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Reliability of Air Displacement Plethysmography

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Abstract. Anderson, D.E. Reliability of air displacement plethysmography. *J. Strength Cond. Res. 21(1):169–172. 2007.*—The purpose of this study was to examine the reliability of an air displacement plethysmography device (BOD POD) over trials performed on 3 different days. Subjects consisted of 24 healthy adults (8 men, 16 women), ages 18–38 years, with body weights 46.8–93.6 kg, body mass indexes of 19.1–30.1 kg·m^{-2}, and percentage body fats (BF) of 7.9–43.1%. Two estimates of BF were performed on 3 days. Paired *t*-tests revealed no significant within-day differences in body volume (BV), thoracic gas volume (V_{TG}), body density (BD), and BF. Correlations between the two V_{TG} measures on a day were $r = 0.86$ for day 1, $r = 0.93$ for day 2, and $r = 0.96$ for day 3. BF estimates within a day had high correlations of $r = 0.98$. Significant differences were found between days for measures of BV, V_{TG}, BD, and BF. These results indicate a high reliability for within-day estimates of BF and significant differences in between-day estimates of BF using air displacement plethysmography. Reliability of BF may be increased by requiring subjects to practice the procedure for V_{TG} measurement.

Key Words. BOD POD, body composition, reproducibility

Introduction

Air displacement plethysmography (ADP) and the BOD POD Body Composition System (Life Measurement Inc., Concord, CA) for measuring body volume have become more available. It is a quick and easy system that can be used with a wide range of subjects. A number of studies have been conducted that include reliability measurements for trials performed on a given day (2, 3, 7, 10, 11). Other investigators (5, 8, 11, 13) have examined reliability over trials performed on more than 1 day, however the number of subjects used in most of these studies (8, 11, 13) has been unknown or relatively small. The purpose of this project was to examine the reliability of an ADP device, the BOD POD, over trials performed on 3 different days using a larger subject pool.

Methods

Experimental Approach to the Problem

The present study was designed to investigate the reliability of an ADP device, the BOD POD, over trials performed on more than 1 day. Two estimates of percentage fat were performed on each testing day in order to assess reliability on a single day. To examine the reliability of estimates performed on more than 1 day, these trials were repeated on 2 additional days with the first and last trials being at most 7 days apart.

Subjects

Twenty-four healthy adults were recruited to serve as subjects. The training activities of the subjects varied widely, ranging from no physical activity to activities such as distance running and strength training. Their summary data (mean ± *SD*) are presented in Table 1. Prior to the onset of this investigation, each subject was informed verbally and in writing of the purpose, methods, and possible risks associated with the study and signed an institutionally approved informed consent.

Procedures

Each subject reported for testing on 3 days within a 3- to 7-day period and completed 2 estimates of body composition, using ADP on each day. Testing was conducted according to the manufacturer's recommendations, the details of which are presented elsewhere (2, 6, 10). Subjects were instructed not to have exercised or to have eaten for 3–4 hours prior to each testing session; however, minimal water consumption was allowed. Upon arrival at the laboratory, subjects were asked to void the bladder before the first measurements were taken. Clothing consisted of either a lightweight swimsuit or spandex shorts and a nonpadded sports bra. A tight-fitting acrylic swim cap was worn also. Standing height was measured to the nearest 0.1 cm using a stadiometer. Subjects then were weighed to the nearest 0.01 kg. An average of 2 uncorrected body volume measurements (if measurements were within 150 ml of each other) was used for calculations of body volume (BV) and body density (BD).

Thoracic gas volume (V_{TG}) was then measured during normal tidal breathing into a tube connected to the ADP. McCrory et al. (10) found no difference between measured and predicted V_{TG} in adults, thus a predicted value was used for subjects who could not satisfactorily perform the procedure after 3 attempts during the first trial. For those subjects who were unable to perform the procedure after 3 attempts and had at least 1 previously successful attempt, a V_{TG} from a previous trial was entered. The uncorrected BV was adjusted for V_{TG} and was used to determine actual BV. BF then was calculated using the equation of Siri (15). All testing sessions were conducted by the same technician.

Statistical Analyses

All values presented are mean ± *SD*. Paired *t*-tests were performed using JMP 5.5.1 (SAS Institute Inc., Belmont, CA) to assess within-day differences of variables. Paired *t*-tests also were used to examine between-day differences by analyzing the lowest and highest obtained values of the 6 trials for a given measure. Statistical significance was set at $p \leq 0.5$. Intraclass correlation coefficients (ICC) were determined for trials performed on a given day using SPSS (version 11.0.4; SPSS, Inc., Chicago, IL), and the 95% confidence intervals (CI) were determined for each ICC (12). To allow for comparison with other published data, the precision for measurements on a given day the technical error of measurement (*TEM*) was cal-

TABLE 1. Subject characteristics.*

	Age (y)	Weight (kg)	Height (cm)	BMI (kg·m^{-2})
Men (n = 8)	22.9 ± 6.6 (18–38)	176.3 ± 4.9 (161.1–193.6)	76.9 ± 12.5 (170.0–187.0)	24.7 ± 3.5 (19.9–30.1)
Women (n = 16)	20.0 ± 1.2 (18–22)	166.2 ± 7.6 (146.8–179.7)	65.6 ± 8.6 (155.5–182.0)	23.7 ± 2.8 (19.0–30.1)

* Values presented are mean ± *SD* (range). BMI = body mass index.

culated as $\Sigma d^2/2n$ (where d is the difference between measurements and n is the number of subjects).

RESULTS

Within-day differences in BV are presented in Table 2. There were no significant differences between genders for BV. No significant different differences were found between trials on a given day.

The V_{TG} was significantly lower for women than for men on days 2 and 3, as can be seen in Table 3. However, no differences were found between trials on a given day for V_{TG}.

Body density was significantly lower for women than for men, as can be seen in Table 4. No differences were found between trials on the same day for BD. BF was significantly higher for the women than for the men, as can be found in Table 5. There were no differences between any of the trials on the same day for BF.

TABLE 6. Lowest and highest values measured over 6 trials.*

	Lowest	Highest
BV (L)	63.726 ± 10.427	64.523 ± 10.466†
V_{TG} (L)	3.4 ± 0.7	4.0 ± 0.8†
BD (kg·L^{-1})	1.040 ± 0.018	1.047 ± 0.019†
BF (%)	22.9 ± 8.4	25.8 ± 8.1†

* Values presented are mean ± *SD*. Two trials were performed on each of 3 days. BV = body volume; V_{TG} = thoracic gas volume; BD = body density; BF = body fat.
† Significant difference from lowest value.

Paired t-tests were used to assess between-day differences by analyzing the lowest and highest obtained values of the 6 trials for a given measure. As seen in Table 6, significant differences were found between days for measures of BV, V_{TG}, BD, and BF.

The ICCs between trials performed on a given day and between the lowest and highest values measured over the 6 trials are presented in Table 7. Correlations for BV were high on each day (r = 1.00). The two V_{TG} measures on the first day of testing had the lowest correlation (r = 0.86), however, correlations were higher on the second (r = 0.93) and third (r = 0.96) testing sessions. Correlations between trials performed on the same day were high (r = 0.97–0.98) for BD. BF estimates within a day had high correlations (r = 0.98).

Between-day *SD* and coefficient of variation (CV) also

TABLE 2. Body volume (mean ± *SD*) values for 2 trials performed on each of 3 days.

	Day 1		Day 2		Day 3	
	Trial A	Trial B	Trial A	Trial B	Trial A	Trial B
Men (n = 8)	69.936 ± 11.706	69.991 ± 11.768	69.785 ± 11.853	69.711 ± 11.867	69.986 ± 11.603	69.966 ± 11.566
Women (n = 16)	61.207 ± 8.610	61.246 ± 8.589	61.345 ± 8.811	61.317 ± 8.911	61.217 ± 8.686	61.150 ± 8.768
All (N = 24)	64.116 ± 10.379	64.161 ± 10.392	64.158 ± 10.484	64.115 ± 10.535	64.139 ± 10.393	64.089 ± 10.434

TABLE 3. Thoracic gas volume (mean ± *SD*) values for 2 trials performed on each of 3 days.

	Day 1		Day 2		Day 3	
	Trial A	Trial B	Trial A	Trial B	Trial A	Trial B
Men (n = 8)	4.1 ± 0.8	3.9 ± 0.7	4.1 ± 0.7	4.1 ± 0.7	4.1 ± 0.7	4.1 ± 0.6
Women (n = 16)	3.5 ± 0.7	3.6 ± 0.9	3.4 ± 0.6*	3.4 ± 0.5*	3.5 ± 0.6	3.5 ± 0.6*
All (N = 24)	3.7 ± 0.8	3.7 ± 0.9	3.6 ± 0.7	3.7 ± 0.7	3.7 ± 0.7	3.7 ± 0.7

* Values for women were significantly lower than those for men.

TABLE 4. Body density (mean ± *SD*) values for 2 trials performed on each of 3 days.

	Day 1		Day 2		Day 3	
	Trial A	Trial B	Trial A	Trial B	Trial A	Trial B
Men (n = 8)	1.062 ± 0.013	1.062 ± 0.014	1.061 ± 0.015	1.061 ± 0.013	1.060 ± 0.013	1.061 ± 0.012
Women (n = 16)	1.035 ± 0.013*	1.034 ± 0.013*	1.036 ± 0.013*	1.036 ± 0.013*	1.035 ± 0.013*	1.037 ± 0.016*
All (N = 24)	1.044 ± 0.018	1.043 ± 0.019	1.044 ± 0.018	1.044 ± 0.019	1.044 ± 0.019	1.045 ± 0.018

* Values for women were significantly lower than those for men.

TABLE 5. Body fat (mean ± *SD*) values for 2 trials performed on each of 3 days.

	Day 1		Day 2		Day 3	
	Trial A	Trial B	Trial A	Trial B	Trial A	Trial B
Men (n = 8)	16.5 ± 5.7	16.3 ± 6.1	16.7 ± 6.5	16.5 ± 5.8	17.0 ± 5.7	16.8 ± 5.5
Women (n = 16)	28.3 ± 6.0*	29.0 ± 5.9*	28.1 ± 5.8*	27.8 ± 6.9*	28.2 ± 6.2*	27.6 ± 7.3*
All (N = 24)	24.1 ± 8.1	24.8 ± 8.5	24.3 ± 8.0	24.0 ± 8.4	24.4 ± 8.0	24.0 ± 8.4

* Values for women were significantly lower than those for men.

TABLE 7. Intraclass correlation coefficients (95% confidence intervals) of 2 trials performed on each of 3 days and between the lowest and highest values over the 6 trials.*

	Day 1	Day 2	Day 3	High and low
BV (L)	1.00 (1.00–1.00)	1.00 (1.00–1.00)	1.00 (1.00–1.00)	1.00 (1.00–1.00)
V_{TG} (L)	0.86 (0.71–0.94)	0.93 (0.84–0.97)	0.96 (0.91–0.98)	0.88 (0.75–0.95)
BD (kg·L^{-1})	0.98 (0.96–0.99)	0.98 (0.94–0.99)	0.97 (0.94–0.99)	0.98 (0.95–0.99)
BF (%)	0.98 (0.96–0.99)	0.98 (0.94–0.99)	0.98 (0.95–0.99)	0.98 (0.96–0.99)

* BV = body volume; V_{TG} = thoracic gas volume; BD = body density; BF = body fat.

TABLE 8. Day-to-day reliability of air displacement plethysmography.*

	SD	CV
BV	0.329 L (0.176–0.608 L)	0.522% (0.277–0.952%)
V_{TG}	0.2 L (0.0–0.6 L)	6.1% (0.0–14.5%)
BD	0.002 kg·L^{-1} (0.001–0.008 kg·L^{-1})	0.232% (0.078–0.727%)
BF	1.10% (0.24–3.4%)	5.30% (0.94–18.03%)

* Values presented as mean (range). Two trials were performed on each of 3 days. CV = coefficient of variation; BV = body volume; V_{TG} = thoracic gas volume; BD = body density; BF = body fat.

TABLE 9. Techincal error of measurement of 2 trials performed on each of 3 days.*

	Day 1	Day 2	Day 3
BV (L)	0.101	0.162	0.158
V_{TG} (L)	0.2	0.2	0.1
BD (kg·L^{-1})	0.002	0.003	0.003
BF (%)	1.15	1.28	1.28

* BV = body volume; V_{TG} = thoracic gas volume (only measured volumes were used); BD = body density; BF = body fat.

were determined and are presented in Table 8. The *SD* and CV for BF over the 6 trials were 1.1% and 5.3%, respectively.

The *TEM* values are presented in Table 9. The *TEM* for BV ranged from 0.101–0.162 L. For the 3 days, the *TEM* for V_{TG} and BD were very close with values of 0.1–0.2 L and 0.002–0.003 kg·L^{-1}, respectively. The *TEM* for BF was 1.15–1.28%.

DISCUSSION

Uncorrected BV is normally determined from the average of 2 body volume measurements. If these values differ by more than 150 ml, a third measurement is taken. Of the 24 subjects, 12 needed to complete a third BV measurement during 1 of the testing sessions, 2 needed to do so during 2 testing sessions, and 4 needed to perform a third BV measurement during 3 of the 6 trials.

The procedure for measuring V_{TG} during normal tidal breathing into a tube connected to the ADP gave some subjects difficulty. Because McCrory et al. (9) and Collins and McCarthy (2) found no difference between measured and predicted V_{TG} in adults, a predicted value for V_{TG} was used for the 3 subjects who could not satisfactorily perform the procedure after 3 attempts during the first trial. In subsequent trials, 18 subjects were unable to perform the procedure after 3 attempts. For these subjects who had at least 1 previously successful attempt (28 of 144 trials), a V_{TG} from a previous trial was entered. Two subjects who were unsuccessful during the first trial were able to correctly perform the procedure on later trials. Their data revealed significantly lower estimated values than measured values. One such subject had an estimated V_{TG} of 3.6 L and measured values of 3.8–4.1 L. The other subject had an estimated V_{TG} of 3.0 L and measured values of 2.9–3.4 L. These are similar, but in the opposite direction as found by Collins et al. (4), who found measured V_{TG} (range = 2.897–6.304 L) to be significantly less that the estimated V_{TG} (range = 3.647–4.977 L). Results of the present study are also more consistent with the modest correlation (r = 0.28) between predicted V_{TG} and measured V_{TG} found by Demerath et al. (5). The lack of difference between predicted and measured lung volumes is not a consistent finding, however. In fact, according to Collins and McCarthy (2), there may be a difference of only 3% BF when using predicted and measured lung volumes.

The reliability of body density measurements was high. ICCs of 0.97 to 0.98 were found on a given day. These values are similar to the correlations of 0.98 and 0.993 found by Sardinha et al. (14) and Vescovi et al. (16), respectively. In each of these studies, the subject pool of 16–19 subjects was slightly smaller than the 24 used in the present study. The *TEM* values for 2 trials performed on 1 day (0.002–0.003 kg·L^{-1}) are only slightly higher than the 0.0021 kg·L^{-1} found by Sardinha et al. (14) and the 0.0017 kg·L^{-1} found by Vescovi et al. (16).

The within-day reliability of BF measurements was also high. The ICCs within a day were all 0.98. These are higher than the correlations of 0.93–0.94 found by Ballard et al. (1), but slightly lower than the correlation of 0.994 found by Collins et al. (4). The within-day *TEM* in the present study of 1.15–1.28% is larger than the 0.448% found by Collins et al. (4), the 0.75% found by Vescovi et al. (16), and the 0.8% found by Collins and McCarthy (2).

Other investigators have examined between-day differences of BF using ADP tested once on 2–7 days (5, 8, 11, 13). The CV for BF of 5.3% found is higher than the CV of 2.0–2.7% found in previous studies using a smaller subject pool of up to 10 subjects measured once on 3–7 days (8, 11, 13). The CV (5.3%) found in this study with 2 ADP measurements taken on each of 3 days is lower than the CV (6.1%) found in a group of 50 subjects tested once on 2 days (5).

These results indicate a high reliability for within-day estimates of BF and significant differences in between-day estimates of BF using ADP.

PRACTICAL APPLICATIONS

The BOD POD Body Composition System is a quick and easy system that can be used with a wide range of subjects. The results of this study indicate a high reliability for estimates of BF taken on the same day and significant differences in estimates of BF taken on different days using this method. Reliability of BF may be increased by requiring subjects to practice the procedure for lung volume measurement until it is mastered prior to conducting testing.

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