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Collegiate Athletes Made by the BOD POD Air Displacement
Plethysmography System**

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**Predicted Versus Measured Thoracic Gas Volumes of Collegiate Athletes Made by the
BOD POD Air Displacement Plethysmography System**

Dale R. Wagner, Ph.D.

Human Movement Science Program, Utah State University, Logan, UT, USA

Correspondence:
Dale R. Wagner, PhD
Utah State University
7000 Old Main Hill
Logan, UT 84322-7000
Phone: 435-797-8253
Fax: 435-797-3759
Email: dale.wagner@usu.edu

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Abstract

Measured (TGVm) and predicted (TGVp) thoracic gas volumes from the BOD POD were compared in 33 lean, university athletes. On average, TGVp (3.529 L) was not significantly different ($p = 0.343$) from TGVm (3.628 L); however, there was a bias ($r = -.703$, $p < 0.001$). The difference in %BF was within $\pm 2\%$ BF for 76% of the sample, but athletes at the extremes of height should have TGV measured.

Keywords: body composition, body fat, body volume, lung volumes, precision

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23 Introduction

24 The body composition of athletes is often assessed to identify the optimal level of body
25 fat for elite athletes within a given sport, track changes to monitor the effectiveness of training
26 programs, estimate minimal body weights for those competing in sports with weight classes, and
27 monitor health status to detect and prevent disorders associated with excessively low body fat
28 levels (Heyward and Wagner 2004). The BOD POD, an air displacement plethysmograph, is
29 one of many methods available for estimating body fat percentage (%BF), and it has steadily
30 increased in popularity since its introduction in 1998. This method is thought to be similar in
31 accuracy to hydrostatic weighing, yet the procedure is quicker and easier for the client and
32 requires minimal technician skill (Heyward and Wagner 2004).

33 The BOD POD uses the relationship between pressure and volume (Boyle's law) to
34 determine body volume (V_b); body density and %BF are subsequently calculated. However, V_b
35 must be corrected for thoracic gas volume (TGV), the quantity of air in the lungs during normal
36 tidal breathing (McCrory et al. 1998). Thoracic gas volume can be measured (TGV_m) using a
37 breathing maneuver in the BOD POD, but the machine also offers a predicted TGV (TGV_p) that
38 saves time, eliminates the need for disposable breathing tubes and filters, and bypasses a
39 maneuver that some people have difficulty performing successfully. Previous investigators
40 reported good agreement between TGV_m and TGV_p (Collins and McCarthy 2003; Demerath et
41 al. 2002; McCrory et al. 1998; Peeters 2012), but others found significant differences (Collins et
42 al. 1999; Lockner et al. 2000; Minderico et al. 2008). The purpose of this study was to compare
43 TGV_m and TGV_p from the BOD POD in lean, collegiate athletes. Tegenkamp et al. (2011)
44 demonstrated that BOD POD-derived %BF estimates of university athletes could be significantly
45 changed by having the athletes deliberately inhibit full exhalation or inhalation and take shallow

breaths. However, a comparison of TGVm and TGVp was not included in this research, and this comparison has yet to be made in an athletic population.

Materials and Methods

Subjects

Body composition was measured on 45 student-athletes (22 males, 23 females; 20.1 ± 1.6 y) from a National Collegiate Athletic Association (NCAA) Division 1 program. The student-athletes were from 7 different sports: football ($n = 8$), golf ($n = 7$), women's gymnastics ($n = 9$), softball ($n = 4$), women's volleyball ($n = 1$), and men's ($n = 7$) and women's tennis ($n = 9$). The study was approved by the institutional review board of Utah State University, and the subjects signed a written informed consent prior to their participation.

Procedures

The BOD POD (model GS, Cosmed USA, Inc., Concord, CA) was calibrated according to the manufacturer's instructions. Subjects arrived in the lab at least 2 h after practice, prior to eating, and were instructed to void before being measured. Female subjects wore sports bras, and all subjects wore lycra compression shorts and swim caps, the recommended attire for BOD POD testing (Heyward and Wagner 2004). Height was measured to the nearest 0.1 cm with a wall-mounted stadiometer (Seca 216, Seca Corp., Ontario, CA). Weight was measured to the nearest 0.001 kg on the BOD POD scale.

During the BOD POD procedure to obtain Vb, TGVm was determined by a panting or puffing maneuver. For this maneuver, the subject took several normal breaths through a tube while wearing a noseclip. When prompted on the computer screen, the subject gently exhaled 3 times, as if fogging a pair of glasses before cleaning them. The computer prompt for "puffing" coincided with midexhalation and a 3-s period during which the airway through the tube was

occluded. A “merit score” is given by the BOD POD following this procedure to indicate if the TGVm is acceptable. Details regarding the calculations to determine TGVm and TGVp from the BOD POD are described elsewhere (McCrory et al. 1998). Body volume and %BF were recorded for both TGVm and TGVp.

Statistical Analyses

Normality of TGVm and TGVp data were analyzed with the Shapiro-Wilk test. Mean differences between TGVm and TGVp, as well as Vb and %BF from TGVm and TGVp, were evaluated with paired-samples *t*-tests. Linear regression was used to determine how well predicted variables reflected measured variables. Individual error scores were evaluated with a Bland and Altman (1986) analysis. Statistical significance was established *a priori* as $p < .05$. All statistical analyses were done with the Statistical Package for Social Sciences (SPSS version 22, IBM, Armonk, NY).

Results

Measured thoracic gas volume and TGVp were normally distributed ($p = .070$). Twelve of the subjects (26%) were unable to achieve acceptable “merit” scores during the puffing maneuver to determine TGVm even after 5 trials; consequently, these subjects were excluded, leaving 33 subjects for data analyses. The mean differences for the variables of interest (TGV, Vb, and %BF) were not significantly different when TGVm was compared to TGVp (Table 1). The Bland and Altman (1986) analysis (Figure 1) to evaluate individual variability revealed a significant bias ($r = -.703, p < .001$) such that TGVp was systematically overestimated in subjects with a small TGV and underestimated in those with a large TGV. Nevertheless, the standard error of estimate (*SEE*) was only 1.3% BF, and 76% of the sample were within $\pm 2\%$ BF when comparing %BF derived from TGVp and TGVm.

Discussion

The primary finding from this study was that, on average, TGVm and TGVp were not significantly different, and consequently the differences in Vb and %BF between measured and predicted thoracic gas volume trials were not different. This finding coincides with the original investigation of TGVm versus TGVp from the BOD POD by McCrory et al. (1998). These researchers reported no difference between these volumes in 50 adults, and the %BF estimation was not affected by TGVp. Other researchers have also reported that mean TGVm and TGVp are similar in adults ranging in age between 16 and 69 y and body mass index (BMI) between 17.8 and 47.2 kg·m⁻² (Collins and McCarthy 2003; Demerath et al., 2002; Peeters 2012), but it appears that there might be significant differences in children (Demerath et al. 2002; Holmes et al. 2011; Lockner et al. 2000).

Despite no mean difference between TGVm and TGVp, there was a significant bias such that those at the extremes of TGV had the highest predictive errors. McCrory et al. (1998) reported no bias in the residual scores of their sample. However, in a study of 85 overweight and obese women, Minderico et al. (2008) reported a systematic bias in TGVp similar in direction and magnitude to the current study of lean, university athletes. The reason for this bias is not apparent, but the similarity to Minderico et al.'s study suggests that it is not population specific. Admittedly, the bias in the present study is created by only a few subjects. If the athlete with the smallest TGV and the four athletes with the largest TGVs are eliminated, the bias disappears. However, their placement at the extremes of TGV is meaningful and indicates a tendency for TGVp from the BOD POD to error toward the mean.

Overall, the bias in TGVp had little effect on the estimate of %BF. This is because only 40% of the TGV is used in the calculation of Vb; thus, the impact of even a fairly large error in

TGVp has only a small effect on the estimate of %BF from the BOD POD (McCrory et al. 1998). However, for the five subjects whose TGVm and TGVp values differed by more than 1 L, the difference in %BF was greater than $\pm 2\%$ BF. For most athletes, predicting TGV is not likely to substantially affect their %BF estimate from the BOD POD; however, for small athletes that might have a TGVm < 2 L or large athletes that might have a TGVm > 5 L, it seems prudent to measure TGV. Height is a variable in the calculation of TGVp (McCrory et al. 1998). In the present study, the shortest athlete (156 cm) had the most severe overestimation of TGV. Athletes with the largest underestimation of TGV were among the tallest (> 185 cm; 80th percentile). However, not all short athletes had overestimated TGVp, and not all tall athletes had TGVs that were underestimated.

Finally, it was interesting to observe that 26% of the athletes failed the TGVm procedure. This substantial failure rate further highlights the importance of this research, because for some people TGVp is the only option when being tested in the BOD POD. The majority of these failures were due to high “merit” scores. According to the manufacturer, this suggests that the subject did not maintain a tight seal around the tube while puffing or puffed too hard. Most researchers that have previously compared TGVm to TGVp have not acknowledged or commented on the failure rate to complete the TGVm procedure. Anderson (2007) noted that 3 of the 24 adults (13%) in that study could not complete the procedure, and Lockner et al. (2000) were able to get measurements on only 37 of 54 children aged 10 to 18 y, a 31% failure rate.

In summary, this was the first study to compare TGVp and TGVm in an athletic population. There was a systematic bias in TGVp in this sample of university athletes such that TGVp was overestimated in those with the smallest TGV and underestimated in those with the largest TGV. However, this bias affected only a small portion of athletes, and the mean

difference in TGVp was not significantly different from TGVm. Furthermore, errors in TGVp did not substantially impact the estimation of %BF for the majority of athletes.

Practical Applications

When possible, TGVm is recommended when estimating the %BF of athletes using the BOD POD. Remind athletes to keep a tight seal around the tube and not puff too forcefully in order to achieve an acceptable TGVm. Athletes shorter than 156 cm or taller than 185 cm are the ones most susceptible to having a TGVp different from a TGVm. Nevertheless, TGVp will likely provide a valid estimate of TGV for those athletes who are unable to achieve an acceptable merit score during the puffing maneuver. Furthermore, using TGVp rather than TGVm does not substantially change the %BF estimate for most athletes.

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186 **Figure Legend**

187 **Figure 1.** Plot of the TGV residual scores. The solid line is the constant error. The dashed line
188 is the significant relationship ($r = -.703$, $P < 0.001$) between error scores and the average TGV.

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Table 1. Variables of interest calculated from measured and predicted TGV ($N = 33$)

Variable	Measured	Predicted	Mean Difference	<i>P</i> -value	R^2	<i>SEE</i>
TGV (L)	3.628 ± 0.894	3.529 ± 0.500	0.099 ± 0.591	0.343	0.613	0.566
Vb (L)	66.722 ± 11.163	66.682 ± 11.129	0.040 ± 0.237	0.344	1.000	0.238
%BF	15.2 ± 6.2	15.0 ± 6.9	0.2 ± 1.5	0.361	0.958	1.303

TGV = thoracic gas volume; Vb = body volume; %BF = body fat percentage

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