Exploration of a Variation of the Bottle Buoyancy Technique for the Assessment of Body Composition

DAWN T. GULICK AND PAULA RICHLEY GEIGLE

Institute for Physical Therapy, Widener University, Chester, Pennsylvania 19013.

ABSTRACT
Hydrostatic weighing has long been recognized as a reliable and valid method for the assessment of body composition. An alternative method known as bottle buoyancy (BB) was introduced by Katch, Hortobagyi, and Denahan in 1989. The purpose of this clinical investigation was to determine the accuracy of the BB technique using an 11-L container. Sixteen individuals (8 men, 8 women) were weighed hydrostastically using a chair/scale and the BB technique. The overall intra-class correlation coefficient for the two techniques was 0.9537. A 2-variable ANOVA was significant for gender but not for technique, and there was no interaction between variables. Thus, the BB technique appears to be an accurate substitute for the chair/scale technique for hydrostatic weighing. The BB method does not involve elaborate equipment and is portable. It could be improved with the use of multiple bottles of various volumes or a calibrated bottle to minimize the number of trials needed for accurate measurements. BB is a valuable, simple clinical tool for assessing body composition based on the principles of hydrostatic weighing and can be performed in any high school, college, or community swimming pool.

Key Words: body fat, body composition, hydrostatic weighing


Introduction
A variety of methods have been utilized to assess body composition. These methods vary in cost and complexity. The dual-energy x-ray absorptiometry (DXA) is a valid method (7) that is both costly and complex. Hydrostatic weighing (HW) is also a valid method of assessing body composition, but can be costly given the apparatus needed to perform the technique. The search for a cost-effective, clinically simple method of body fat analysis has been the subject of much research (1, 3, 5, 8, 10, 12, 16, 17).

In 1989, Katch, Hortobagyi, and Denahan (10) introduced an alternative technique known as bottle buoyancy (BB). This technique involves a 7.57-L (2 gal) rigid plastic container similar to a water cooler jug and a graduated cylinder and is based on the principles of HW. To date, only one other study has been done comparing the HW and BB techniques (3), yet this method could be very valuable for 2 reasons. First, the portability of such a technique would allow HW to be performed in any vat of water at least 4 ft deep, i.e., any high school, college, or community swimming pool. Second, the need for expensive equipment, i.e., an elaborate apparatus to suspend a chair over the water, is completely avoided. Although this technique has been examined using a 7.57-L container, other container sizes have not been explored. The purpose of the present investigation was to explore the accuracy of another size of container (a standard 11-L water cooler jug that is readily available) for the BB technique to assess body composition. If accurate, this method would offer a simple, inexpensive, and portable method of assessing body composition.

Methods
Subjects
Sixteen white individuals from an academic setting consented to participate in this comparison. The following information was collected on each subject: gender (8 men, 8 women), age (28.03 ± 3.77 years), land weight (86.75 ± 10.66 kg for men; 59.31 ± 3.07 kg for women), and height (1.82 ± 0.05 m for men; 1.65 ± 0.06 m for women). The subjects were instructed in the 2 techniques and then were randomly assigned to perform the HW technique or the BB technique first. The alternative technique was performed in the same session when the subject was ready.

Instruments
The equipment utilized for the HW technique included a 20-lb-capacity spring-loaded suspension scale that was accurate to within 2 oz (McMaster-Carr, New...
Brunswick, NJ), a flexible plastic playground swing, and a 5-lb lead weight. The swing was suspended from a horizontal crossbar that was attached to the scale by an "S" hook (Figure 1). The length of the vertical chains was adjusted for each individual to accommodate the torso length. For the BB technique, the only equipment used was an 11-L rigid plastic bottle with a cap and a graduated cylinder accurate to 5 ml.

**Procedure**

**Hydrostatic Weighing.** The baseline weight of the weighing apparatus was recorded prior to the weighing of each subject. The subject was positioned on the hydrostatic swing with hands firmly holding the vertical chains and buttocks in contact with the swing at all times. The subject performed several forceful exhalations prior to submerging in the water (Figure 1). The subject was then verbally encouraged to exhale maximally in an attempt to leave only the residual volume (RV) in the lungs. Subject performed repeated trials until 2 measurements within 0.25 lb (4 oz) were obtained. A minimum of 3 trials were performed by each subject (6). Rest periods between trials were based on the comfort of the subject. However, all subjects remained in the pool until both techniques were completed. The baseline weight was deducted from the final measurement on the scale, and this was identified as the underwater weight. RV was estimated using the following formula (16):

\[
RV \text{ (men)} = (0.069 \times \text{height in inches}) \\
+ (0.017 \times \text{age in years}) - 3.45
\]

\[
RV \text{ (women)} = (0.081 \times \text{height in inches}) \\
+ (0.009 \times \text{age in years}) - 3.9.
\]

Body density was calculated using the following formula (9, 12):

\[
\text{body density} = \frac{\text{land weight}}{\text{volume of water}} \\
+ \frac{\text{volume of water}}{\text{density of the water}} \\
- \text{(RV in liters + 0.1 for GI gas)}.
\]

Land and water weights were measured in pounds and converted into kilograms. The density of the water was 0.99574 at 93°F, and GI = gastrointestinal.

Percent body fat was then calculated using the equation developed by Siri, as reported by Lohman (11):

\[
\% \text{body fat} = \frac{495}{\text{Body density}} - 450.
\]

**Bottle Buoyancy.** The BB technique involved a rigid 11-L plastic bottle with a cap. The clinician filled the bottle with approximately 7–8 L of water initially and instructed the subject to hold the bottle against the chest snugly while submerging slowly in the water. The subject was again encouraged verbally to maximally exhale while underwater. The goal was for the subject to achieve a buoyancy-neutral position. Carey and Serfass (3) defined neutral buoyancy as the position in which the subject is suspended in the water approximately 6–12 in. beneath the surface, i.e., the subject neither sank nor floated. If the subject continued to sink toward the bottom of the pool, water was removed from the bottle. If the subject floated to the surface or if any portion of the body was out of the water, more water was added to the bottle. This process continued until neutral buoyancy was achieved (Figure 2). Upon completion of the BB technique, the volume of water needed to fill the bottle was measured and recorded. The conversion of volume to mass (1 L of water = 1 kg) was performed (http://www.fourmilab.ch/hackdiet/www/subsection1.4.2.0.7.html). A correction factor of 0.08845 kg (corresponding to the mass needed to sink the plastic bottle) was added.
to the underwater weight of each subject to compensate for the buoyancy of the bottle itself. Katch et al. (10) also employed such a correction factor. Their use of a 7.57-L (2 gal) bottle required the addition of 0.095 kg. This compensated measurement was then inserted into the body density formula as the water weight. Thus, the identical formulae used for the HW technique were used to calculate body density and percent body fat for the BB technique.

**Statistical Analyses**

Descriptive statistics were calculated for each subject. The mean and SE for percent body fat were calculated for each technique for all subjects and by gender. The intraclass correlation coefficient (ICC\(_{2,1}\)) for the 2 techniques was calculated for all subjects and by gender. A 2-variable (gender and technique) repeated-measures analysis of variance (ANOVA) was performed with a \( p \leq 0.05 \) level of significance to evaluate interaction between the 2 variables. All analyses were performed with the SPSS 9.0 statistical software package.

**Results**

Data for all 16 subjects were analyzed. The body fat calculations for each technique are displayed in Figure 3. The means and SEs for the percent body fat for HW and BB across gender are displayed in Table 1. An ICC\(_{2,1}\) matrix is displayed in Table 2. A 2-variable repeated-measures ANOVA by gender and technique revealed a significant difference for gender only (\( F = 19.388, p = 0.000 \)). There was not a significant difference between techniques (\( F = 0.014, p = 0.906 \)), and there was no interaction (\( F = 0.175, p = 0.679 \)).

**Discussion**

A variety of techniques to assess body composition have been studied (4, 5, 8). Until 7 years ago, most techniques were compared to hydrostatic weighing (12). Recent studies have examined the DXA method and found it to be valid but costly (2). The underwater weighing technique is based on Archimedes' principle that a buoyancy force acts upon an immersed body, resulting in a loss of weight in the water that is equal to the weight of the fluid displaced (13, 15).
nique has a measurement error of <1% (11, 17). Nevertheless, some quantitative assumptions must be made. Because direct measurement of RV is impractical, this value must be estimated. The RV formula utilized in this study resulted in very little loss of accuracy in body density computation (9, 14, 16, 17). Weltman and Katch (16) studied underwater weighing using RV and total lung capacity and found that the difference in percent body fat was negligible (0.5% in men and 0.9% in women). In addition, the methodology utilized in the study involved the one-time calculation of RV. This estimate was used for both the HW and BB techniques. Hence, any measurement error in the estimation would be nullified by having each subject perform both techniques.

The results of this study demonstrated that the BB technique can be used as a valid substitute for the scale/chair technique of HW to assess body composition. The ICC data support this conclusion. The ANOVA ruled out the influence of any interaction effect. Given that both techniques are based on the same principle of water displacement, these results make sound clinical sense, and the data are consistent with previous work (3, 10). The point in question prior to conducting this study was whether the size of the bottle would be relevant. Katch et al. (10) utilized a 7.57-L bottle, and Carey and Serfass (3) used an 11-L bottle. We used an 11-L bottle and found high values for ICC across men and women and overall. Hence, the simplistic nature of the BB technique and the minimal equipment needs make this method very desirable. It can be performed in any pool with a depth of at least 4 ft. The fact that the only items needed are the bottle and a graduated cylinder makes this a portable method for serial measurements in any aquatic environment. Hence, an athlete can be monitored over the course of a season or an individual interested in reducing body mass can monitor ongoing progress using this simple process.

It may be advantageous to have a variety of bottles of different volumes. This would allow the clinician to quickly exchange one bottle for another to reduce the time and possibly the number of trials needed to achieve neutral buoyancy. We recommend 6-8 with 0.25-L differences in volume for women and 0.5-L differences for men. If only one bottle was available, markings similar to those of a graduated cylinder could be made on the bottle so that the volume added with each trial is quantified rather than arbitrary. The position that the bottle is held relative to an individual's body type is also important because the distribution of an individual's body mass influences the position of the body in neutral buoyancy. The higher an individual's center of mass, the higher the bottle should be positioned on the person's trunk (in the chest region). Likewise, the lower an individual's center of mass, the lower the bottle should be held (in the hip region). This slight alteration serves as a counterbalance to achieve a neutral buoyancy position with the individual's trunk parallel to the surface of the water. Recognition of these differences in anthropometrics will minimize the number of trials necessary to achieve neutral buoyancy.

**Practical Applications**

The BB technique is a simple method of calculating body composition that can be used in a variety of environments. The portability can be advantageous, and the size of the bottle does not appear to be an issue as long as the appropriate buoyancy correction factor is included in the calculations. The bottle may not even be necessary. A belt with pouches containing lead weights or calibrated floats could result in a high correlation with the gold standard of hydrostatic weighing (with a chair/scale). The selection of weights versus floats would be dependent on the anthropometrics of the individual. Thus, the time component of measuring water volume displaced could be reduced. The mass of the weights or the buoyancy of the floats (on the belt) would be an indicator of the density of an individual. The evaluation of a fitted belt is the next step in this ongoing investigation.

**Acknowledgments**

The authors acknowledge Professor Robert Wellmon for his statistical expertise and assistance with SPSS. His contribution to this manuscript is greatly appreciated. The authors also thank the Widener University Physical Therapy Class of 2000 for their assistance in exploring this technique.

**References**


Address correspondence to Dawn T. Gulick, dawn.t.gulick@widener.edu.