA, TE, CV%, and TEM was ~two-times better than the BIA method.

Procedures for the BB method used in this study were modified from the previous studies in an effort to expedite the speed and ease of the measurement. For instance, a smaller container (7.57 L) was used in the originating study (11). We recommend use of a larger container because participants have an easier time hugging the container and remaining upright. In our pilot testing, it took ~45 to 60 min to attain neutral buoyancy in the prone position, whereas using our modified procedure with the upright position, hugging the container (Figure 1), the total time for testing was ~5 to 15 min. With the 7.57 L bottle, Katch et al. (11) described participants "having a tendency to curl forward or list sideways." We observed similar action during pilot testing when using the 7.57 L bottle, in addition to participants "bobbing" up and down and creating turbulence. Such a result prohibits others from testing at the same time and lengthens the time to establish neutral buoyancy for given participant.

In comparing our modified procedure with the original method reported by Katch et al. (11), we used the same statistics they used to evaluate D_b. Each of our procedures had r^2 values exceeding 0.95 and a D_b SEE statistic of <0.006 kg·L^{-1}. Moreover, our ICC value for the overall sample for estimated %BF (α = 0.95) was identical to the value reported by Gulick and Geigle (8). Thus, our modification of the BB protocol did not alter validity of the original method.

Despite previous research on the BB method, the BB method has experienced little traction within the scientific literature and therefore with non-clinical practices. The reasons, quite possibly, for the lack of adopting the BB method is a combination of a lack of awareness and the time involved with using the prone position method to arrive at a suitable volume for establishing neutral buoyancy. We believe our modification allows the participant to remain in a position of comfort with less "bobbing," therefore simplifying the BB method.

It is worth mentioning two aspects of our protocol that allowed for enhanced comfort of the participants. First, we recommend conducting the BB method in a pool at a depth of ~2 meters. In our pilot testing, participants that were in the pool at a depth greater than 2 meters reported feeling anxious because they were out of breath and had to swim a greater distance to return to the surface. Second, participants reported greater comfort with the BB method when they were able to hold on to the side of the pool and expel all their air and then let go of the pool edge once

almost all their air was expired and calmly sink underwater.

We acknowledge several limitations that, if removed, would enhance confidence in the BB method. Firstly, we relied on an estimate of RV for both the BB and HD measures. A more direct estimate of RV (e.g., dilution method) (18) would remove the estimate of RV as a source of error. Secondly, investigations using criterion measures such as CT scan, deuterium oxide dilution techniques or air-displacement plethysmography would increase our knowledge about the validity of the BB method. Finally, methods to enhance deriving at a starting volume for the BB method would further decrease the time to complete the protocol. Conceivably, a different surrogate estimate of %BF, or a combination of estimates (e.g., BM, body mass index), might expedite arriving at an estimated under water weight, and by extension, a volume of air necessary to establish neutral buoyancy.

Another consideration for alternative procedures for the BB method is the utilization of tare weighting. As Katch et al. (11) used a 7.57 L container; they described encountering two participants for which their container was too small necessitating the addition of adding external mass to establish neutral buoyancy. We would not recommend using external mass with the BB method described in this study due to increased risk to the participant. Moreover, with use of the 12.15 L bottle, we do expect added weight would be necessary.

CONCLUSION

The present study, to our knowledge, marks only the fourth study to report on the validity of the BB method for determination of %BF. Using a 12.15 L bottle, with participants hugging the bottle in an upright position, we saw less "bobbing" and turning/tilting of the bottle as described previously (11), thus offering the potential to conduct multiple tests simultaneously. Although BIA represents a popular, non-invasive surrogate measure of %BF, measures of absolute error were ~2 times greater than the error observed with the BB method. Thus, we recommend the BB method over the BIA method as a non-invasive valid estimate of %BF.

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