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Assessment of body composition by air-displacement plethysmography: influence of body temperature and moisture

David A Fields*[1], Paul B Higgins[2] and Gary R Hunter[3]

Address: [1]Department of Health and Exercise Sciences, University of Oklahoma, Norman, OK, USA, [2]Division of Physiology and Metabolism, Department of Nutrition Sciences, University of Alabama at Birmingham, Birmingham, AL, USA and [3]Department of Human Studies University of Alabama at Birmingham, Birmingham, AL, USA

Email: David A Fields* - dafields@ou.edu; Paul B Higgins - higginsp@uab.edu; Gary R Hunter - ghunter@uab.edu

* Corresponding author

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Abstract

Background: To investigate the effect of body temperature and moisture on body fat (%fat), volume and density by air-displacement plethysmography (BOD POD).

Methods: %fat, body volume and density by the BOD POD before (BOD POD_{BH}) and immediately following hydrostatic weighing (BOD POD_{FH}) were performed in 32 healthy females (age (yr) 33 ± 11, weight (kg) 64 ± 14, height (cm) 167 ± 7). Body temperature and moisture were measured prior to BOD POD_{BH} and prior to BOD POD_{FH} with body moisture defined as the difference in body weight (kg) between the BOD POD_{BH} and BOD POD_{FH} measurements.

Results: BOD POD_{FH} %fat (27.1%) and body volume (61.5 L) were significantly lower ($P \leq 0.001$) and body density (1.0379 g/cm³) significantly higher ($P \leq 0.001$) than BOD POD_{BH} %fat (28.9%), body volume (61.7 L), and body density (1.0341 g/cm³). A significant increase in body temperature (~0.6°C; $P \leq 0.001$) and body moisture (0.08 kg; $P \leq 0.01$) were observed between BOD POD_{BH} and BOD POD_{FH}. Body surface area was positively associated with the difference in %fat independent of changes in body temperature and moisture, $r = 0.30$, $P < 0.05$.

Conclusion: These data demonstrate for the first time that increases in body heat and moisture result in an underestimation of body fat when using the BOD POD, however, the precise mechanism remains unidentified.

Background

Air-displacement plethysmography (i.e. BOD POD) has gained popularity among body composition researchers since its introduction in 1995. This is mainly attributable to the non-invasive test-procedure and the lack of technical expertise required compared to the traditional hydrostatic weighing procedure.

The BOD POD is a single fiberglass unit composed of two chambers. The test chamber accommodates the subject during testing and the reference chamber contains instrumentation for measuring changes in pressure between the two chambers [1]. The operating principles of the BOD POD are detailed elsewhere [1-3]. Briefly, the volume of the test chamber is determined by pressure changes precipitated between the test chamber and reference chamber

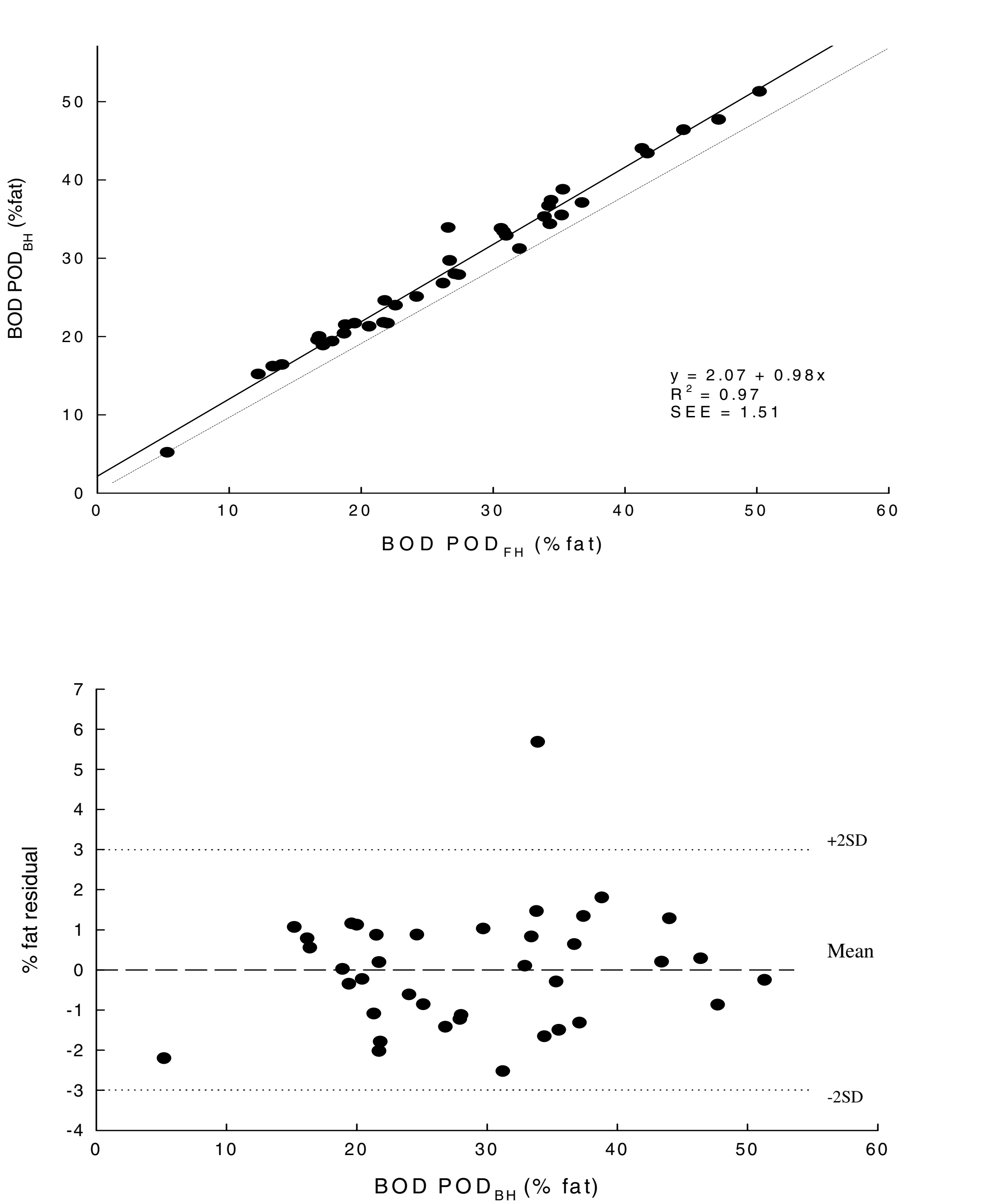

Figure 1
Panel A is the regression of percent fat determined by BOD POD$_{BH}$ before hydrostatic weighing against percent fat determined by BOD POD$_{FH}$ following hydrostatic weighing. The dotted line is the line of identity (regression slope = 1 and regression intercept = 0). The regression line significantly deviated from the line of identity. Panel B are the residuals from linear regressions of the percent fat from the BOD POD$_{BH}$ on percent fat from the BOD POD$_{FH}$. The middle line represents the mean difference while the upper and lower dashed lines represent ±2 SD from the mean. No bias was observed as indicated by the non-significant *P* value.

Table 1: Subject characteristics and body composition variables before and immediately following hydrostatic weighing.

Variable	BOD POD_{BH}	BOD POD_{FH}	*P* value
Body weight (kg)	63.58 ± 13.7	63.66 ± 13.7	$P \leq 0.05$
Body temperature (°C)	36.3 ± 0.97	36.9 ± 1.00	$P \leq 0.001$
Body surface area§ (cm^2)	17090 ± 1714	17090 ± 1714	
SAA (L)	-0.7976 ± 0.01	-0.7976 ± 0.01	
TGV (L)	3.46 ± 0.11	3.37 ± 0.11	*NS*
Raw Body Volume (L)	61.1 ± 2.4	60.9 ± 2.4	$P \leq 0.001$
Corrected Body Volume* (L)	61.7 ± 14.5	61.5 ± 14.5	$P \leq 0.001$
Body density (g/cm^3)	1.0341 ± 0.022	1.0379 ± 0.023	$P \leq 0.001$
Percentage body fat	28.91 ± 10.3	27.12 ± 10.3	$P \leq 0.001$

§ 71.84 × $weight^{0.425}$ × $height^{0.725}$ * Corrected for TGV and surface area artifact (raw body volume - SAA + 40%TGV) SAA: surface area artifact BOD POD_{BH} : BOD POD measures before hydrostatic weighing. BOD POD_{FH} : BOD POD measures following hydrostatic weighing. Data are mean ± SD

by a moving diaphragm mounted on the common wall between the chambers. The pressure ratio relationships between the chambers are inversely related and are characterized by Boyle's Law:

$$P_1/P_2 = V_2/V_1$$

where V_1 and P_1 are the volume and pressure prior to subject entry into the test chamber and V_2 and P_2 are the volume and pressure while the subject is in the test chamber. Therefore, subject body volume will equal the volume of the test chamber before subject entry less the test chamber volume with the subject present.

Because of difficulty maintaining isothermal conditions in the enclosed environment of the test chamber, the BOD POD functions under adiabatic conditions (i.e. air temperature is gaining/loosing heat), thus Poisson's Law more accurately characterizes the pressure volume relationship in the testing chamber:

$$P_1/P_2 = (V_2/V_1)^{\gamma}$$

where V_1 and P_1 are the volume and pressure prior to subject entry into the test chamber, V_2 and P_2 are the volume and pressure while the subject is in the test chamber, and γ is the ratio of the specific heat of a gas at constant pressure to constant volume (1.4 for air) [4,5]. Moreover, isothermal air present in the test chamber during a body volume measurement will result in an underestimation of body volume because isothermal air is more easily compressed (40%) than an equivalent volume of adiabatic air, resulting in a lower pressure output signal for a given body volume [1]. There is one source of isothermal air (i.e. air in the lungs) and several sources that are "isothermal-like" (air trapped within the fabric of clothing and air trapped within hair on the head and body). Instructions and procedures have been recommended by the manufactures to correct and control for these sources of error [1,6].

To avoid erroneous data the BOD POD manufacturers recommend that testing be conducted prior to exercise, that the subject be dry, and that the testing environments temperature remain stable [7]. Strict adherence to these conditions can sometimes prove difficult when testing large numbers of subjects in a short period of time and when testing people who are perspiring or have an elevated temperature due to illness. In one study, BOD POD measurements were performed following hydrostatic weighing, which resulted in a regression that significantly deviated from the line of identity [8]. However, other studies have reported significant differences when the BOD POD preceded hydrostatic weighing [9,10]. Thus, the specific effect of elevated body temperature and body moisture (resulting from hydrostatic weighing) on BOD POD measurements needs clarification. An increase in body temperature and moisture could increase the quantity of isothermal-like air surrounding the skin. Therefore, the purpose of this study was to determine the effect of increased body temperature and moisture on BOD POD estimates of %fat, body volume, and body density. We hypothesized that an increase in body temperature and moisture would result in an underestimation of %fat. We also speculated that the increase in temperature, the increase in moisture, and total body surface area (BSA) would be positively associated with the magnitude of this underestimation.

Methods

Subjects

Thirty-two adult females (33 ± 11 yr., 64 ± 14 kg., 167 ± 7 cm) representing a wide range of BMI (19 – 36 kg/m^2)

gave their informed consent to participate in the study. Approval for the use of human subjects was obtained from the Institutional Human Subject Review Board from the University of Alabama at Birmingham.

Protocol

Subjects arrived for testing after an overnight fast. Height was measured using a wall mounted stadiometer while body weight was measured to the nearest 0.01 kg using the BOD POD system electronic scale, as previously described and was calibrated prior to each BOD POD test [2]. Body temperature was measured in the right ear using a Thermoscan IRT 3520 orbital thermometer (Braun, San Diego, CA). The repeat measures, between multiple measurements for body temperature in eight healthy subjects had an intra-class correlation of r = 0.98 and a SEE = 0.03°C. After body temperature was determined and before hydrostatic weighing, the first BOD POD (BOD POD_{BH}) test was performed, subjects were then asked to shower (this was done to keep the tank free of debris, wash off excess lotion, and sweat from the subjects) and prepare for hydrostatic weighing. Hydrostatic weighing was performed as part of an alternative study objective, (data not presented). Immediately following hydrostatic weighing subjects dried off thoroughly using towels provided by the laboratory. A second body temperature was determined and the second BOD POD test was performed (BOD POD_{FH}). The moisture trapped in body hair and the fabric of the swimsuit was defined as the difference in body weight (kg) prior to hydrostatic weighing and upon completion of hydrostatic weighing (after toweling dry). All testing was undertaken by the same investigator (DAF).

BOD POD instrumentation

Whole body air-displacement was evaluated with the BOD POD version 1.69 (Body Composition System; Life Measurement, Incorporated, Concord, CA) as previously described [2]. Each subject was tested in a one – piece swimsuit and Lycra® swim cap. Thoracic gas volume (TGV) was measured in all subjects and BOD POD conditions (i.e. BOD POD_{BH} and BOD POD_{FH}) according to the procedures described in the manual, while %fat was determined by the Siri equation [11]. In the calculation of body density for each testing condition, the body weight obtained in the dry state was used; this was done to investigate the effect of moisture and temperature increases on estimates of %fat independent of effects caused by increases in body weight. BSA was calculated according to the Dubois formula [12]: BSA = 71.84 × Weight $(kg)^{0.425}$ × Height $(cm)^{0.725}$. Same-day repeat measures of body density by the BOD POD in our laboratory had an intraclass correlation of r = 0.98 and an SEE of 0.00365 (g/cm^3) [6]. The room that housed the BOD POD was well ventilated between tests.

Data analysis

Group mean estimates of %fat, body volume, and body density, by the BOD POD were compared using paired t-tests. Linear regression analysis and residuals from the regressions (percent fat and body density) were used to assess the agreement between BOD POD_{BH} and BOD POD_{FH} for body density and %fat. Estimates were not considered different if the regression slope did not differ from one or the intercept from zero (line of identity). BOD POD_{FH} %fat, body volume and density estimates were calculated using dry body weight to control for the effect of weight gain (due to moisture). Pearson correlation coefficients were used to examine the relation between the changes in body temperature, moisture, %fat, body volume and BSA before hydrostatic weighing (BOD POD_{BH}) and following hydrostatic weighing (BOD POD_{FH}). The independent relationships of Δ temperature (difference in BOD POD_{BH} temperature and BOD POD_{FH} temperature), moisture, and BSA with Δ %fat (difference in BOD POD_{BH} %fat and BOD POD_{FH} %fat) were determined using partial correlations. Statistical significance was set at $P \leq 0.05$. All statistics were derived using SPSS statistical software (version 10.0; SPSS Inc., Chicago, IL).

Results

The %fat (28.9 vs. 27.1), raw body volume (61.1 L vs. 60.9 L), and corrected body volume (61.7 vs. 61.5 L) were significantly higher for the BOD POD_{BH} vs. BOD POD_{FH} (Table 1).

Linear regression analysis revealed that the regression of BOD POD_{BH} %fat vs. BOD POD_{FH} %fat significantly deviated from the line of identity, $P \leq 0.005$ (Figure 1 panel A), though no bias was found across the range of body fatness $P = 0.66$ (Figure 1 panel B). However, BOD POD_{BH} body density versus BOD POD_{FH} body density did not significantly deviate from the line of identity (Figure 2 panel A) and no significant bias was observed between body density estimates across the range of fatness $P = 0.36$ (Figure 2 panel B).

Following hydrostatic weighing (i.e. BOD POD_{FH}) subjects demonstrated a significant increase in body temperature (36.9°C vs. 36.3°C; $P \leq 0.001$) and body weight (63.66 vs. 63.58 kg; $P \leq 0.05$) as compared to BOD POD_{BH} (Table 1 and Figure 3).

Δ%fat was not associated with Δ temperature after controlling for BSA and moisture gain, similarly Δ%fat was not associated with moisture gain after controlling for BSA and Δ temperature (Table 2). However, BSA was positively correlated (r = 0.30, $P < 0.05$) with Δ %fat after controlling for moisture gain and Δ temperature (Table 2).

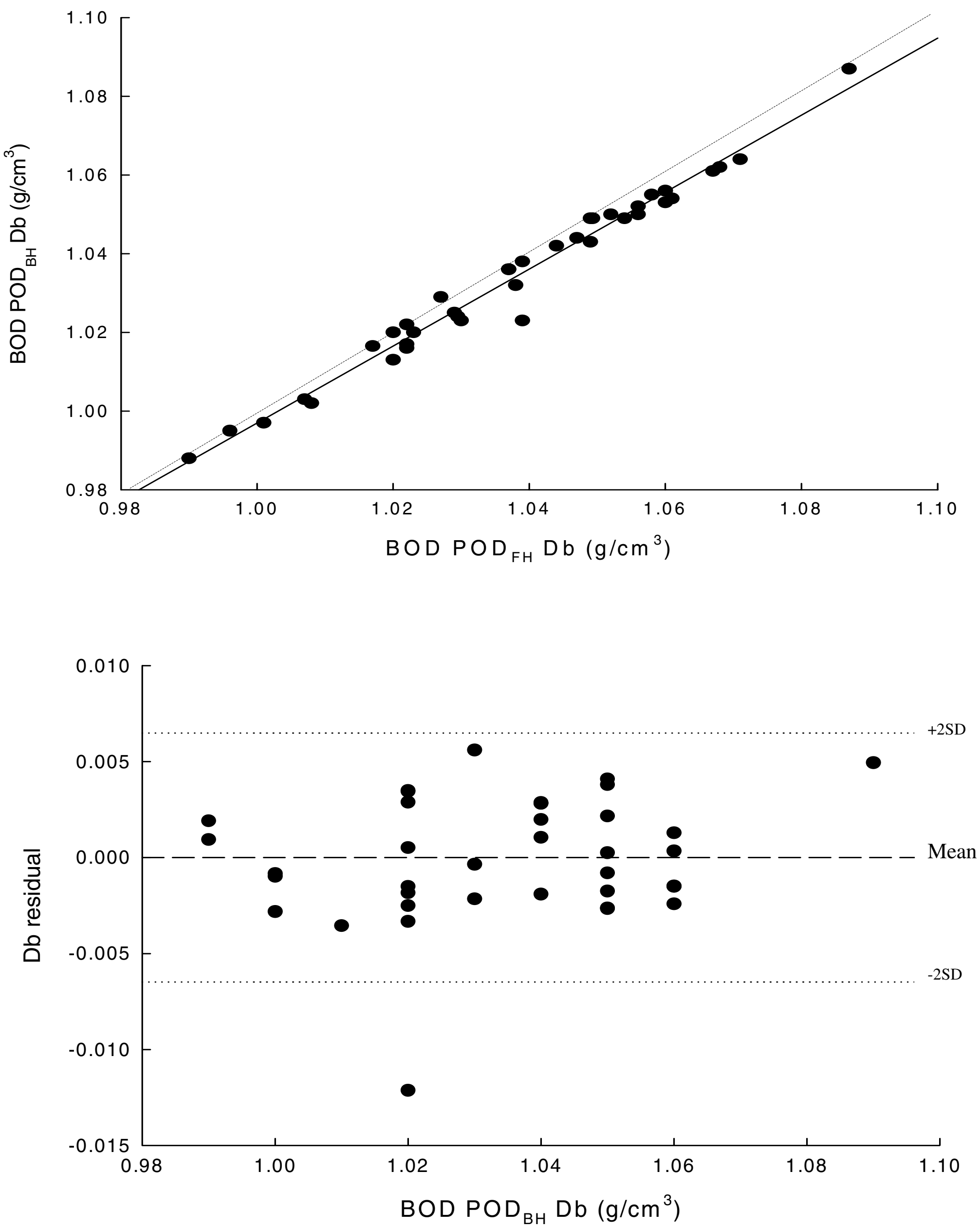

Figure 2
Panel A is the regression of body density (g/cm^3) determined by BOD POD$_{BH}$ before hydrostatic weighing against body density determined by BOD POD$_{FH}$ following hydrostatic weighing. The dotted line is the line of identity (regression slope = 1 and regression intercept = 0). The regression line did not significantly deviate from the line of identity. Panel B are the residuals from linear regressions of body density BOD POD$_{BH}$ on body density from the BOD POD$_{FH}$. The middle line represents the mean difference while the upper and lower dashed lines represent ±2 SD from the mean. No bias was observed as indicated by the non-significant *P* value.

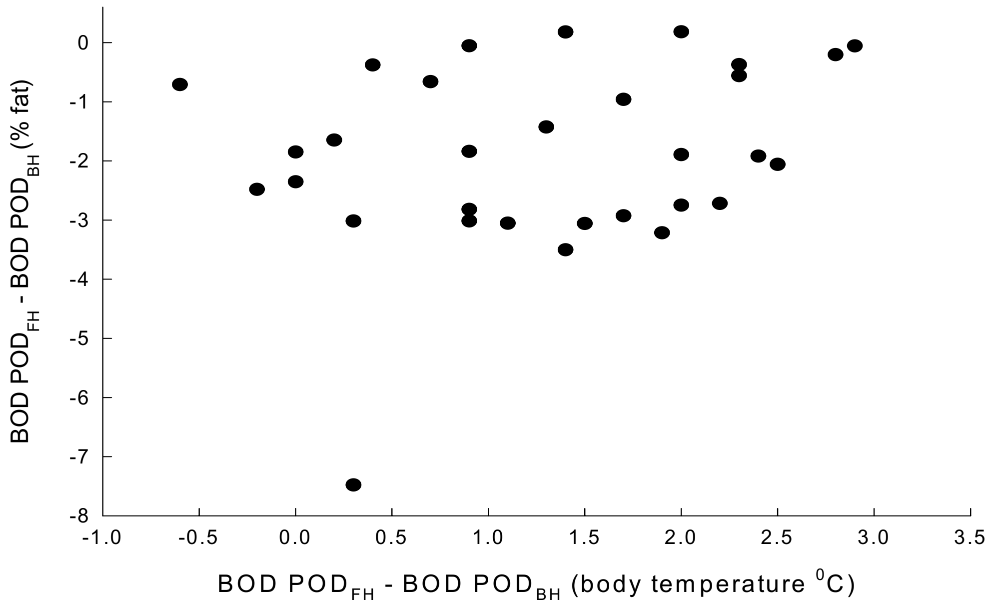

Figure 3
Scatter plot between the difference in %fat (BOD POD_{BH} and BOD POD_{FH}) and the difference in body temperature (BOD POD_{BH} and BOD POD_{FH}).

Table 2: Partial correlations to test the independent effect of temperature, moisture and BSA on %fat.

	Δ Temperature (moisture, BSA, BMI)	Moisture (Δ temperature, BSA,)	BSA (moisture, Δ temperature,)
Ä %fat	0.21	0.28	0.30*

Δ %fat: BOD POD_{BH} %fat – BOD POD_{FH} %fat*P < 0.05 BSA:Body surface area Δ Temperature: BOD POD Moisture: BOD POD_{BH} weight – BOD POD_{FH} weight

Discussion

The effect of body temperature and moisture on %fat, body volume, and body density using the BOD POD was addressed in the present study. Subjects underwent hydrostatic weighing between BOD POD tests, analogous to spending 30 minutes in a bath of 40°C water. Consequently, body temperature and body moisture were significantly elevated for the BOD POD_{FH} measurement. Since subjects had not consumed any liquids or food, nor were they allowed to void between BOD POD_{BH} and BOD POD_{FH} measurements, it was assumed that the net body weight gain was due to water trapped on the skin, in the hair follicles, or within the fabric of the swimsuit. As a result of body volume being underestimated (0.210 L), the estimation in %fat by the BOD POD_{FH} was significantly lower (1.8 %fat) than the estimation of %fat by BOD POD_{BH}, independent of the weight gain due to moisture retention.

The precise mechanism by which elevated body temperature and moisture affect BOD POD measures is unclear. The BOD POD operates under adiabatic conditions and therefore can accommodate changes in air temperature due to the presence of the test subject (1). Isothermal air present in the thoracic cavity is corrected for using measures of TGV during testing. The isothermal like air surrounding the skin is adjusted for using the surface area artifact, which is a correction factor calculated from BSA (1). However, under the present aberrant conditions the changes in the internal environment may have been too rapid to be controlled. Furthermore, the isothermal-like air surrounding the skin may have increased in quantity and the usual correction (SAA) may have been inadequate. In addition, the release of water vapor from the skin surface, swimsuit, or hair may have altered the composition of the chamber air such that the correction constant γ (1.4) was no longer appropriate to control for the adiabatic conditions.

There was a significant relation between BSA and the reduction in %fat. The reduction in % fat was not related to the change in body temperature or to the gain in body moisture. This suggests that a larger BSA facilitates a greater dissipation of heat and/or water vapor into the BOD POD testing chamber resulting in a greater underestimation of body volume. We emphasize that the independent effects of body temperature and moisture on body volume measurement could not be assessed with the present study design. The lack of correlation between temperature and %fat might be related to the small variability in the average change in temperature from the first and second BOD POD measurements (~0.6°C with range of 0.1 – 1.6°C). Since the variability in the temperature change was truncated, a relationship may have been undetectable. In addition, it is likely that the effects of moisture within the test chamber were not readily quantifiable by weight gain alone. Moisture on the skin and body hair was likely to be the variable of interest; this could not be quantified independent of moisture in the swimsuit.

In conclusion, the presence of excess heat and moisture in the BOD POD testing chamber leads to a small but significant underestimation in estimates of %fat. These findings are similar to those reported for the effects of clothing and body hair on BOD POD measures [6,13]. The specific mechanism(s) by which body heat and moisture effect estimates of body volume remain to be elucidated. The results from this study lead to the following recommendation: the BOD POD should always precede hydrostatic weighing or a bout of exercise. In addition, caution should be practiced when testing subjects with elevated body temperatures.

Authors' contributions

DAF participated in study design, participated in data collection data analysis and writing the manuscript.

PBH participated in data analysis and editing the manuscript, and making all tables and figures.

GRH participated in study design, data analysis, and writing the manuscript.

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