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Indian Journal of Physiology and Pharmacology

Original Article

Test-retest reliability of air displacement plethysmography (BOD POD) in the adult healthy Indian male population

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Received : 09 July 2022
Accepted : 22 November 2022
Published : 29 December 2022

DOI
10.25259/IJPP_306_2022

Quick Response Code:

ABSTRACT

Objectives: Several studies have shown that air displacement plethysmography (ADP) has excellent reliability, accuracy and precision in body fat percentage (BF%) measurement, but its reliability has not been assessed in the Indian population. Thus, this study aimed to determine the test-retest reliability of BF% by ADP in healthy Indian men.

Materials and Methods: A total of 74 healthy Indian men (>18 years old) belonging to different parts of India voluntarily participated in the study and completed multiple trials to determine BF% immediately after the initial measurements. All tests were performed according to the manufacturer's instructions.

Results: A paired *t*-test showed no significant differences in body volume (BV) ($P = 0.53$), body density (BD) ($P = 0.39$) and BF% ($P = 0.27$) between trials 1 and 2. However, there was a significant decrease in body mass (BM) observed between trials 1 and 2 ($P = 0.0001$) which did not influence reliability. A significant intraclass correlation was observed for BM (intraclass correlation 1 [ICC1] = 1, $P < 0.001$), BV (ICC1 = 1, $P < 0.001$), BD (ICC1 = 0.996, $P < 0.001$) and BF% (ICC1 = 0.995, $P < 0.001$) between the initial test and retest trial. The third assessment of BF% was performed when the initial trial difference was greater than 1% point. Significant intraclass correlations were also observed for pairs with maximum and minimum differences.

Conclusion: ADP appears to be a reliable measure for determining the BF% of the Indian adult male population, and conducting multiple trials are necessary to detect small differences.

Keywords: Body density, Body composition, Body volume, Body fat percentage

INTRODUCTION

Body weight has been considered over time as an indicator of good health. Although, when examined closely, it is the composition of this body weight that is most important. Body weight comprises the weight of body water, muscle, organs, bones and fat (both essential and non-essential). The underlying issue is the excessive fat that accumulates due to unhealthy eating and lifestyle habits. This excess fat leads to multiple health issues, which further lead to being overweight and eventually, obesity.

Researchers and clinicians have shown that people of the same age, weight and height have different body shapes, body compositions, metabolic profiles and energy requirements.[1] Investigations of obesity and malnutrition, weight loss composition following bariatric surgery,

muscle wasting, sarcopenia, lipodystrophy, altered states of hydration and osteoporosis/osteopenia give rise to the need for assessing body composition.[1] The athletic population is required to undergo body composition assessment for their sports performance monitoring and further enhancement.

Various techniques are available to safely and accurately estimate the body composition in humans from birth through senescence. These are divided across basic field methods such as anthropometry and measurement of body mass index (BMI); progressive field methods such as measurement of skinfold techniques, bioelectrical impedance and near-infrared interactome measurements and advanced laboratory and imaging techniques such as hydrostatic weighing, air displacement plethysmography (ADP), MRI scans and DEXA scans.[1]

ADP, the trade name for which BOD POD, is widely gaining more acceptances due to the ease and less time required to measure the body composition. BOD POD has shown excellent reliability, accuracy and precision in volume measurement. BOD POD is an ADP that uses whole-body densitometry to determine body fat percentage (BF%).[2] It measures body volume (BV) by air displacement inside a sealed chamber. It is a non-invasive and quick technique that does not require the exhaustive technical training of technicians and is convenient for a wide variety of subjects from obese to elderly and for estimating percentage of fat in a large population.[3]

The principle underlying ADP centres on the relationship between pressure and volume. At isothermal conditions, volume and pressure are inversely related. Thus, in accordance with Boyle's law, we can calculate BV when the person is inside the BOD POD chamber. Once BV is calculated, body density (BD) can be calculated, and the percentages of fat and fat-free mass can be estimated by the Siri equation.[4-7]

Measuring body composition by ADP is a safe and reliable method, which was first introduced in the year 1995.;[3] in the volume measurement by ADP, the mean percentage error was <0.1% at all levels except for the very small values, where the mean error was slightly larger at 0.13%.[4] A study conducted on female collegiate athletes to compare BOD POD and DEXA showed that ADP seems to be a reliable and valid method for body composition assessment. Due to high reliability and ease of conducting the assessment, patient compliance is better, and tracking changes in the body composition is possible at frequent intervals.[3] Since then, BOD POD has been used extensively in Western countries, but its use and application in the Indian subcontinent have been very limited, mainly due to the high technological expenses. Hence, data to confirm the reliability of this technology in the Indian population is limited.

To the best of the author's knowledge, no studies to assess body composition using ADP by BOD POD in the Indian population have been published. Thus, the purpose of our study was to determine the test-retest reliability of body fat percentage by the BOD POD in healthy Indian men.

MATERIALS AND METHODS

Study design and participants

This cross-sectional study was conducted among the Indian population at a national-level sports training institute between October 2020 and July 2021. A total of 74 healthy Indian male adults (>18 years old) belonging to different parts of India voluntarily participated in the study. Written informed consent was obtained from all participants, and the test results were communicated to them. The study was approved by the Institute's Ethics Committee (Letter No: 301/ Ethical Committee, September 18, 2020) according to the Helsinki Declaration of 1975, as revised in 2000. Exclusion criteria were the following: history of smoking, chronic diseases such as hypertension, diabetes, hypothyroidism, obesity, endocrine disease, metabolic disease and recent hospitalisation due to any major injury or trauma.

Procedures

The study was conducted at the high-performance laboratory at the National Sports Institute in Western India.

Participants were instructed not to exercise and not to eat 3–4 h before each testing session; however, minimal water consumption was allowed. During the appointment, height, weight and BF% were measured with the participant barefoot and wearing spandex shorts. A tight-fitting acrylic swim cap was also worn before changing into the spandex shorts, and participants were asked to use the restroom to eliminate waste to minimise measurement error.[7]

Before measurement of anthropometric parameters and fat percentage by BOD POD, all participants completed the International Physical Activity Questionnaire (IPAQ) to assess their daily physical activities over the past 7 days.

Anthropometric measurements

Each participant underwent an anthropometric assessment performed by a Level 1 anthropometrist qualified by the International Society for the Advancement of Kinanthropometry (ISAK), in accordance with the ISAK guidelines.[8] Height was measured with the participants standing barefoot and with their head held in the Frankfort plane. Body weight was measured using the BOD POD electronic scale, and BMI was calculated as weight divided by height squared (kg/m^2). We measured the waist circumference (WC) with a measuring tape (precision of 1 mm) using

the horizontal plane midway between the lowest rib and the upper border of the iliac crest at the end of a normal inspiration/expiration. We measured the hip circumference (HC) at the maximum extension of the buttocks as viewed from the right side. Waist hip ratio (WHR) was calculated by dividing WC by HC.[8]

Body composition analysis

BOD POD was employed to estimate the BF% (BOD POD GS-X, model 2020, COSMED) [Figure 1]. The thoracic gas volume (TGV) was also measured using BOD POD during participants' normal tidal breathing into a tube connected to the ADP. McCrory *et al*. found no difference between measured and predicted values of TGV in adults; thus, a predicted value was used for participants who could not able to perform satisfactorily the procedure after three attempts during the first trial.[9] After three attempts, for those participants who were not able to perform the procedure and had at least one previous successful attempt, a TGV value from a previous trial was entered. The uncorrected BV was adjusted for TGV and used to determine the actual BV. Body fat was calculated using the Siri equation. All testing sessions were conducted by the same technician.

All tests were performed according to the manufacturer's instructions. Before testing each day, the scale was calibrated using two 10-kg weights, and volume calibration was automatically performed at the beginning of every test using an internal calibration cylinder connected to the test chamber with a controlled valve. BOD POD is designed to automatically measure BV twice on each run, and if the software spots a difference of 150 mL or greater in BV, it performs a third test on the participant. After the first measurement, each participant repeated the entire process, including the measurement of body weight and two-point calibration.

All repeated measures were performed immediately after the initial measurements and were completed by the same technician. If a difference of more than 1% in BF% between the initial test and the retest was noted, a third test was administered, and reliability was assessed using the two closest values.

Statistical analysis

All statistical analyses were performed using R Studio (Version 1.4.1106). Descriptive statistics of key variables were expressed as mean, standard deviation, minimum and maximum range. For test-retest, if the difference between the first two observations varied by 1%, a third observation was conducted. Of these three observations, the pair with the smallest absolute difference was considered for test-retest reliability. Positive and negative differences may affect reliability; hence, the absolute difference was calculated. The coefficient of variation (CV) for the repeated measures was calculated. The technical error of measurement (TEM) was calculated as $\sqrt{\sum d^2/2n}$, where d represents the absolute test-retest difference and n is the sample size. Test-retest reliability was calculated using the intraclass correlation (ICC). The formula used for the calculation was $R = MS_R–MS_e/MS_R + (k–1)\ MS_E + k/n(MS_C\text{-}MS_E)$.[10] ICC provided an index of reliability.

RESULTS

In this study, 74 participants voluntarily participated in the study. Of the 74 participants, ten were sedentary, 23 had low activity levels, 36 were active and five were highly active in their daily routine based on activity level inferred from the IPAQ.

[Table 1] presents the descriptive statistics of basic anthropometric characteristics such as age, height, weight,

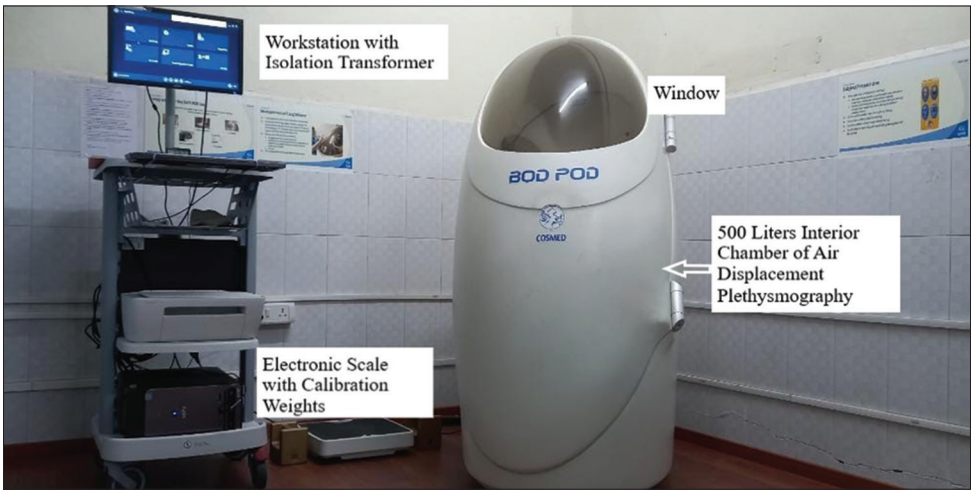

Figure 1: Air displacement plethysmography (BOD POD GS-X, model 2020, COSMED).

BMI, WC, HC and WHR. The mean age of the participants was 35.65 years (SD = 6.44), mean height was 173.50 cm (SD = 6.83) and mean weight was 76.89 kg (SD = 9.47).

The mean BMI was observed to be 25.54 (SD = 2.78), mean waist was 85.03 cm (SD = 7) and mean WHR was 0.89 (SD = 0.05). According to the WHO, the cutoff value for WHR was 0.90 for the Asian population.

[Table 2] shows descriptive statistics of BM, BV, BD and BF% for all three trials. If the difference between the test-retest fat percentage of the initial trials was more than 1%, the test was repeated for the 3rd time. Out of the 74 participants, 21 performed the test for the 3rd time, which was approximately 28% of the total data points.

Reliability of BOD POD

No significant differences were observed over time for BV ($P = 0.53$), BD ($P = 0.39$) and BF ($P = 0.27$) between trials 1 and 2 using a paired *t*-test. However, there was a significant decrease in BM observed between trials 1 and 2 ($P = 0.0001$).

BM and BV had excellent ICCs of 1 ($P < 0.001$), whereas BD and BF% had reliability factor ICC values of 0.996 and 0.995, respectively, between the initial test and retest trial. When the difference between the test and retest trials was more than 1%, a third trial was conducted. Hence, ICC2 represents reliability for pairs with minimum difference, and ICC3 represents the reliability of pairs with a maximum difference. We observed that when pairs with a maximum difference were considered, the reliability index ICC3 for BV and BM did not change. However, the reliability for BD and BF% was reduced by 0.009 and 0.008, respectively. However, the ICC was > 0.98.

The CV for BF% was 2.62 and the standard error of measurement (SEM) was 0.44%. The CV for BM and BV was close to zero. BD had a CV of 0.11 and SEM of 0.005.

Table 1: Physical characteristic of participants (*n*=74).

	Mean	SD	Median	Minimum	Maximum
Age (years)	35.66	6.45	35.29	24.4	55.86
Height (cm)	173.5	6.83	174	154.4	191.5
Weight (kg)	76.89	9.47	75.43	61.74	101.3
Body mass index	25.54	2.78	25.15	18.74	32.03
Waist (cm)	85.03	7	85	69	98
Hip (cm)	95.54	5.66	95	81	110
Waist/hip ratio	0.89	0.05	0.89	0.77	0.98

DISCUSSION

This study aimed to test the test-retest reliability of BOD POD in a healthy Indian population to assess body composition. BOD POD is an attractive tool for measuring body composition in a variety of clinical, research and commercial settings due to its ease of use and excellent subject compliance. At present, there is limited research regarding the reliability of BOD POD in the Indian population.

Descriptive statistics of basic anthropometric characteristics of the participants suggests that the subjects of the present study were below the borderline, healthy and non-obese.[11] In the present study, multiple trials were conducted to determine BF% based on the results obtained after the completion of each trial. Out of 74 data points, 21 samples had a difference of more than 1%, and hence, a third trial was conducted. This was approximately 28% of the total sample, which suggests the need for multiple trials.

Overall, BOD POD reported good test-retest reliability. BM and BV had a reliability index of 1 ($P < 0.001$) for all three comparisons as ICC1, ICC2 and ICC3, suggesting excellent reliability of BOD POD for BM and BV. Noreen and Lemon observed ICC index of 0.999,[12] whereas Anderson, DE observed ICC index of 1,[13] which are similar results for BV as compared to the present study. Anderson reported a CV of 0.52%,[13] whereas Noreen and Lemon reported a CV of 0.16% for BV[12] which was higher than that reported in the present study. These studies included men and women; hence, the variation observed may be on a higher side.

The present study showed a significant reduction in BM between trials 1 and 2. Noreen and Lemon reported similar results as BM.[12] This is the second study as per our

Table 2: Results of three complete body composition assessments collected over 20–30 min (mean±SD).

	Trial 1 (*n*=74)	Trial 2 (*n*=74)	Trial 3 (*n*=21)	ICC1 (*P*-value)	ICC2 (*P*-value)	ICC3 (*P*-value)	CV %	SEM	TEM
Body Mass (Kg)	76.792±9.529	76.786±9.525	75.957±9.516	1 (<0.001)	1 (<0.001)	1 (<0.001)	0.011	0.00	0.0
Body Volume (L)	73.358±9.51	73.368±9.48	72.670±9.46	1 (<0.001)	1 (<0.001)	1 (<0.001)	0.10	0.00	0.011
Body density (L/Kg)	1.050±0.015	1.049±0.015	1.054±0.016	0.989 (<0.001)	0.996 (<0.001)	0.987 (<0.001)	0.11	0.002	0.005
Body fat (%)	21.95±6.28	22.07±6.25	20.69±6.09	0.989 (<0.001)	0.995(<0.001)	0.987 (<0.001)	2.62	0.44	0.44

ICC1: Test-retest reliability between trial 1 and trial 2 ICC2 test-retest reliability between trials with minimum differences, ICC3 test-retest reliability between trials with maximum difference, SEM: Standard error of measurement, TEM: Technical error of measurement

knowledge to report a significant reduction in BM after Noreen and Lemon.[12] BV showed a slight increase between trial 1 and trial 2, but the difference was not significant ($P = 0.53$). BD showed a negligible decrease between the two trials, and the difference was not significant ($P = 0.39$).

The reliability index ICC1 for BF% between trial 1 and trial 2 was 0.989 (p<0.001), which was lower than the ICC observed by Noreen and Lemon[12] and Tucker *et al*.[5] and was higher than the results obtained by Anderson.[13] ICC3, which represents pairs with a maximum difference, was 0.987 ($P < 0.001$), whereas Tucker *et al*.[5] observed an ICC of 0.989. Correlation coefficients >0.8 for test-retest data of physiological variables are considered high.[14] Therefore, based on all previous studies and the present study, we can say that BOD POD has good test-retest reliability, even in the Indian adult healthy male population.

The present study observed a CV of 2.62% for three trials of BF%, which was higher than the CV observed by Tucker *et al*. for three trials (2.1%).[5] Anderson reported a CV of 5.3% for the day-to-day variation in BF%, higher than the CV of the present study.[13] However, the present study has performed multiple testing on the same day. Miyatake *et al*. reported a CV of 2.5% performed on five participants with five measurements each on the same day.[15] The CV was 1.7% in a study by McCrory *et al*.,[16] which included 16 participants. Noreen and Lemon reported a CV of 3.1% using their multiple testing protocols, which was higher than the CV of the present study.[12] These variations in the present study as well as previous studies suggest that multiple trials may help to obtain more precise results.

The ICC was 0.993 for men and 0.995 for women in the Noreen and Lemon study,[12] Tucker *et al*. reported 0.998 as compared to 0.989 in the present study,[5] both using multiple measures when needed. The higher ICC ($P < 0.001$) in all three comparisons observed in the present study suggests good test and retest reliability of the BOD POD.

Noreen and Lemon reported that the TEM was 1.07% in their investigation using multiple measurements,[12] and Tucker *et al*. reported a TEM of 0.48% as compared to 0.44% in the present study.[5] These observations suggest that BOD POD is a reliable tool to determine the BD in the Indian population, as observed in other populations.

CONCLUSION

The present study included the Indian adult male population from various regions of India and showed that BOD POD appears to be a reliable measure for determining the body composition of this group of populations. Conducting multiple trials and subsequently comparing the two closest values have been shown to provide an excellent test-retest reliability index for BOD POD. A small but significant decrease in BM was observed with repeated measures, which was also found to not influence the reliability of the body composition measurements.

Acknowledgements

We would like to thank Col Devraj Gill, Commandant and Ms Mitali Ambedkar, Sports Nutritionist of Sports Institute for support, helpful suggestions and discussions.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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How to cite this article: Singh RK, Guru CS, Rastogi J, Jaipurkar R, Sharma A, Apte VV. Test-retest reliability of air displacement plethysmography (BOD POD) in the adult healthy Indian male population. Indian J Physiol Pharmacol 2022;66:251-6.